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The goals of this research project are to enhance and expand MDIS capabilities, to develop and test a prototype system that can support MDIS images and to conduct post-installation evaluation studies of the MDIS network and telemedicine for the US military medical command. To enhance the MDIS capability, Georgetown University Medical Center (GUMC) has developed computer aided diagnosis routines, a data compression method, advanced image processing, a CR training program, interfaces with new technologies, and a teleradiology system using the Internet. To expand the MDIS capability, we have defined initial requirements for telepathology and a prototype system in collaboration with the AFIP and Nikon Corporation, Japan. A teleradiology capability was integrated into a conventional PC-based videoconferencing system to support MDIS images. A telemedicine evaluation study protocol has been developed to support post MDIS installation. To educate others of the DOD vision of telemedicine, Georgetown has organized the National Forum on Telepresence in Washington, D.C. in cooperation with the Army. To develop a general framework of a telemedicine study evaluation study, Georgetown organized the Chestertown Roundtable with 50 participants including technology assessment experts, practitioners of telemedicine and health policy experts. To highlight the medical imaging activities of Tripler Army Medical Center and the State of Hawaii, IMAC 95 was organized in Hawaii in conjunction with the Annual Governor's Symposium on High Technology.

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1.0 Introduction

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Shih-Chung B. Lo, PhD	Chief Scientist
Betty A. Levine, MS,	Chief Engineer
Wendelin S. Hayes, DO	Clinical Telemedicine Coordinator
Jeff R. Collmann, PhD	Administrator

A. Introduction

The US Army Medical Research and Development Command (USAMRDC) has championed the development and deployment of a filmless radiological imaging network over the past 10 years. Georgetown University was a digital imaging network system (DINS) research and demonstration site as a subcontract to MITRE for USAMRDC chosen to deploy, test, and evaluate prototype DINS networks in the 80's. The DINS project laid the foundation for the current Medical Diagnostic Imaging Support (MDIS) filmless radiology and associated teleradiology deployed throughout military medicine. Since the deployment of teleradiology during the Gulf War and telemedicine during the Somalia deployment, the use of digital imaging and high speed communication have become a cornerstone of telepresence initiative of the Army Surgeon General. MDIS, Composite Health Care System (CHCS), teleradiology, electronic medical records and telemedicine and medical information management programs are all critical components required to support comprehensive telepresence. But capabilities of each subsystems must be improved and integrated with each other to be clinical effective. Telemedicine (T-MED) has three major components: telecommunication infrastructure, telemedicine technologies and clinical protocols. These three components must be integrated at the technical, clinical and management levels for the telemedicine system to be an integral part of the routine clinical system.

MDIS experiences at Madigan Army Medical Center, Brooke Army Medical Center and Wright Patterson Air Force Medical Center indicate that the system can support filmless radiology service for the entire hospital and it can support teleradiology, which is one of the most technically demanding parts of telemedicine. The MDIS network with its teleradiology capability is one of the most powerful technological infrastructures that can support telepresence.

A.1 Three Thrusts of the Akamai Initiative.

This five year Akamai initiative consists of three thrusts:

- **Thrust 1:** Establishment of deployable telemedicine and teleradiology links from Pacific Rim DoD clinics to Tripler Army Medical Center (TAMC),
- **Thrust 2:** Implementation of a filmless electronic medical imaging environment and teleradiology hub at TAMC, and
- **Thrust 3:** Establishment of a research program at Georgetown University Medical Center for MDIS/telemedicine research to conduct related R&D activities in cooperation with the DoD.

Thrusts 1 and 2 are the responsibility of the DoD, and efforts have been underway for the past three years to establish telemedicine, teleradiology and MDIS capabilities at various Akamai project sites. Thrust 3 is the responsibility of Georgetown University Medical Center. This report

highlights the progress that has been made during the first 12 months of the Akamai project.

A.2 Akamai Research.

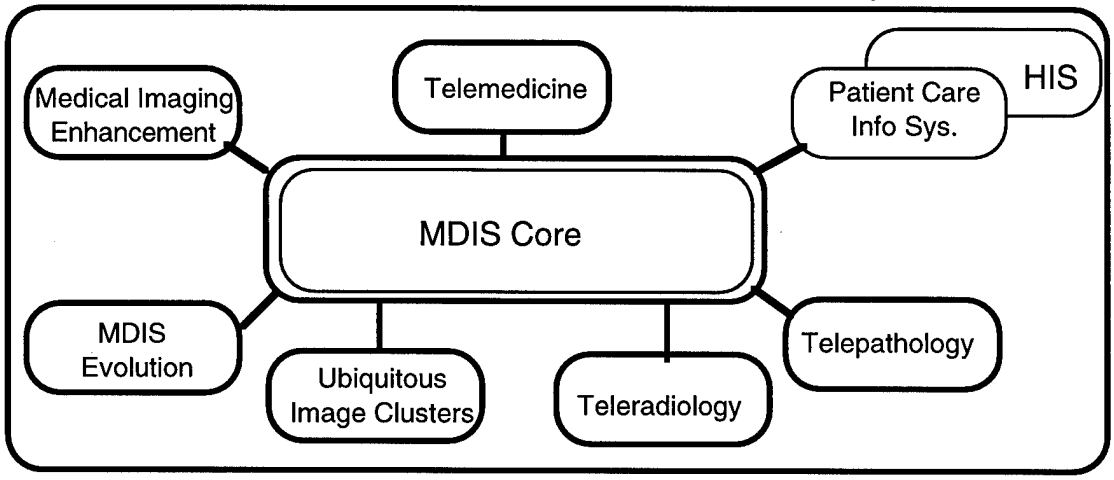
The purpose Akamai Research is to:

- Enhance the radiological image management and operational capabilities of MDIS
- Develop telemedicine capable of handling MDIS images
- Expand imaging capabilities beyond radiology to include pathology, cardiology, ophthalmology, dermatology and others
- Make hospital information systems image capable
- Conduct evaluation studies of MDIS and telemedicine

B. Akamai Research Network

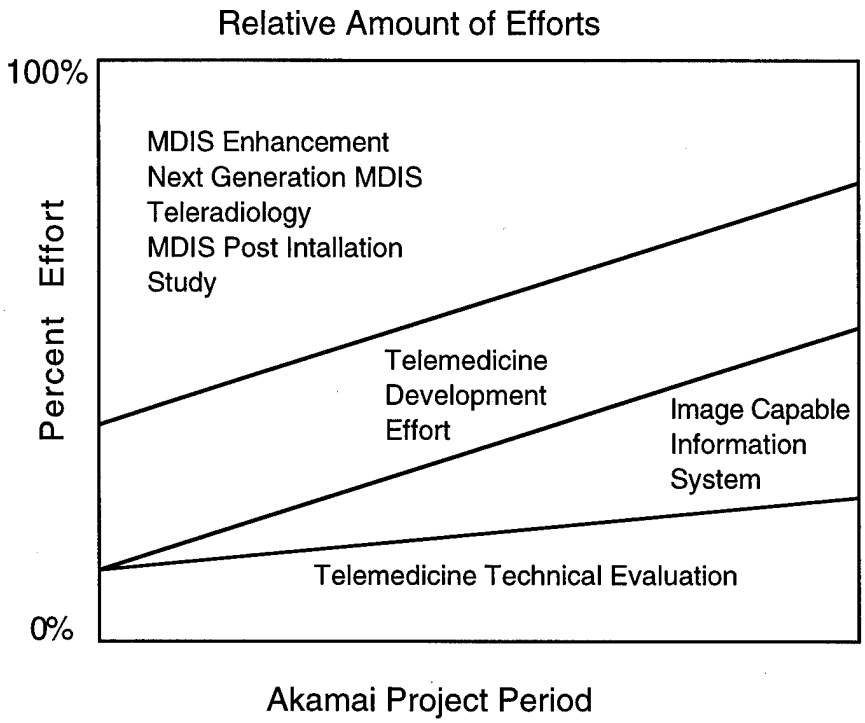
The following diagram highlights the Akamai research network that will evolve over the course of the project. MDIS technology will serve as a core for this effort. The MDIS network has the necessary bandwidth and data base capacity to expand for future imaging applications or radiological images.

AKAMAI Network Built Upon MDIS Core to Support Omnipresence



This core functionalities will be improved to support various advanced capabilities shown in the above diagram. The results of this research will aid in making the MDIS network more intelligent, efficient, and ubiquitous, and it will serve as a smart engine for telepresence. This continuous evolution will also keep the network up-to-date in technology, thus protecting the DoD's investment in medical imaging technology.

The MDIS network is the technical foundation of the Akamai project. As such, a greater proportion of R&D efforts were directed toward the advanced concept of MDIS at the beginning of the project and MDIS related efforts will be reduced in the out years of this project as shown in the following diagram.



This report is organized in the following manner:

Chapter 2 deals with the research and development effort to enhance the radiological capabilities of the MDIS network in the areas of intelligent network through the use of computer aided diagnosis and pattern recognition and automatic reorientation of chest images at workstations. There is a need to continuously improve the quality of images in the MDIS network. This is achieved through the use of innovative data compression, quality control of CR based digital radiography including the reader and plate handing system. A new prototype high resolution film scanner with 21 micron capability was evaluated in terms of image quality. The reading throughput on a workstation is an important factor in the clinical acceptance of MDIS. In order to improve the visualization techniques of MRI studies that can involve hundreds of images, a neural network has been applied to view 3D image data of MRI of the breast.

Teleradiology is a significant portion of MDIS for a peace time as well as a deployment environment. For clinics with small work loads, there is a critical need for a teleradiology system that can use "no-cost" communication capability. A set of software tools have been developed to conduct teleradiology sessions on the Internet.

To keep MDIS on the cutting edge of technology and to protect the investment, MDIS must integrate new technologies. A new approach to interface computed radiography to MDIS is discussed. A new digital radiography system will be made available from AGFA Corporation. We have developed an MDIS digital interface for this AGFA product. Standard interfaces are making systems integration much simpler now, but there are still many blind spots despite great progress in interface standards. Some of these blind spots are analyzed. To test the idea of an intelligent MDIS network, a new prototype system experimental network with higher performance is under development in collaboration with Cray.

The implementation of an MDIS network accented the importance of training for users of the workstation and computed radiography. We have developed a three-day, hands-on CR training program which can be taught at Georgetown as well as any DoD site with a CR system.

Telemedicine is an important extension of teleradiology which is an integral part of the military MDIS network. A teleradiology experiment was conducted using T-1 ACTS between Washington, D.C. and Tripler Army Medical Center, Hawaii. A system that can support high resolution teleradiology and multimedia telemedicine is necessary. Georgetown has developed such a system in collaboration with KLT Communications by integrating a high resolution film scanner and Osiris radiology software with Shared-View VTC. The system is under operational evaluation between Martinsberg, WV and Georgetown University.

MDIS is a powerful technological and clinical infrastructure with an inherent capability to support more than just radiology service. To expand the capability of MDIS, Georgetown has been experimenting with digital pathology and telepathology in collaboration with the AFIP and Nikon Corporation. A prototype system has been designed and an operational protocol has been established during the first year. The use of a neural network in pathology has been explored.

As a part of the image capable hospital workstation project, we have reviewed industry trends in the use of various standards.

There are a number of MDIS networks at a number of DoD sites, but no formal evaluation has been conducted. An evaluation plan has been under development for the post MDIS installation study. The first study will focus on Korea teleradiology.

Telemedicine is a complex issue for the DoD from the technological, clinical and management perspectives. A major national conference was organized by Georgetown in collaboration with the DoD and AUSA. The meeting was attended by 1,200 people representing military, government, industry, and academia. It was a highly successful meeting to establish the vision of the military medical leadership and set the goals of telemedicine for the military.

The evaluation study of telemedicine is an important step in re-engineering military medicine. No past studies evaluating such technology in medicine have been performed. To develop a general framework of telemedicine evaluation studies, a roundtable discussion group was organized of 50 experts including practitioners, assessment experts, scientists, engineers, policy makers and managers.

To highlight the medical research activities of Tripler Army Medical Center, the Fourth International Conference on Image Management and Communication (IMAC) was organized in Hawaii in collaboration with the Governor's Symposium on High Technology. The Governor of Hawaii, The Honorable Benjamin Cayetano, delivered a keynote speech.

An evaluation study of telemedicine has a number of major components, including clinical, management, and technical. The Georgetown team has focused on the technical aspect during the first part of this project. Evaluation parameters have been established and study protocol is under development.

The electronic network presents a great challenge in confidentiality and ethics of privacy. A sociology professor with anthropology training at Georgetown is developing a guideline on these issues.

This research project is designed to support and benefit the MDIS project, telemedicine and other medical research projects of the Department of Defense. The benefits to the military are maximized by close collaboration with a number of DoD project sites and offices. Georgetown now has on-going research collaborations with several offices within the US Army Medical Research and Materiel Development Command, Advanced Research Program Agency, Armed

Forced Institute of Pathology and Brooke Army Medical Center, Bethesda Navy National Medical Center and Walter Reed Army Medical Center. As Tripler Army Medical Center has established research efforts in telemedicine and MDIS, Georgetown will be prepared to provide research assistance.

2.1.1 CADx for Lung Nodule Detection for an Intelligent MDIS Network

Investigator: Jyh-Shyan Lin, PhD, Shih-Chung B. Lo, PhD,
Matthew T. Freedman, MD, MBA, Kevin Legendre, MD, Seong K. Mun, PhD

A. Significance to the Military MDIS Project and Executive Summary

We have developed a neural-digital computer-aided diagnosis (CADx) system for the Medical Diagnostic Imaging Support (MDIS) network to assist radiologists in the early detection of lung cancer. This research is a corner stone to the development of an "intelligent" MDIS network. The MDIS network is a passive network. The MDIS of tomorrow should be an intelligent network that can automatically optimize the image quality and to make a computer assisted diagnoses. The CADx system is based on a parameterized two-level convolution neural network (CNN) architecture and a special multi-label output encoding procedure. The CADx system performs automatic "suspect" localization, feature extraction, and diagnosis of a particular pattern-class aimed at a high degree of "true-positive fraction" detection and low "false-positive fraction" detection. In this report, we present the two-level neural classification method developed for reducing false-positives in our system. We employed receiver operating characteristics (ROC) method with the area under the ROC curve (A_z) as the performance index to evaluate all the simulation results. The two-level CNN achieved an A_z value of 0.93 which is equivalent to 80% sensitivity with 1 ~ 2 false-positives per chest image. Preliminary results show that the proposed two-level CNN architecture is promising, extensible, problem-independent, and therefore applicable to other medical or difficult diagnostic tasks in two-dimensional (2-D) image environments. The results of this research will be provided to the MDIS program so that the MDIS network can incorporate the capability.

B. Introduction

Lung cancer is one of the most common and deadly diseases in the world. The prognosis and the cure of lung cancer depend highly on the early detection and treatment of small and localized tumors. As reported by Heelan, Brett, and Nash, the detection of lung tumors in the early stage of growth can result in a better prognosis for survival. The 5-year patient survival rate is approximately 40% when lung cancer is detected in the early stage. The early detection and diagnosis of pulmonary nodules in chest radiographs are among the most challenging clinical tasks performed by radiologists. Previous studies showed that radiologists fail to diagnose small pulmonary nodules in as many as 30% of positive cases. A long-term lung cancer screening program that was conducted at the Mayo Clinic by Muhm *et al.* found that 90% of peripheral lung cancers were visible in small sizes in retrospect on earlier radiographs. Due to human observer errors the current miss rate in detecting small lung nodules larger than 3 mm in diameter is as high as 35% of the abnormal cases, of which one half of the missed nodules can be detected retrospectively. In the 5-year screening project at Johns Hopkins Hospital for early detection of lung nodules, it has been shown that the miss rate can be decreased to less than 20% if two or more radiologists work together. Computer-aided diagnosis (CADx) has been shown to be a promising approach as a radiologist's assistant for improving diagnostic accuracy.

Various CADx schemes, which utilize both digital image processing techniques and artificial neural networks (ANNs), have been proposed to assist radiologists in detecting lung nodules. Typically, CADx schemes perform successively two diagnostic functions: (1) location of suspected nodule areas (SNAs), also known as a "prescan process", on the digitized chest radiograph and (2) differentiation of "true" nodules from "false" nodules, i.e., lung and chest structures. In recent literature, many effective digital processing algorithms have been developed for locating suspected nodules. It has been determined that too many false-positive classifications per chest radiograph are made. These false-positives include rib crossings, rib-vessel crossings, vessel-vessel crossings, and end-on vessels. Thus, the problem of early diagnosis of lung cancer is coupled with the problem of reducing the number of false-positive classifications while maintaining a high degree of true-positive diagnoses. Various methodologies have been proposed to reduce the number of false-positives while maintaining a high true-positive detection rate, i.e., sensitivity. Most of them used the conventional two-step pattern recognition approach, i.e., feature extraction followed by feature classification. Several morphology-based algorithms have been proposed to extract specific features, such as circularity, size, and contrast. Advanced neural network technologies have also been applied to classify those predetermined features. The critical task herein, which is also the most difficult, is to define and specify a "good" feature space. Unfortunately, suitable feature definition, and corresponding extraction implementation algorithms, proved to be very difficult to define and specify. Thus, diagnosis and classification performances, based on morphology alone and on a priori knowledge of suitable features, especially for the early diagnosis cases, have been limited. In summary, the principal difficulty in those methodologies is in specifying the kind of features identified, which will discriminate between nodules and non-nodules.

In this report, in order to enable ANNs to extract the suitable features from 2-D images of digital chest radiographs, a two-level (the first and second level) convolution neural network (CNN) architecture, trained by the image blocks of prescanned SNAs, has been configured and tested for each cancer nodule diagnosis. The first level CNN (called CNN-I) and the second level CNN (called CNN-II) are trained by operating directly on the selected images of prescanned SNAs, rather than some subspace of preidentified image features. CNN-I aims at the identification of nodules and nodule-like patterns in the SNAs, while CNN-II is applied to assist CNN-I in further classification between "true" nodules and those nodule-like "false" patterns. Furthermore, we have applied fuzzy linguistic concepts and developed a multi-label output encoding procedure for the first level (CNN-I) neural training and interpretation of the activity distributions in the output neurons. The activity distribution over five output neurons, which were used in the nodule diagnosis problem, is interpreted by the centroid as the "normalized disease index" (NDI). ROC curves and A_z values of the CNN-I, CNN-II, and the two-level CNN are reported.

C. Data Base

The data base of image blocks which contain suspected nodule objects on the original chest images are generated by the prescan process. In the prescan process, digital image processing techniques, such as image subtraction, contour search, and growth test, are used for noise reduction, image enhancement, and "suspect" search and localization. The generation of image blocks of SNAs involved the following stages:

(i) Acquisition of digitized chest radiographs - The chest radiographs used in this study contain cases of (i) primary peripheral lung cancers, (ii) metastases of know cancers, and (iii) the new developed lung nodules or nodules in patients with known metastasis on therapy. We used 54 posterior-anterior (PA) chest radiographs that were selected mainly from routine cases at GUMC. There are 28 biopsy proven cancerous cases which contain primary and metastasis lung cancers with single and multiple nodules. There are 26 normal cases confirmed by computed tomography (CT) that show no change of the suspected nodules in the follow-up films. The chest radiographs

(14" × 17" actual size) were digitized to 2048 × 2500 × 10 bits by using a Konica KDFR-S laser film scanner. For computational simplicity, the digitized chest films were averaged to 512 × 625 × 10 bits such that one pixel represents 0.7 mm × 0.7 mm actual size.

(ii) Extraction of image blocks - Image blocks of SNAs on the digitized chest images were extracted automatically from the cancerous and normal chest images by the prescan process. Each image block has a size of 32 × 32 pixels (about 22 mm × 22 mm) which is sufficient to encompass the various sizes of small nodules in which we were interested. In other words, we concentrate on the detection of small nodules at their early development stage which is clinically important. The prescan process was operated at high sensitivity in order to capture all possible primary nodules and metastases on the chest image. Several subtle nodules were extracted manually and included in our database. Locations of the nodules, especially those extracted from the multiple nodule cases, are confirmed by an experienced radiologist and related pathology report. The suspected nodule is located approximately at the center area of each image block. Examples of the extracted image blocks of nodules and lung and chest structures (i.e., prescanned false-positives) are shown in Figs. 1(a) and 1(b), respectively. In Fig. 1(b), the top two rows show end-on vessels and round objects surrounded or overlapped with ribs and vessels and the bottom two rows show rib crossings and rib-vessel crossings. Note that it is very difficult even for radiologists to identify a nodule that is close to the hilum area, the central portion of the lung where all the blood vessels enter the lung. Therefore, all image blocks were selected from the area away from the hilum to eliminate the possibility of mistakenly selecting a nodule as normal lung structure or vice versa.

(iii) Preprocessing - In general, the average optical density of the perihilar area in a chest radiograph is greater than that of the peripheral regions because of the non-uniform thickness of chest walls and the differences in the amount of tissue and other lung and chest structures traversed by the x-ray beam at the two locations. Since the image blocks of SNAs were obtained from different regions of the lung, each image block contains non-uniform chest background. We applied the 2-D surface-fitting technique to each SNA whose background trend is estimated and corrected by fitting a second-order polynomial surface to the gradual change in the background density distribution. Note that there is no normalization or scaling process performed on the image blocks. The potential use of the CNN architecture for feature extraction as well as classification of the preprocessed SNAs is investigated.

D. Convolution Neural Network

D.1 Network Architecture.

The CNN architecture with one hidden layer shown in Fig. 2 is investigated for its ability to classify SNAs. The network has one input layer, one hidden layer, and one output layer. The input layer consists of M^2 neurons which correspond to the $M \times M$ pixel preprocessed input image.

The hidden layer is composed of n groups of $N \times N$ neurons arranged as n independent $N \times N$ feature maps, where N is equal to M-k+1 and the $k \times k$ area is called the receptive field. Each hidden neuron takes input on a $k \times k$ neighborhood on the input image block. For neurons in the same feature map that are one neuron apart, their receptive fields in the input layer are one pixel apart. Moreover, each neuron in the same feature map is constrained to have the same set of k^2 weights and perform the same operation on the corresponding parts of the input image. Namely, each neuron is constrained to process exactly the same way over its receptive field. The benefit of constraining the weights enables the network to perform shift-invariant pattern recognition. Thus, the total effect of the operation can be expressed as a 2-D discrete convolution with the $k \times k$ convolution kernel (i.e., the receptive field). Namely, the feature map is the output of the input

image convolution with the kernel. All neurons in another feature map share another set of k^2 weights in the same way. Each hidden neuron y_j generates its output through an activation function which is given by Eq. (1) where w_{ji} is the weight between hidden neuron j and pixel i of the input image block, x_i is the gray value of input pixel j, and a_j is the bias of the hidden neuron j. Note that $x_1,...,x_{k^2}$ are the pixels on the input image block which are connected to the neuron j. The minimum and maximum activation are 0 and 1, respectively. Note that the function (to be defined for CNN-I and CNN-II in section V) in Eq. (1) must be first order differentiable, a necessary condition in using the back-propagation (BP) algorithm. The output layer is fully connected to the hidden layer. The sigmoid activation z_o of the output neuron is given by Eq. (2) where w_{oi} is the weight between the output neuron and neuron i in the hidden layer, nN^2 is the total number of neurons in the hidden layer, and g_o is the bias of the output neuron.

$$y_j(\underline{w}, \underline{x}, a_j) = f(\sum_{i=1}^{k^2}(w_{ji}x_i) + a_j) \qquad (1)$$

$$z_o(\underline{w}, \underline{y}, g_o) = \frac{1}{1+\exp\left\{-\left[\sum_{i=1}^{nN^2}(w_{oi}y_i) + g_o\right]\right\}} \qquad (2)$$

In summary, the network consists of $O + M^2 + nN^2$ neurons (including the input neurons) and $nN^2(k^2 + O + 1) + O$ links (including the bias links) in which $nN^2(O+1) + nk^2 + O$ are independent links (including the independent bias links), where O is the number of output neurons equal to five for the first level CNN (CNN-I) and one for the second level CNN (CNN-II).

D.2 Network Training.

All the network weights including the bias weights are updated using the BP algorithm. The BP algorithm iteratively adjusts the network weights so as to minimize the total error (over all the training samples) between the actual output vector $(z_0,...,z_{N_z-1})$ of the network and the target vector. The error function that is to be minimized by gradient descent is the sum-of-squared error (SSE). During the training phase, the receptive fields within one hidden group are constrained to have the same pattern of weights. The weights of each receptive field, which are shared by the neurons in the same feature map, are updated by using "stochastic mode". The whole field of hidden neurons (within one hidden group) consists simply of duplicates of a single feature detector centered on different regions of the input space, and the learning that occurs in one part of the field is automatically generalized to the rest of the field. The bias weight of each neuron is independent and is also updated by using the stochastic mode.

E. Two-Level CNN Classification

The CNN architecture is investigated to identify nodules among the image blocks of SNAs. We proposed a two-level CNN (CNN-I and CNN-II) classification method (Fig. 3) to classify the SNAs. In the first level CNN (i.e., CNN-I), the neural classification concerns feature extraction and diagnosis of a particular nodule-like pattern class aimed at a high degree of "true-positive fraction" detection. The second level CNN (i.e., CNN-II) is trained specifically on separating the similar "false" patterns, which provide a "gray" diagnostic value. We intend to train the CNN-I to identify nodules and nodule-like lung and chest structures, such as end-on vessels, among the SNAs. The CNN-II is trained in an attempt to distinguish the image blocks of nodules and nodule-like lung structures classified by the CNN-I. In Fig. 3, θ represents a threshold value that controls the flow of the SNAs which will be evaluated by the CNN-II. $\overline{\text{NDI}}$ represents the mean NDI value (generated by either CNN-I or CNN-II for each testing image block) which is calculated as the average of the eight output values for eight rotated versions of the same input image block of

SNA (to be described in Section V). If an SNA has an $\overline{NDI}$ value (generated by the CNN-I) larger than θ, the control signal (cs) is set to 1, the SNA will be further evaluated by the CNN-II and the newly generated $\overline{NDI}$ value is used as the final diagnostic value for the SNA. Otherwise, the original $\overline{NDI}$ value generated by CNN-I is used. The $\overline{NDI}$ values generated by the two-level CNN, either by CNN-I or CNN-II, are analyzed by the ROC method. The architecture, training, and testing procedures of CNN-I and CNN-II are described in the following sections.

E.1 The First Level CNN (CNN-I).

Currently, most radiologists do not make strict decisions, i.e., "nodule" or "no nodule"; instead they use some intermediate expressions, such as "percentage of probability", and "likely", during the diagnostic process. In actual practice, radiologists do not make a "yes or no" decision for those probable nodule cases until more information is supplied. This information can be obtained from patient history, follow-up films, CT, and biopsy. There are five linguistic labels which are commonly used by radiologists: "definitely a nodule", "probably a nodule", "possibly a nodule", "probably no nodule", and "no nodule". We propose an encoding procedure to incorporate the information into the CNN-I network through supervised BP learning. First, each preprocessed SNA is assigned with one of the linguistic labels given by an expert radiologist. Then an encoding process is applied to translate qualitative information into real numbers which are then used as teaching signals during the network learning.

• **Output-Encoding and Network Training -** The target signals in Eq. (3) for training the CNN-I are generated by using the following encoding procedure. First, an experienced radiologist assigns one of the five above mentioned linguistic labels to each training image block which is displayed on a monitor. The image size, intensity, and contrast can be manipulated by the radiologist. Since an image block may contain a nodule as well as end-on vessels, ribs, and vessels, the center portion of the image is the main focus during the label assignment process. Basically, the radiologist uses circularity and density *versus* size relationship as criteria to decide the suitable label for each SNA. It is easier for a radiologist to determine that an image block is a rib crossing and not a lung nodule, however, it is harder to determine whether a round object is a lung nodule or end-on vessel. Therefore, most round objects, such as end-on vessels, which visually resemble nodules are more likely to be assigned the label of "possibly a nodule" or "probably a nodule". However, obvious vessels, such as small-sized and radiodense end-on vessels with vessel lines leading up to them, are assigned the label of "probably no nodule" or "no nodule". The determination of the suitable label for each training image block is quite complex and the criteria used are not equally weighted and not necessarily applied in a fixed order. Each label is then encoded into a five-component target vector which is defined in terms of fuzzy class membership values. Encoding of the five linguistic labels is described as follows. A set of membership functions is first defined for the linguistic labels. The membership functions are used to translate qualitative information into quantitative numbers for computer processing. Then for each label associated with the image block, a five-component membership vector is obtained; each component is a real number between 0 and 1 which reflects the relation of the block to the corresponding output class. The five-component membership vectors for the five linguistic labels for "no nodule", "probably no nodule", "possibly a nodule", "probably a nodule", and "definitely a nodule" are respectively (1, 0.2, 0, 0, 0), (0.5, 1, 0.2, 0, 0), (0.2, 0.5, 1, 0.5, 0.2), (0, 0, 0.2, 1, 0.5), and (0, 0, 0, 0.2, 1). Note that the membership vectors of the image block named "probably a nodule" and "probably no nodule" are asymmetric about the firing output neurons 1 and 3, respectively. Since each one of the five linguistic labels corresponds to an output class (a neuron in the output layer), there are five output neurons, rather than two neurons (true or false). During training, each output class is assigned a membership value instead of choosing the single neuron with the highest activation. This allows efficient modeling of ambiguous SNAs with appropriate weighting factors being assigned to the back-propagated errors depending upon the membership values at the corresponding outputs. During training, the back-propagated error is computed with respect to each target output, which is the degree of "belongingness" of the input

vector to that class.

• **Output-Decoding and Network Testing** - After the network converges to a minimum SSE, SNAs that are not used in the training are input to the CNN to test the network's performance. Note that the training and testing SNAs are uncorrelated, i.e., they are generated from different patients' images. SNAs in the testing set are processed in the same way as those in the training set. Since the CNN has five output neurons in the output layer, a five-component output vector is generated when one testing image block is presented to the network. A decoding process is employed to decipher the network outputs and to resolve the conflict between competing neurons. Several decoding techniques, such as maximum, mean of maximum (MOM), and center of gravity (COG), are proposed in the literature. Among them, the COG method is considered to be one of the most simple and widely used methods in many practical applications. The COG method takes the contribution of all output neurons and the degree of membership of each neuron into account. The decoded output value is computed by COG as

$$\mathrm{COG} = \frac{\sum_{i=0}^{N_z-1} z_i \left(i - \frac{N_z - 1}{2} \right)}{\sum_{i=0}^{N_z-1} z_i} \qquad (3)$$

$$\mathrm{NDI} \equiv \frac{(\mathrm{COG} - \mathrm{COG}_{\min})}{\mathrm{COG}_{\max} - \mathrm{COG}_{\min}} \qquad (4)$$

where z_i is the output of ith output neuron and N_z is the number of output neurons. The normalized COG (Eq. (4)) is called the normalized disease index (NDI) where $\mathrm{COG}_{\max}$ and $\mathrm{COG}_{\min}$ are the maximum and minimum COG values, respectively. Note that the $\mathrm{COG}_{\max}$ and $\mathrm{COG}_{\min}$ correspond to the actual output vectors (0,0,0,0,1) and (1,0,0,0,0), respectively. By Eq. (3), $\mathrm{COG}_{\max}$ and $\mathrm{COG}_{\min}$ are +2 and -2, which correspond to NDI values of 1 and 0, respectively. A higher value of NDI indicates a highly suspected nodule area. NDI is defined as 0 when all neurons have zero intensity, i.e., $z_i = 0,\ \forall i \in \{0,\ldots,N_z - 1\}$.

E.2 The Second Level CNN (CNN-II).

A second level CNN classification stage (CNN-II) is used to discriminate greatly similar image patterns, such as nodules and end-on vessels, classified by CNN-I. CNN-II has only one output neuron in the output layer (Fig. 2). The target output at the output neuron has a highest activation value 1 and lowest value 0 when, respectively, a nodule and an end-on vessel are presented at the input of the network. Since there is only one output neuron, the actual activation of the output neuron is defined as the NDI value for each testing pattern.

F. Simulation Results

• **The training sets** - The training set for CNN-I consists of image blocks of 40 nodules and 52 lung and chest structures. The 40 nodules and 52 lung and chest structures were selected from the image blocks extracted from four chest images containing multiple nodules. Each training image block for CNN-I was assigned a linguistic label, i.e., a target output vector. The training set for CNN-II consists of image blocks of 40 nodules (the same as those used in training CNN-I) and 53 end-on vessels. The 53 end-on vessels were randomly selected from the image blocks extracted from 10 normal chest images which have been confirmed to be "definitely no nodule" cases. For CNN-II, the target output values are 1 and 0 for a nodule and an end-on vessel, respectively.

To improve the situation where only a small and limited number of training patterns are available, patterns of different orientations are generated from a single training example and are used in network training. For each training pattern p, three rotated versions of p are generated by

rotating p at 90, 180, and 270 degrees. In addition, four more patterns are obtained by left-right flipping of pattern p followed by rotations of 0, 90, 180, and 270 degrees. As a result, the number of training patterns is increased virtually eightfold. These patterns have the same target output vector during network training. Accordingly, the training set for CNN-I has increased to virtually 320 nodules and 416 chest structures. The training set for the CNN-II has increased to 320 nodules and 424 end-on vessels. During training, all rotated and left-right flipped training patterns of different orientations are presented in random order to the input of CNN-I and CNN-II.

• **Activation functions for the hidden neurons** - The hidden neurons in CNN-II and CNN-I employed, respectively, a Gaussian-type (Eq. (5)) and a sigmoid function (Eq. (6)). The Gaussian-type activation function is simply the derivative of the sigmoid function. Each hidden neuron y_j in CNN-II generates its output through the activation function (see also Eq. (1)) which is given by

$$y_j(\underline{w}, \underline{x}, a_j) = A_j(\underline{w}, \underline{x}, a_j)(1 - A_j(\underline{w}, \underline{x}, a_j)) \quad (5) \qquad A_j(\underline{w}, \underline{x}, a_j) = \frac{1}{1 + \exp\left\{-\left[\sum_{i=1}^{k^2}(w_{ji}x_i) + a_j\right]\right\}} \quad (6)$$

where $A_j(\underline{w}, \underline{x}, a_j)$ is the sigmoid activation. For the Gaussian-type activation, when the input has value greater than 10 or smaller than -10, the output activation is close to 0. For both activation functions, the minimum and maximum activation are 0 and 1, respectively. The Gaussian-type activation function is a particular example of locally tuned receptive fields used in radial basis functions.

• **Network initialization** - Initially, the network weights are preset with random numbers using a uniform distribution between $-1/F_i$ and $+1/F_i$ where F_i is the number of inputs (i.e., fan-ins) from the previous layer that are connected to neuron i. The initial learning rate is preset to 0.001 and is gradually decreased to 0.0001 and 0.00001. The training procedure is terminated whenever one of the following three conditions is satisfied: (i) the SSE reaches a value below 0.1, (ii) there is less than 1% change of SSE for 100 consecutive iterations, and (iii) there are more than 1000 training iterations. In the following experiments, CNN-I and CNN-II (see Figs. 2 and 3) have this setup: (1) Input image blocks of 32 ¥ 32 pixels, i.e., M = 32, (2) kernel size is 5 ¥ 5 pixels, i.e., k = 5, (3) 10 feature maps, i.e., n = 10, (4) 5 output neurons and 1 output neuron for the CNN-I and CNN-II, respectively, and (5) an additional bias input 1 to each neuron in the hidden and output layers.

• **The testing set** - The test data base consists of 66 nodules (from 19 chest images) and 263 lung and chest structures (from 26 chest images). For each test pattern, we obtain eight rotated versions by using the same method as in the training of CNN. Then, a mean NDI value is calculated as the average of the eight output values generated by the CNN for each rotated testing pattern. The mean NDI values for the "true" and "false" nodule image blocks are analyzed by the ROC method.

• **ROC performance** - We first evaluate the ROC performance of the CNN-I and CNN-II individually. When tested on the testing image blocks of 66 nodules and 263 lung structures, the CNN-I and CNN-II achieve A_z values of 0.85 and 0.82, respectively. The corresponding ROC curves with A_z values of 0.85 and 0.82 are shown in Fig. 4. It is interesting to see that the two ROC curves cross each other at the point where TPF and FPF equal to 0.85 and 0.35, respectively. Though the CNN-I has a slightly greater A_z value than that of the CNN-II, it cannot be concluded that CNN-I has a better performance than CNN-II. Actually, at a higher sensitivity level (TPF > 0.85), CNN-II has a smaller FPF (i.e., a smaller number of false-positives per chest image) and performs better than CNN-I. However, at a lower sensitivity level (TPF < 0.85),

CNN-II has a larger FPF value and worse performance than CNN-I. This phenomenon is often observed when using ROC and A_z for performance evaluation. We apply the second level CNN to further classify the SNAs classified by CNN-I as shown in Fig. 3. The θ (Fig. 3) controls the number of image blocks that will be evaluated by the second level CNN. As θ changes from 0 to 1, the number of image blocks which have mean NDI values (generated by CNN-I) greater than θ will also change. In general, the larger the value θ, the fewer image blocks will be evaluated by the second level CNN. The new mean NDI values (generated by CNN-II) together with the NDI values (generated by CNN-I) are analyzed by the ROC method. Fig. 5 shows the changes of A_z values as the value of θ changes. The two-level CNN achieves an A_z value of 0.93 when θ is set between 0.25 and 0.5 (the region of "gray" diagnostic values). The corresponding ROC curve with an A_z value of 0.93 for the two-level CNN is shown in Fig. 4. As shown in Fig. 4, the two-level CNN has a smaller value of FPF than the single level CNN-I at all sensitivity levels. However, the single level CNN-II outperforms the two-level CNN at a high sensitivity level when TPF is between 0.96 and 0.98. Specifically, at 80% sensitivity, the FPF rates generated by the two-level CNN, CNN-I, and CNN-II are approximately 10%, 28%, and 30%, respectively.

G. Conclusions

In this report we have developed and tested an efficient, two-level neural diagnostic architecture, for highly non-orthogonal classes of patterns presented in noisy and obstructing environments of 2-D images. The CNN extracted the appropriate features directly from the original training images, proving its ability to deal successfully with 2-D image data. By applying fuzzy linguistic concepts, we have developed a multi-label output encoding procedure for training the neural network classifier. The activity distribution is decoded by its centroid value (or NDI). The simulation results have proven the architecture's success in the detection and diagnosis of lung nodules on digitized chest radiographs. Through the training by using the image blocks of SNAs, rather than prespecified features, the CNN has learned to extract and classify features, such as rib edges, vessel lines, and round object signals. The CNN was trained using samples of nodules and end-on vessels to extract features that may or may not be observed by a radiologist. No normalization or other image enhancement processes were applied to the image and no complex feature extraction techniques were involved. The potential usage of Gaussian-type activation function, as opposed to a sigmoid function, in the convolution layer for the task of lung nodule detection needs to be further investigated. The simulation results show that the overall system performance achieved an A_z value of 0.93 after the second level neural processing stage, while the A_z value of single level CNN-I and CNN-II alone were 0.85 and 0.82, respectively. The trained CNN-II, which was appended to the CNN-I, remarkably improved the ROC performance of the system. Future research will focus on the optimization of the number of feature maps and the size of the receptive field, on the analysis of trained convolution kernels, and on the minimization of the network architecture through weight-elimination and pruning of least significant neurons or weights. The over-fitting problem of oversized networks should be further investigated in order to find a minimal network architecture with maximum generalization performance.

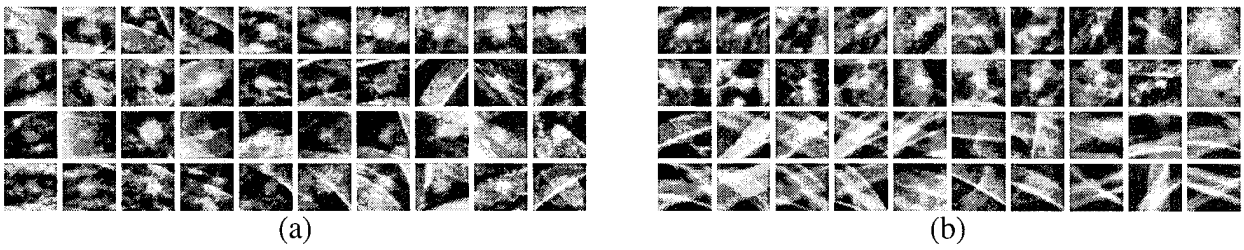


Fig. 1. Image blocks of (a) nodules and (b) normal lung and chest structures.

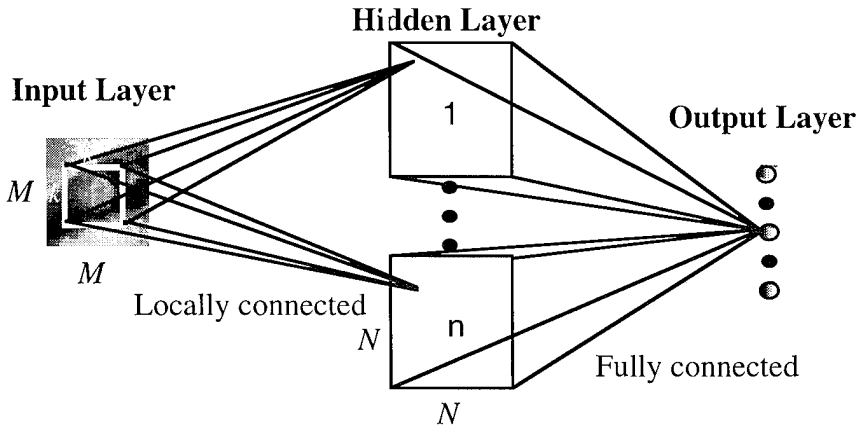


Fig. 2. The one-hidden layer CNN.

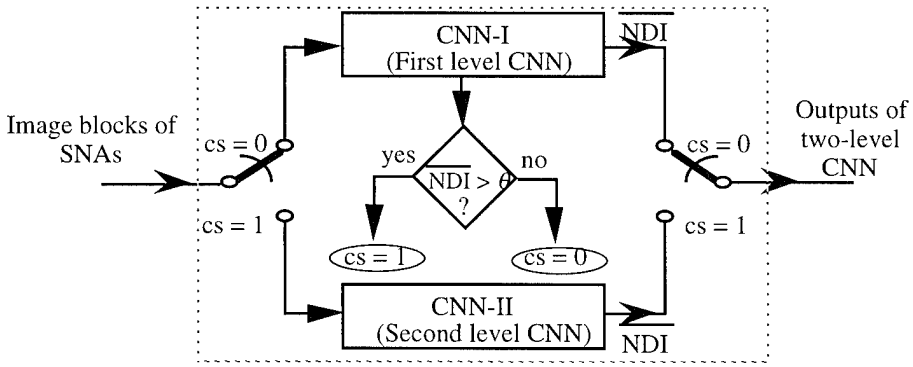


Fig. 3. The two-level CNN classification.

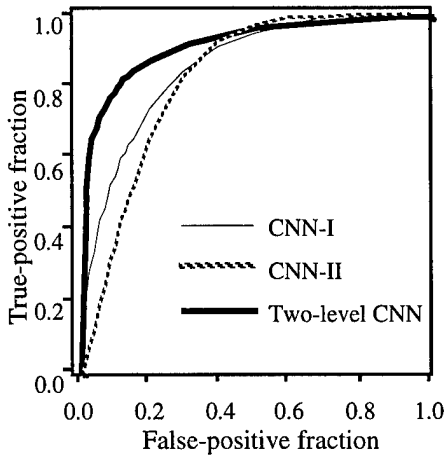


Fig. 4. ROC curves with values equal to 0.93, 0.85, and 0.82 for the two-level, CNN-I, and CNN-II, respectively.

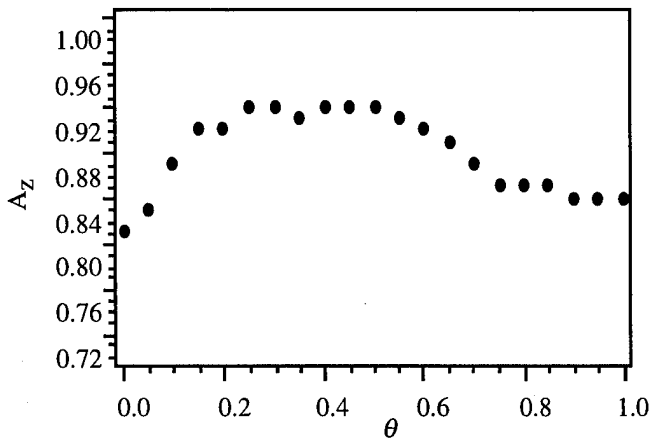


Fig. 5. The values of the two-level CNN at different q settings.

2.1.2 Wavelet-Based Convolution Neural Network for Disease Pattern Recognition

Investigators: Shih-Chung B. Lo, PhD, Huai Li, MS, Jyh-Shyan Lin, PhD, Yuzheng C. Wu, PhD, Akira Hasegawa, PhD, Matthew T. Freedman, MD, MBA and Seong K. Mun, PhD

A. Significance to the Military MDIS Project and Executive Summary

The program to be developed from this disease pattern recognition research will eventually provide radiologists using the MDIS system with clinically relevant information based on image patterns. This work also represents research on the use of advanced wavelet processing to train the neural network for the recognition of disease patterns such as lung nodules on chest radiographs and clustered microcalcifications on mammograms. We foresee that the development of intelligent system in the MDIS will eventually improve the use of MDIS. The intelligent system will function as a self organizer to presort patient data and predefine the image parameters as user friendly functions. The system also can perform computer-aided diagnosis as an alerting system or as a second reader to assist in the diagnosis.

B. Introduction

We modified the two-dimensional convolution processing of a newly developed neural network to adapt the kernels using wavelet basis. The reasons for using wavelet kernels for the convolution process in the neural network are: (a) extracted features are linearly independent with wavelet decomposition, (b) many choices of wavelet bases allow the optimization of the system, and (c) the capability to perform multi-resolution analysis.

In this report, we chose the convolution neural network (CNN) as the fundamental architecture of signal propagation platform and would like to explore a possible advanced image pattern recognition algorithm for medical image applications when an abnormality of a disease pattern can be shown in a small image area.

C. Algorithm Development

C.1 Review of the CNN.

The artificial neural network described in this paper is a simplified version of the neocognitron. We used only a one-hidden layer structure and eliminated all the complex-cell layers. Figure 1 shows the structure of the simplified neural network. The convolution kernels to be trained are responsible for the feature extraction from the input matrix. The fully connected nets are trained in the same time as the kernels between input and the first hidden layers and are responsible for merging extracted features for classification.

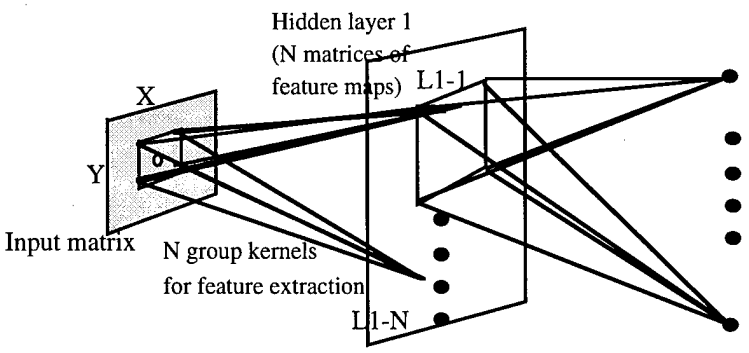


Figure 1. A single section of the convolution neural network.

An image block of 16×16 pixels (i.e., 1.7×1.7 mm^2) with a convolution kernel size of 6×6, which was suggested by the author in a previous study for the detection of microcalcifications, was used in this study. The second layer consists of 24 groups and 60 groups in two different experiments. Each group has 12×12 pixels formatted in a square array. The output layer has M nodes (only 2 nodes are used in the following experiment) which fully connect to the second layer.

Signal Propagation and Training of the CNN - The signal propagation and backpropagation (BP) for fully connected networking follow the standard BPNN algorithm. However, the signal propagation from input layer to feature maps involving convolution computation is given below:

$$S_p((u,v);n) = \frac{1}{1+\exp\left\{-\sum_{m\Leftrightarrow n}\left[K_p((u,v);n)\otimes S_{p-1}((u,v);n)\right]\right\}} \qquad ...(1)$$

where $S_p((u,v);\ n)$ represents the signal at node *(u, v), nth* group, and *p* layer. $K_p(u,v);\ n)$ denotes a weighting factor value at net *(u, v), nth* group, and connecting from *p-1* to *p* layer. m⇔n represents the connection between groups *m* in layer *p-1* and *n* in layer *p*. Similar to a fully connected networking in a BPNN, the iterative version of kernel weights is:

$$K_p((u,v);n)[t+1] = K_p((u,v);n)[t] + \eta\sum_{i,j}\delta_p((i,j);n)S_{p-1}((i-u,j-v);m) + \alpha K_p((u,v);n)[t] \qquad ...(2)$$

where t is the iteration number during the training, α is the gain for the momentum term received in the last learning loop, η is the gain for the current weight changes, and δ is the weight-update function which is given as

$$\delta_p((i,j);n) = S_p((i,j);n)\left[1-S_p((i,j);n)\right]Q_p((i,j);n) \quad \text{and} \quad Q_p((i,j);n) = \sum_{i,j,m\Leftrightarrow n} K_{p+1}((u,v);m)\delta_{p+1}((i+u,j+v);m).$$

Classification of Output Values in the Testing - Corresponding to the grading system arranged in the training, a polarized (linearly weighted) function is given as an indication. With this we can define a normalized disease detection index (NDDI) for the judgment of a suspected area:

$$NDDI = \sum_{n=N/2}^{N-1}\left[O_n\times(n-(N-1)/2)\right] \Big/ \sum_{n=0}^{N-1}\left[O_n\right]\times(N-1)/2 \qquad ...(3)$$

where n denotes the node in the output layer, O_n is the output value at node n, and N is the total number of output nodes. Hence a nodule detection index of 0 or near 0 indicates a definite non-nodule and a nodule detection index of 1 or greater implies a definite nodule case with the judgment

of the neural network. This is because the score line is centered at (N-1)/2 (i.e., 0.5 for 2 nodes in the output layer) and polarization of true and false depends on the position of the nodes.

After receiving NDDI value from each suspected area, we use a computer program (LABROC), based on receiver operating characteristic (ROC) analysis to evaluate the performance of the neural networks. The area under the curve referred to as A_Z, can be read as a performance index of the system using ROC analysis. In general the higher the A_Z, the better the performance.

C.2 Wavelet Kernels for CNN.

Two-Dimensional Wavelet Transform - In the process of a two-dimensional wavelet decomposition, horizontal (x-) and vertical (y-) directions are considered preferential. Following Mallat's 2-D wavelet analysis, the two-dimensional scaling function is composed of two one-dimensional scaling functions in both directions:

$$\phi(x,y) = \phi(x)\phi(y) \qquad ...(4)$$

where $\phi(x)$ is a scaling function. The associated two-dimensional wavelets are defined as

$$\psi^H(x,y) = \phi(x)\psi(y) \qquad ...(5)$$

$$\psi^V(x,y) = \psi(x)\phi(y) \qquad ...(6)$$

$$\psi^D(x,y) = \psi(x)\psi(y) \qquad ...(7)$$

where $\psi(x)$ is the 1-D wavelet corresponding to the 1-D scaling function. Using the sub-band coding algorithm, the wavelet transform (2-D DWT) of a matrix has four parts:

$$W_{LL}(f(x,y)) = \sum_{u,v}[(f(x,y)h(u-2x,0))h(0,v-2y)] = \sum_{u,v}[f(x,y)h_{LL}(u-2x,v-2y)] \qquad ...(8)$$

$$W_{LH}(f(x,y)) = \sum_{u,v}[(f(x,y)h(u-2x,0))g(0,v-2y)] = \sum_{u,v}[f(x,y)h_{LH}(u-2x,v-2y)] \qquad ...(9)$$

$$W_{HL}(f(x,y)) = \sum_{u,v}[(f(x,y)g(u-2x,0))h(0,v-2y)] = \sum_{u,v}[f(x,y)h_{HL}(u-2x,v-2y)] \qquad ...(10)$$

$$W_{HH}(f(x,y)) = \sum_{u,v}[(f(x,y)g(u-2x,0))g(0,v-2y)] = \sum_{u,v}[f(x,y)h_{HH}(u-2x,v-2y)] \qquad ...(11)$$

where h and g functions are the low and high pass filters of the sub-band decomposition with condition $g(u) = (-1)^u h(1-u)$. The low pass filter, h, also must satisfy three criteria to construct the orthonormal basis of compactly supported wavelets: (a) $\sum_u h(2u) = \sum_u h(2u+1) = \sqrt{2}/2$; (b) should be orthonormal; and (c) have a certain degree of regularity. The 2-D filters at the second forms of the above four equations are the vector products of h and/or g filters. The relationship between high pass and low pass filters make the unification of the above four sets of decomposition possible.

According to the wavelet theory, it is known that given a set of h, one can calculate the Fourier transform of the scaling and wavelet functions as follows:

$$\Phi(w) = H_0(e^{iw/2})\Phi(w/2) \qquad ...(12)$$

$$\Psi(w) = H_1(e^{iw/2})\Phi(w/2) \qquad ...(13)$$

where $H0$ and $H1$ are Fourier transforms of h and g filters, respectively. Hence, both the scaling and wavelet functions can be obtained through infinite recursion by using Eqs. (12) and (13), respectively.

Using the Low Pass Filter for the Four Channels Decomposition of 2-D DWT - Using Eq. (9) as an example to rewrite the decomposition equation by replacing g with h filter, we have:

$$W_{LH}(f(x,y)) = \sum_{u,v}\left[(f(x,y)h(u-2x,0))(-1)^v h(0,2y+1-v)\right] \qquad ...(14)$$

or

$$\begin{aligned} W_{LH}(f(x,y)) &= \sum_{u,v}\left[(((-1)^v f(x,-y))h(u-2x,0))h(0,v-2y)\right] \\ &= \sum_{u,v}\left[(((-1)^v f(x,-y))h_{LL}(u-2x,v-2y)\right] = \sum_{u,v}\left[f_{LH}(x,y)h_{LL}(u-2x,v-2y)\right] \end{aligned} \qquad ...(15)$$

Converting Eq. (10) to use the 2-D low pass filter as the kernel is a matter of changing the orientation from y- to x-direction (or combining both directions for Eq. (11)). These conversions also indicate that one can use a single 2-D filter to compute the four quadrants of the 2-D wavelet transform by flipping the matrix position in x- and/or y-direction(s) and alternating the sign of the flipped matrix corresponding to the direction(s).

The alternated sign of the source matrix makes the convolution operation unconventional. We have developed a precalculation method that involves a cross product of two matrices: the flipped version of the original image is the first matrix, and the associated second matrix shown in Figure 2 is composed of +1 and -1. After precalculation, the size of the intermediate images is $(k/2 \times k/2)$ times the original image size. The factor of $1/2 \times 1/2$ is due to the 1/2 down sampling two-dimensionally in a conventional forward wavelet transform. The largest three blocks shown in Figure 3 are the intermediate images $S_O(xk/2, yk/2)$.

$$\begin{bmatrix} + & + & + & + & + & + \\ - & - & - & - & - & - \\ + & + & + & + & + & + \\ - & - & - & - & - & - \\ + & + & + & + & + & + \\ - & - & - & - & - & - \end{bmatrix} \qquad \begin{bmatrix} + & - & + & - & + & - \\ + & - & + & - & + & - \\ + & - & + & - & + & - \\ + & - & + & - & + & - \\ + & - & + & - & + & - \\ + & - & + & - & + & - \end{bmatrix} \qquad \begin{bmatrix} + & - & + & - & + & - \\ - & + & - & + & - & + \\ + & - & + & - & + & - \\ - & + & - & + & - & + \\ + & - & + & - & + & - \\ - & + & - & + & - & + \end{bmatrix}$$

Horizontal operator *Vertical operator* *Diagonal operator*

Figure 2. Three matrices used for the cross product precalculation.

Development of the CNN Convolution Process with Wavelet Kernels - Since we can combine all four convolution operations by using only one kernel, the wavelet convolution operation can be adapted by the CNN convolution processing described earlier. This decomposition platform is particularly convenient for the CNN backpropagation training. Figure 3 shows the block diagram in four sections of the wavelet decomposition processes for the forward and backpropagation calculation.

The above convolution processing using a wavelet kernel (CNN/WK) would only replace one out of N feature maps in the hidden layer of Figure 1. To replace all N feature maps, a total of $4N$ channels with N independent wavelet kernels is required. In Figure 3, the updated filter kernel, $h'_u h'_v$, does not guarantee holding the criteria to serve as a low pass filter for a wavelet transform.

The 2-D composed low pass filters h_{LL} in the CNN/WK serves the same role as the kernels K in the conventional CNN. To satisfy the criteria of a wavelet transform, the updated low pass filters would require the following conditions to be fulfilled:

(a) using known wavelet kernels h_u for the initialization of CNN kernels;

(b) updating the kernel with the constraint: $\sum_u \Delta h_{2u}[t] = \sum_u \Delta h_{2u+1}[t] = 0$ which ensures the orthogonal property between h_u and g_u filters;

(c) computing new scaling and wavelet functions using the recursive algorithm as indicated by Eqs. (12) and (13) to ensure their existence, otherwise, Δh_u in (B) must be modified.

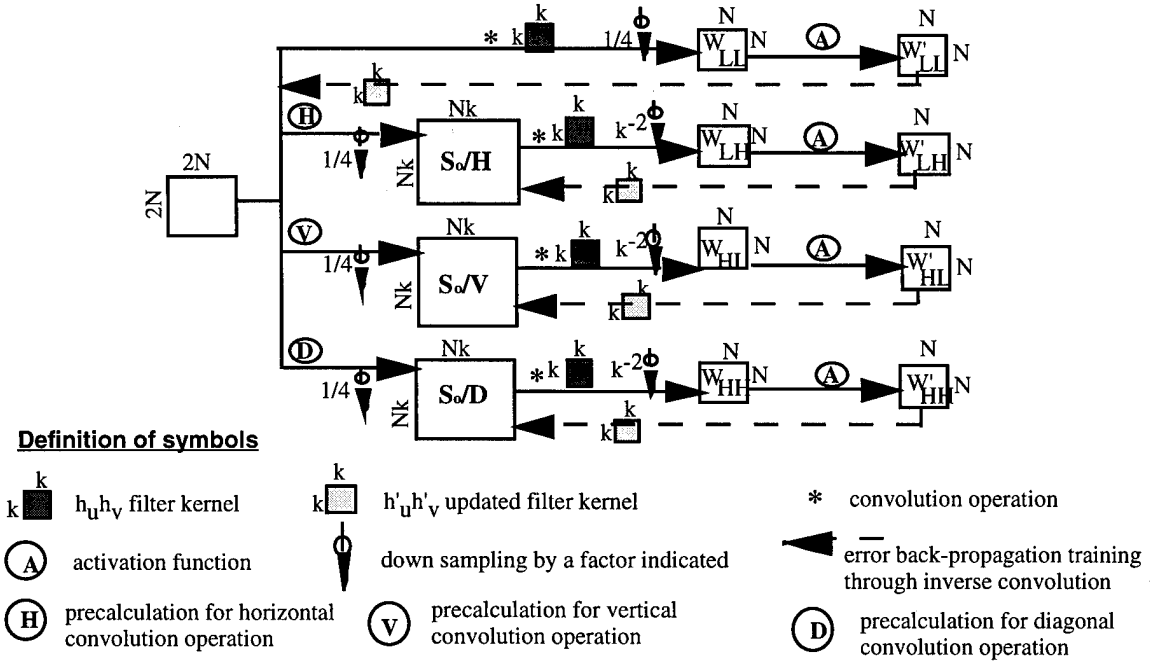


Figure 3. Signal propagation block diagram for a section of the convolution operation using a wavelet kernel in the CNN/WK architecture.

Based on each precalculated image $S_O(xk/2, yk/2)$ described earlier, Eq. (2) can be rewritten for updating 2-D WK

$$K_{u,v}[t+1] = K_{u,v}[t] + \eta \sum_i \delta(i) S_0(xk/2+u, yk/2+v) + \alpha \Delta K_{u,v}[t] \qquad ...(16)$$

where index i = 0,1,...$(k\text{-}1)^2$ corresponds to the sub-image of S_O matched to the kernel size. Eq. (16) represents the updated kernel suggested by the BP, these values require a conversion to a new wavelet kernel $h'_u h'_v$. Assuming the wavelet filter is a scale vector (i.e., $h_u h_v = h_v h_u = h_{LL}$, where $u\&v$ = 0,1,2, ... k-1), then only k free parameters ought to be trained for a set of wavelet transform. A solution to satisfy condition (B) and to make $h'_u h'_v$. approximately equal to $K_{u,v}$ is determined.

Since the decomposed feature maps on the low-low sub-channel have different image characteristics from the others, we free the kernel so that the low-low channel is not constrained by the other three channels. In this way, each set of decomposition has two kernels, one operates on

the low-low channel, the other one operates on the remaining three channels. Without the separation of kernels, we found that the neural network had a difficulty in reaching a convergence in the training.

D. Application To The Detection Of Disease Patterns

Detection of Microcalcifications - We have evaluated the CNN and CNN/WK algorithms in the detection of subtle microcalcifications. A total of 68 mammograms (only 38 of them consist of subtle microcalcifications) were digitized by a laser scanner with a pixel size of 0.105 mm. The initial search prior to the final interpretation by the neural network follows the basic scheme which uses background removal and signal extraction methods to pre-scan the mammograms and to extract all possible suspected areas. After the pre-scan process by the computer program, the 68 digital mammograms provide 265 true and 1,821 false subtle microcalcifications.

The image blocks of suspected calcifications were automatically extracted and were centered. Prior to the CNN process, the backgrounds of all the image blocks were removed using a three-level wavelet high-pass filtering technique. Specifically, after extracting each suspected region from the original digital mammogram, a three-level wavelet transform suggested by Daubechies was used and only the lowest frequency was eliminated prior to reconstructing the image block. The high-pass filtered image blocks were used as the input of the CNN. The kernels of CNN/WK were initialized with Daubechies' 8-tap, 6-tap of a composed trigonometrical function, or Haar's 4-tap filters. Each filter was used repeatedly with an additional 7 times for 24 groups and an additional 19 times for 60 groups in the CNN/WK studies.

In this study, we randomly selected two sets of mammograms (i.e., 34 for training and 34 for testing). Three kernel sizes (4×4, 6×6, and 8×8) were used to operate on an image block of 16×16 pixels (i.e., a square area of 1.7 mm). The experiment was repeated by swapping the training and testing sets of the mammograms. The average NDDIs of eight rotated image versions were used to evaluate the performance of the neural networks using the LABROC program.

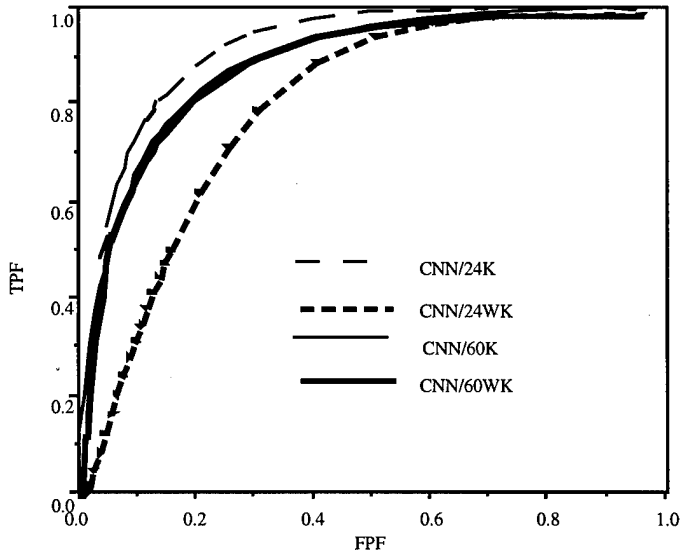


Figure 4.

Four ROC curves represent different performances of convolution neural networks in the detection of clustered microcalcifications.
(a) CNN/24K: Az = 0.91;
(b) CNN/24WK: Az = 0.83;
(c) CNN/60K: Az = 0.89; and
(d) CNN/60WK: Az = 0.90.

One must realize that the detection of clustered microcalcifications is clinically more significant than that of individual calcifications, since the clustered microcalcifications (three or more) are a strong indication to breast carcinoma in radiological diagnosis. Once NDDIs were collected, the clinical criterion was added. Hence, the computer program rejected suspected clusters containing only one or two calcifications and calculated the average NDDI among the clustered calcifications

for the ROC evaluation. The clustering procedure was done by grouping the detected microcalcifications in a $1cm^2$ region of the mammogram. Four ROC curves with different CNN kernels are shown in Figure 4. The syntax of "nK" and "nWK" represent "n" groups of non-constraint kernels and wavelet constraint kernels used in CNN and CNN/WK experiments, respectively. The A_Zs of the original CNN and newly developed CNN/WK were 0.91 and 0.83, respectively, by using 24 groups of kernels. However, the results of the A_Zs were 0.89 and 0.90 with the CNN and CNN/WK respectively, by using 60 groups of kernels.

Detection of Lung Nodules - We also evaluated the use of the CNN in the detection of lung nodules. Chest radiographs of patients with primary and metastatic cancer and with one or several lung nodules are converted into digital form using a laser film digitizer (Konica Laser Film Scanner Model: KDFR-S; Tokyo, Japan). About one-third of chest images were acquired from a computed radiographic system (AGFA ADC prototype computed radiography; Mortsel, Belgium). The digital data were transmitted and stored in our PACS until needed for the research project. The images were then retrieved to a high speed workstation and the computer searches were used sequentially: a thresholding evaluation, use of background reduction, a test of profile matching rate, and neural network classification.

The pre-scan process was performed first to locate the center of the island and isolate the image block for training. The pre-scan program was running in a highly sensitive mode with a matching rate (MR) of 0.7 for all images involved in the training. Suspected image blocks included various types of rib crossing, and various sizes of end-on vessels and vessel clusters. The true-positive nodules may also overlap with lung, vessels, and rib structures. These image blocks were mirrored and rotated 90^o, 180^o, and 270^o for the training. Note that each original and its seven "brother" image blocks share the same score vector (probability of a disease and output fuzzy association). During the training, the original and its seven "brother" image blocks as a group were entered in the same sequence.

The database had 55 chest radiographs and only 25 images contained at least one nodule. In the pre-scan, 52 nodules and 155 non-nodules were extracted from all 55 images. All cases were confirmed by biopsy or by follow-up showing growth of the nodule. In this study, we employed a grouped jackknife method to evaluate the performance of the CNN. We randomly selected 28 images for training and the other 27 images for testing in the study. Since we used grouped jackknife method to perform the study, it will take a long time to complete the experiment. We expect to receive the results within three more months. Initial results indicated that we need more wavelet kernels to obtain a similar result to that of the regular CNN.

E. Conclusions

In this experiment, the A_Z of the CNN/24WK was 0.83 which was lower than 0.91 of the CNN/24K. However, the A_Z was greatly improved to 0.90 when 60 wavelet kernels were used. This may be because only an average of approximately eight free parameters were available in each kernel of the CNN/WK. On the other hand, the CNN had 6×6 (or 36) free parameters in each kernel. We found that 24 groups for CNN/WK were not sufficient to extract necessary features for classification. When 60 groups of kernels were used, the CNN/WK would have sufficient free parameters which led to a higher ROC performance. On the other hand, 24 groups of kernels were sufficient for CNN and no improvement was observed while the number of kernel was increased. In another experiment, we used a similar CNN structure with two hidden layers for processing feature maps. The average performance index, A_Z, was 0.97 for the detection of clustered microcalcifications.

2.1.3 Automatic Detection of Lung Orientation in Digital Chest Radiographs

Investigators: Kie B. Nahm, PhD and Seong K. Mun, PhD

A. Significance to the Military MDIS Project and Executive Summary

The hospital picture archiving and communication system (PACS) is emerging as the new technology of managing clinical images over the conventional archiving methods. Along with the computer-aided diagnostics (CAD), these applications require images in digital formats. The new generation radiographs from computed radiography (CR) systems are produced in digital formats. But the majority of the images in the current film libraries are to be converted to the digital format through digitizers. While obtaining and handling these images, some of them can be rotated or flipped either by mistakes or by unavoidable circumstances. Unlike the conventional film where the orientation of the images could be corrected manually rather easily, these disoriented images on the display terminal will burden the reader by requiring a few extra keystrokes to correct the orientation.

To avoid the problems associated with the disoriented images, we have developed a computer software of finding correct orientations in chest radiographs. This method assumed that the spinal column is located close to the central section of the image as a starting ground, though it will eventually locate the most likely location after further development. The high values of gray level behind the shadow of the heart are used to determine the parity (left-right) of the image. Of the 66 images tested, this method produced correct orientation for 62 images: the rest were prescreened to be abnormal by the program. These abnormal lungs were the ones with severe size differences between left and right, and one that had the identification marker placed too closely to the region of interest.

B. Test Images

All 66 chest images were in the archive of Imaging Science and Information Systems (ISIS) Center, already digitized. The randomness and the nature of disease were not considered. The original images with the pixel size of 2k x 2.5k were reduced to the size of 512x 620 (57 cases) and 512x 421 (9 cases). Three of the images were rotated 90 degrees and in one case, the parity was reversed (flipped). The 12 bit resolution was converted to 8 bits and images were stored in TIFF format for processing with MATLAB environment running under SGI Onyx system.

C. Methods

The typical chest radiograph had a relatively weak contrast and all the images were preprocessed through the histogram equalization. This raised the contrast level considerably. The rest of the steps of detecting the lung orientation can be presented as shown in appendix A. The procedure consists of two major subprocesses: one to detect the rotation of the image (90 or 180 degrees) and the other to determine the left-right direction. Around these blocks are auxiliary routines to help visualize the processes.

C.1 Detection of the image rotation.

This routine determines whether the image is upside down or simply rotated 90 or -90 degrees with respect to the normal image. The gray level values for the 2 lines on each side of the central-vertical line, each separated by about 5% of the image width are summed to represent the general brightness level of the vertical coordinate. These values when plotted against the distance from the top of the image have very distinctive characteristics: for an upright image, the curve increases monotonically. If the slopes are negative, the lower side is darker, which is indicative of the inverted image. For the 90 degree rotated image, the curve usually comes in the "W" shape and the overall slope is noticeably low and this is used to tell the rotated image. Upon encountering this "low" slope, the routine scans across the horizontal direction at the center of the image, trying to locate the bottom side of the image. The side with the higher gray values is determined as the bottom side and the image rotated accordingly.

An incorrect decision could be made when the rotated image has a severe asymmetry between the lungs. If the scanned portion of the rotated lung contains abnormally bright areas due to a certain disease, the slope criteria adopted in this routine might produce a false result. No such image has been found in the test images.

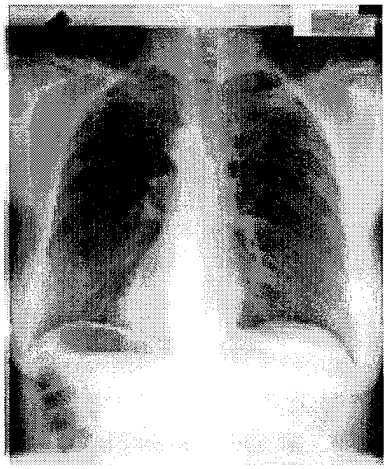


Fig. 1. The original image

Fig. 2. ROI

C.2 Selection of the region of interest.

This is a loosely defined term, meaning the area around the lung and the spinal column. Since the major difference between the left/right lungs is the shadow cast by the heart, it is logical to study this area. The selection of this area is not critical about the extent of coverage around the heart, though. The current setting is the rectangle, covering half the width and height, centered on the mid-point of the image.

Once this region of interest (ROI) is determined, the routine sets out to see if the ROI is reasonable. First, the vertical gray level sums for columns within 20% of the width of the ROI are obtained and it is assumed that the vertical line with the largest sum would be close to the spinal column. Since the column is the radio-densest material in this region, this assumption generally holds. Once this "center line" is determined, the ROI is redefined along this line as per the method mentioned above.

C.3 The lung bottom and the image pre-screening.

The ROI may involve, according to the lung size and the location within the image, a large area of bright levels in the lower half. To determine the extent of the lung toward the lower end, the

image of the ROI is binarized at the threshold level of 0.5 (1.0 is the brightest value). This will leave the most of the lung back, while removing the rest of the images- heart, vessels - from the image. Now the lower bound of each side of the lung is determined.

It has been found that a few images have an abnormal size disparity between the lungs. Since the method adopted in this routine depends on the incremental area, this abnormal disparity in the lung size will inevitably introduce an unacceptable error. Currently, this routine compares the location of the two lower bounds. Of the two bottom lines, the one on top was chosen as the overall lower limit. If the locations differ by more than the pre-set threshold, the image is considered "abnormal" and is rejected from further processing.

Obviously, there is a definite need for a refined method of prescreening. Recent works by Armato et al.[1] were focused on this aspect. For the detection of the lung image orientation, the approach adopted here proved to be sufficient. In one test image, though, the rectangular ID tag was placed too close to the bottom of the lung, confusing the routine and giving a false rejection. Also, for the image that is rotated by some angles, like 10 or 20 degrees, this routine stalls further processing. This false signal would be corrected with the adoption of a subroutine that corrects for the rotation of this size.

C.4 Determination of the parity.

The gray level behind the heart in images after the histogram equalization usually lies between 0.5 and 0.8. If the image is thresholded at 0.4, the shadow of the heart disappears from the resulting image. By subtracting two images thresholded at 0.9 and 0.4, one obtains the differential area between the two.

(a) (b) (c)

Fig. 3. ROI thresholded at 0.4 (a), 0.9 (b), and the differential area (c).

Of the ROI obtained as above, 20% of the remaining lung length was chosen from the lower boundary line of the lung. This is the portion of the image that contains the heart on either side. The differential area is present on both sides, but the area occupied by the heart, now occupying the most of the differential area nearby, is by far larger than the counterpart on the other side. Just before actually computing the area in this zone, it was necessary to perform an erosion operation to remove spots of high gray levels.

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[1] .Samuel Armato III et al. "Computerized detection of abnormal symmetry in digital chest radiographs", Med. Phys, 21(11), November 1994

Now, the differential areas on the both sides of the central line are compared. Whichever side with the larger area corresponds to the left side of the patient.

(a) (b)

Fig. 4. The differential area around heart: (a) left (b) right side of the thresholded ROI.

D. Result

The program was developed in MATLAB interpretive language. The routine was tested with 66 chest images explained in section B. Three of them were rejected for justifiable reasons, 1 for the misplaced ID marker. All the rest of the images passed the routine with the correct result: they all came out with the right side up, left and right properly oriented. Of the three rejected, one was due to the excessive tilt of the image. This puts the lung bottoms at considerably different locations, thus triggering the rejection routine. As such, the success rate of this routine as tested was about 97% (64 out of 66).

E. Conclusions and Remarks

A relatively simple and fast method was developed to detect the proper orientation of the digital chest radiographs. The difference in areas around lung between two different threshold images was used as a criterion for finding the image parity. The slopes of the vertical and the horizontal gray level were utilized to bring the image into an upright position.. The success rate of this routine as it stands now is 97%.

Refinements are desired in the various sectors of the routine. The most urgent one would be the fine tuning of the rotation of the image. As it is, this routine only corrects for the 90 degree rotations. One might as well include a subroutine that detects and corrects the small tilts in the image. This would improve the success rate by eliminating the false rejection due to the small angle rotation. Also needed is the process that detects the operator-introduced artifacts such as the ID marker or the L /R designator.

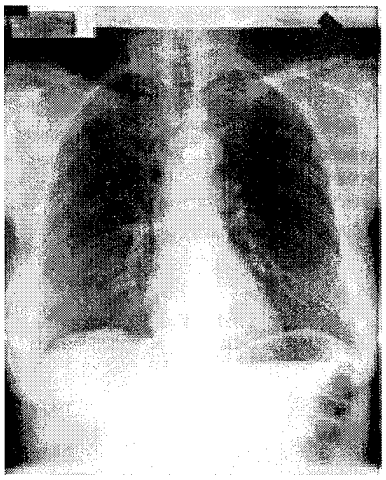
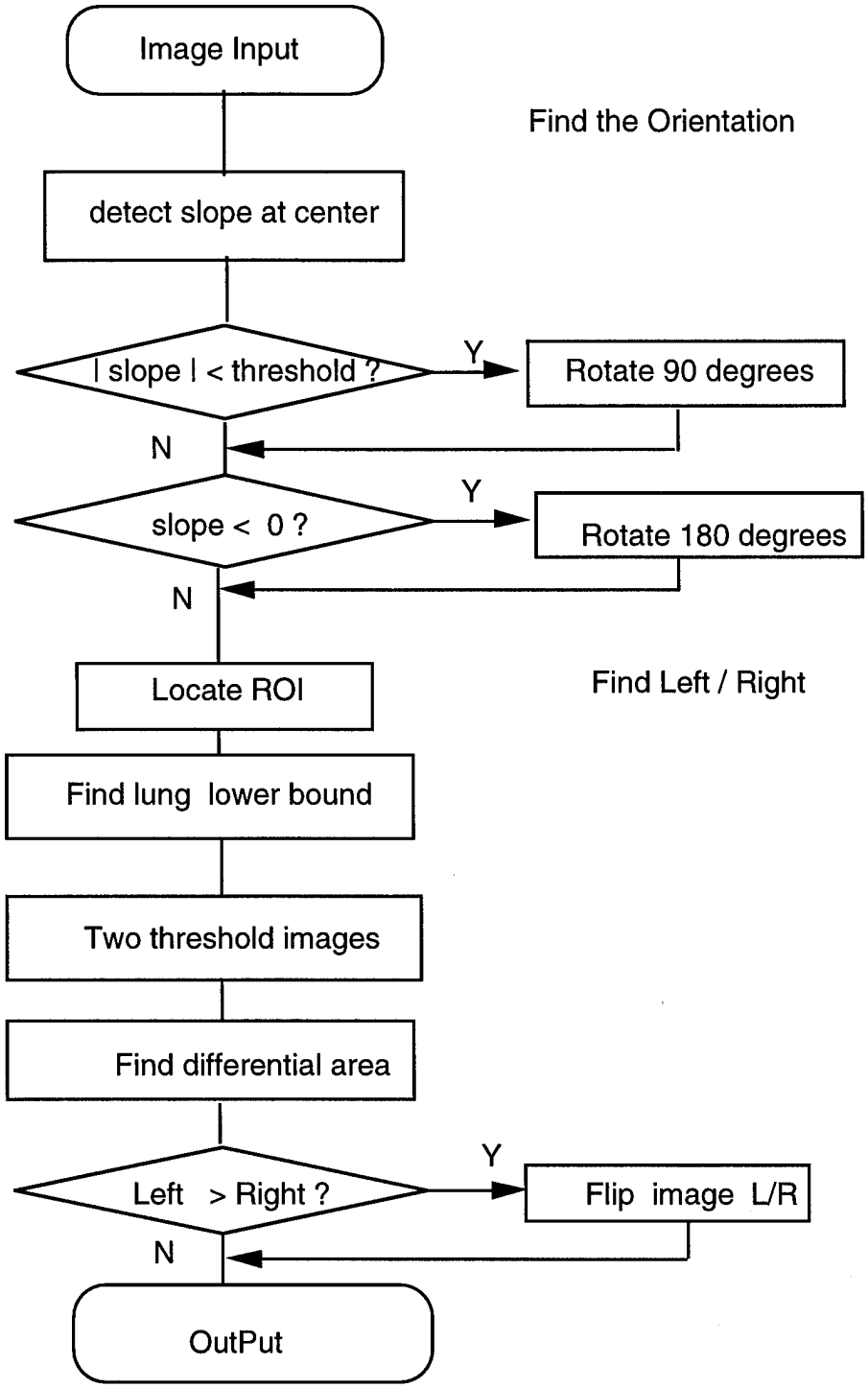


Fig. 5 . The properly oriented output image.



Appendix A: The flow chart for detecting the lung orientation.

2.2.1 A Contour Coding and Full-Frame Compression of Discrete Wavelet and Cosine Transforms

Investigators: Shih-Chung B. Lo, PhD, Huai Li, MS, Brian H. Krasner, PhD, Matthew T. Freedman, MD, MBA and Seong K. Mun, PhD

A. Significance to the Military MDIS Project and Executive Summary

Image data compression benefits MDIS, particularly when serving as a teleradiology system, by reducing storage requirements and the required communications bandwidth. It also benefits physicians by improving the response time for image retrieval, and helps keep the cost of the system lower through more efficient use of existing resources.

B. Introduction

Radiological information currently includes text, voice, single frame, continuous sequences, and motion pictures. For imagery, the generation rate can range from 64,000 bytes/image for a single image to 2 Mbytes/image per one thirtieth of a second for a digital subtraction angiography (DSA) system. As a result, a very large volume of digital data is generated. It is desirable to have both a large data storage resource and extremely fast data transmission channels for communication. On the other hand, it is also essential to compress these data into an efficient form for storage and transmission.

This paper presents a possible hybrid compression platform designed for clinical use. A digital value of each image was decomposed into two parts by using a splitting and remapping method. We employ an error-free contour coding for one part of the digital value containing highly significant value. For the second part of the digital value, two promising compression schemes using the full-frame discrete wavelet (FFDWT) and the full-frame discrete cosine (FFDCT) transforms were evaluated in terms of entropy and mean-square-error (MSE).

C. Compression Algorithms

C.1. Data Decomposition Scheme.

It is very common for a radiographic image to contain sharp edges. Applications of a transform coding to this kind of image sometimes will produce unsatisfactory results. To circumvent this problem, a decomposition method has been developed by the authors as follows: (1) take the top few bits as the most significant bit (MSB) image ($f_M(x,y)$) and (2) remap the remaining LSB image. Equation (1) is a typical data operation of obtaining the top (N-L) most significant value of an image value ($f(x,y)$). The operation of remapping the J LSBs for $f(x,y)$ can be generally expressed as in Equation (2).

$$f_m(x,y) = (f(x,y) + K) \,\&\, (M_N - M_L) \qquad \ldots(1)$$

$$f_L(x,y) = \begin{cases} (f(x,y) + K) \,\&\, M_L & \text{for } (f(x,y) \,\&\, (M_{L+1} - M_L)) = 0 \\ M_L - [(f(x,y) + K) \,\&\, M_L] & \text{for } (f(x,y) \,\&\, (M_{L+1} - M_L)) \neq 0 \end{cases} \quad \ldots(2)$$

where N is the maximum number of bits in the data set, L represents the number of LSB, M_j is a value representing $2^j - 1$, K is a constant integer which can be adjusted to optimize the correlation in $f_m(x,y)$ and in $f_L(x,y)$.

The advantage of the splitting technique is threefold: (a) ≈87.5% of maximum intensity including sharp edges on the original image is retained on the 3MSB image; (b)the extremely high correlation of the 3MSB image yields a high compression ratio with no data loss; and (c) the correlation near the edges of the RLSB image is improved.

C.2. Contour Tracing and Coding.

For an image containing only piece-wise areas, the boundaries between areas are the only information to be retained. Contour tracking is a common outline method for boundaries. A search pointer tries to search the boundary of the predefined area. Once a boundary tracing is finished, only a very small overhead (such as starting point) and the boundary tracking values are needed to encode the region. These 2-bit tracking values can be further reduced by applying an arithmetic coding or a Lempel-Ziv coding. Although, there are 8 values (0-7) in a 3MSB image, often only boundaries of 1 (for 0, 1, and 2), 3 (for 2, 3, and 4), and 5 (for 4, 5, and 6) are needed to code. A boundary of 7 (for 6 and 7) usually is either very small or not shown at all. In addition, the four natural boundaries defining the finite size of the image can be ignored. Some unusual situations, for example multiple value joint areas, can be recovered by a special coding procedure to ensure the error-free requirement. A one-dimensional tracking method of this kind is particularly advantageous to encode a large size for two- or multi-dimensional images.

The 2-3 MSB of the image data is highly correlated and is characterized as a piece-wise image. We have employed the contour coding for a 3MSB image and obtained an error-free compressed data with an average bit rate of about 0.1 bit/pixel.

C.3. Quantization and Entropy Computation on the Discrete Transform Spaces.

In this study, we used a linear quantization method to convert the real numbers of DCT and DWT coefficients to integer numbers:

$$Q_{u,v} = NINT[2^{(B_{m,n}-1)} - 1] \times \frac{F_{u,v}}{|F_{m,n}|} \quad \ldots(3)$$

and inverse quantization

$$F'_{u,v} = Q_{u,v} \times \frac{|F_{m,n}|}{(2^{(B_{m,n}-1)} - 1)} \quad \ldots(4)$$

where *NINT* denotes the nearest integer operation; $F_{u,v}$ and $Q_{u,v}$ are the original and quantized coefficients at coordinates (u,v), respectively; $|F_{m,n}|$ is the maximum absolute coefficient at (m,n) of a given zone; $B_{m,n}$ is the maximum bit value to be assigned corresponding to $|F_{m,n}|$ in

the zone. On the FFDCT space, three zones are treated separately. The two low frequency zones are small and are saved with original real values and two-byte integers, respectively. In addition, a 4×4 block was used to form the bit-allocation table $B_{u,v}$ in the high frequency zone. However, we used the natural zones of decomposition levels for the quantization operation on FFDWT spaces.

As far as information theory is concerned, a more standard definition of entropy would be the ensemble entropy:

$$H(X_c, Y) = H(Y) + H(X_c / Y) \qquad ...(5)$$

where X_c is the current pixel and Y denotes preceding pixels. After quantization, there are many $Qu,v = 0$; and some of them contiguous. A run-length coding was used to estimate the second term of Eq. (5) for the FFDWT. Besides zeros in the high frequency region, no significant correlation was found among the quantized FFDCT coefficients. Thus, there was no need to calculate $H(Y)$ for the quantized coefficients of FFDCT. The compression ratio was controlled only by the parameter Bm,n of the high frequency zone. As long as Bu,v is 0, no code and entropy will be contributed from the 4×4 block.

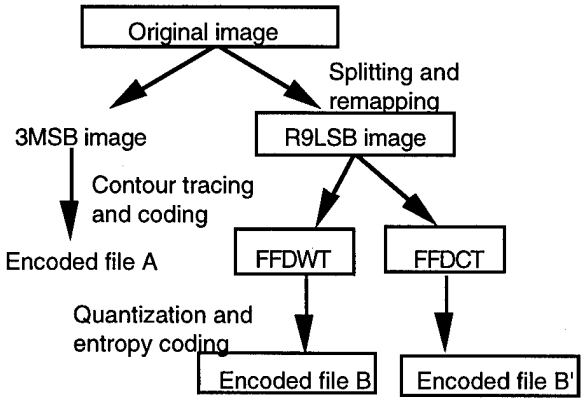


Figure 1. A block diagram of this compression platform.

D. Experiments and Results

D.1. Experiments.

We have collected ten chest radiographs and ten mammograms for the compression study. The chest images were digitized by a Lumiscan 150 laser scanner with a pixel size of 175μm. The mammograms were digitized by the same Lumiscan scanner and an ImageClear R3000 CCD camera with pixel sizes of 50μm and 42μm, respectively. In addition, the "Lena" image formatted at 512×512×8 bit was also used to compare the entropies and MSEs with the compression techniques on FFWDT and FFDCT domains.

Each pixel value of 12-bit datum on the digital chest radiographs or the mammograms was split into 3MSB and R9LSB to yield two images with the same image size as shown on the left hand side of Figure 2. The 3MSB image was encoded by the alternate value contour coding to generate the compressed file "A". The R9LSB image was linearly quantized and entropy was calculated. The inverse procedure was performed to reconstruct the image. The MSE between the original and reconstructed images was calculated for comparison. The resultant bit-rate is estimated by adding the entropy and the bit-rate of file *A* together for the splitting method. The compression

ratios were also calculated based on the original 12 bit/pixel for medical images and 8 bit/pixel for a "Lena" image.

In this study, a three-level FFDWT was used. Therefore, a total of ten zones (level one has three zones, level two has three zones, and level three has four zones) was created for each image. Similar to the bit allocation strategy used in the FFDCT compression, the higher level zones corresponding to lower resolution regions receive more computer spaces than the lower level zones.

For each original image containing 2,048×2,048 pixels, a miniaturized image of 512×512 pixels was generated. The miniaturized images were also studied using the same platform to investigate the resolution effectiveness with various compression techniques.

D.2. Results.

For the 3MSB images, the average bit-rates were 0.98 bit/pixel and 0.14 bit/pixel for 2K×2K chest radiographs and mammograms, respectively. However, the 2MSB "Lena" image can only be encoded by 0.15 bit/pixel.

We have applied the FFDCT and FFDWT coding methods to 10 chest images. The MSEs between original and reconstructed images and the compression ratios (CR) were shown in Tables I and II for image sizes of 2,048×2,048 and 512×512, respectively. A similar study for mammograms, digitized by the ImageClear R3000 camera, was performed (See Tables III and IV). Table V tabulated the compression results obtained from original digital mammograms redigitized by a Lumiscan 150 laser scanner. The differences between these two film scanners differ not only in the digitization pixel size but also in noise level. The modulation transfer functions (MTF) of both systems are comparable, however, the noise level of the ImageClear R3000 camera is much higher than that of the Lumiscan 150 scanner.

From these results, it is seen that the MSEs obtained through the splitting method are smaller than those obtained without using it. This is due to the fact that chest radiographs and mammograms often possess sharp edges. When the image is relatively smooth such as the "Lena" image, the splitting method would have less impact on the compression outcomes (Table VI). In fact, the compression efficiency of the FFDCT is far better than that of the FFDWT for both high-resolution chest radiographs and mammograms as well as low-resolution mammograms. However, they performed about the same for low-resolution chest images. This may be because mammograms are very flat compared to chest radiographs. For flat images, the FFDCT decomposition condenses at a level of higher efficiency than the FFDWT.

By comparing Tables III and V, we found that the decomposition efficiency was increased with the FFDWT but it was decreased with FFDCT for mammograms with less noise. However, the compression efficiency based on the FFDCT techniques still outperforms over the FFDWT.

We have tested several wavelet filters, no significant difference of the results was found through compression techniques based on the FFDWT decomposition. The results shown on Tables I-VI were obtained from Daubechies's 8-tap orthonormal compactly supported wavelets.

E. Conclusions and Discussion

For the high-resolution images, it is evident that higher order correlation can be packed more effectively with the FFDCT algorithms than with the FFDWT. This phenomenon was not observed in the FFDWT study. This may due to the fact that the FFDCT operates on a large space to collect the correlation information into a relatively defined region (more energy is located in a low resolution area resulting from the MTF of the imaging devise) in the DCT domain. The longer tap filter should be able to collect high-order correlation in the image using

the FFDWT techniques. However, the energy localization on the FFDWT is still an open issue toward the optimization of the compression techniques.

The image size of the "Lena" commonly used in the field of compression is much smaller than that of the projection x-ray image. In this paper, we demonstrated that our compression results with the "Lena" were comparable to those obtained in the literature. We found that the decomposition characteristics of the "Lena" image using the splitting method, FFDCT and FFDWT are very different from the radiological images. The compression results obtained from using the "Lena" as an example can not be extrapolated or predict the outcome of a compression technique for radiographs which cover 70%-80% of radiogical imaging volume. Although, CT and MR images are formatted $512\times512\times12$ and $256\times256\times12$ bits, respectively, the image characteristics of them are also very different from the "Lena" and other still pictures. We will report the results of CT and MR images using the same techniques discussed here in future publications.

As indicated earlier, we did not attempt to optimize the compression method on either the FFDWT or FFDCT domain. This study only estimated and compared the entropy on both transform domains. Two methods that may lead to the optimization of quantization procedures for the FFDCT are: (a) non-linear quantizer (e.g., Max quantizer) and (b) two-dimensional generalized Gaussian modeling. For the FFDWT, vector quantization should be a good choice.

Table I. Chest Images (2k×2k×12bit)

	FFDWT (Split)	FFDWT (Non-split)	FFDCT (Split)
CR	14.5	18.8	25.0
(SD)	(1.7)	(3.6)	(5.9)
MSE	106.1	206.9	111.1
(SD)	(36.4)	(123.5)	(45.3)

Table II. Chest Images (512×512×12bit)

	FFDWT (Split)	FFDWT (Non-split)	FFDCT (Split)
CR	10.1	13.7	11.7
(SD)	(1.0)	(1.5)	(1.4)
MSE	200.7	923.5	189.8
(SD)	(38.6)	(404.8)	(62.7)

Table III. Mammograms Digitized by a DBA CCD Camera (2k×2k×12bit)

	FFDWT (Split)	FFDWT (Non-split)	FFDCT (Split)
CR	13.5	23.2	34.7
(SD)	(5.7)	(6.1)	(12.7)
MSE	312.1	1335.4	280.9
(SD)	(146.9)	(574.7)	(124.5)

Table IV. Digital Mammograms (512×512×12bit) shrunk from the images used in Table III

	FFDWT (Split)	FFDWT (Non-split)	FFDCT (Split)
CR	12.5	19.3	22.7
(SD)	(3.1)	(5.6)	(6.1)
MSE	214.0	1345.1	249.3
(SD)	(85.0)	(762.6)	(89.9)

Table V. Mammograms Digitized by a Lumiscan 150 Scanner (2k×2k×12bit)

	FFDWT (Split)	FFDWT (Non-split)	FFDCT (Split)
CR	15.1	30.8	29.3
(SD)	(3.2)	(7.5)	(7.0)
MSE	251.9	1037.5	346.2
(SD)	(64.2)	(433.9)	(98.4)

Table VI. The "Lena" Image (512× 512×8bit)

	FFDWT (Split)	FFDWT (Non-split)		FFDCT (Split)	FFDCT (Non-split)	
CR	18.2	18.6	21.1	21.6	18.5	23.1
MSE	39.1	64.7	69.1	54.1	42.2	56.3
PSNR (db)	32.2	30.0	29.7	30.8	31.9	30.6

2.2.2 Performance Characteristics of High Resolution Film Scanners

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A. Significance to the Military MDIS Project and Executive Summary

In this study, we demonstrated imaging analysis methods to evaluate a digital device. This is important because high quality image acquisition is essential to the whole chain of the MDIS system. The performance of a digital device must fulfill the defined clinical requirements and system specification. The methods outlined in this study can be used for general acceptance testing of a digital imaging device. Part of these methods are also appropriate for checking the imaging devices in routine quality control procedure.

B. Introduction

The recent advancement in high-speed digital computers, networking, and high-resolution fast film digitizers, as well as the gradual acceptance of high-resolution digital radiographic systems has revived the interest in the development of a digital radiology system for routine clinical use. A system that uses storage phosphor image plate/laser readout technology seems very promising for use in digital radioology. Such systems are already available for standard radiographic applications, but the spatial resolution may need to be further improved for mammographic imaging. Currently, it is possible to obtain digital mammograms having high spatial resolution by digitizing screen-film images with a laser digitizer or other scanning systems.

Moreover, to realize a computer-based picture archiving and communication system (PACS) for diagnostic radiology, methods must be developed to convert x-ray film images into digital data. Current digitization methods include the video camera, the optical drum scanner, the laser scanner, and the charge coupled device (CCD). Recently, x-ray film digitization using a high resolution CCD scanner has generated a lot of interest. It is important to ensure that the film image conversion process does not lose clinically useful information. In this paper, we present the results of an investigation of the performance of the high resolution film scanners which can digitize film into 21μm and 42μm per pixel.

C. Materials

The CCD scanners, developed by DBA Systems, are interfaced to an IBM PC486 by a SCSI cable. A software package on the PC is used to control the operation of the scanner. Several optical density ranges can be selected to capture a full 16 bits of information. Moreover, a variety of resolutions (multiple of 21μm) and film sizes can be digitized. In this study, we conducted a physical evaluation on two DBA ImagClear film digitizers: models M2100 and M4200 which project, respectively, 21μm and 42μm square region onto a single CCD sensor through the corresponding optical system. In addition to test patterns used for different experiments, several mammograms acquired from Georgetown University Medical Center (GUMC) were also used for the evaluation. These studies were performed at the Imaging Science and Information Systems (ISIS) Center. All raw data were collected by the Georgetown members assisted by Mr. Philip Butson (an engineer at DBA Systems).

D. Results and Discussion

Following are the experiments that were performed on the 21μm and 42μm CCD scanners. The scanners provide 16-bit transmission data directly acquired from the CCD. The gray values corresponding to the optical density are formatted at 12 bit per pixel which was converted by a 16 to 12 bit logarithmic look up table (LUT) in both systems. This 12 bit data representation is equivalent to direct film viewing and laser based system quantization methods. The data representation does, however, reduce the contrast and MTF performance at the lower optical densities and pronounces the noise components at higher densities.

D.1 Evaluation of System Resolution.

A rectangular area of 120×256 pixels across the boundary between black and white on a clear transparency was digitized. The 2-D data was averaged along the boundary direction and became a line array of 256 pixels to form an edge spread function. The point spread functions were derived from the derivative of the edge spread function. A standard method of measuring the modular transfer function (MTF) based on the point spread function was performed. Figures 1 and 2 show the MTFs of the systems. Figure 1 shows the MTF curves for the 42μm CCD digitizer for the edge directions parallel and perpendicular to the film moving (scan) direction. The performance was better when the edge was scanned in the direction parallel to the scan direction. When the edge was perpendicular to the scan direction and the MTF was 0.1, the corresponding observable spatial frequency was approximately 8.0lp/mm. When the edge was parallel to the scan direction and the MTF was 0.1, the corresponding observable spatial frequency was approximately 8.5lp/mm. This may be due to the temporal signal effect during the CCD data collection. When the edge direction was perpendicular to the scan direction, the adjacent scanning signals were smeared and further spread the edge function. When the edge was parallel to the scan direction, the response characteristics of the detector system were not important because of relative long time delay between sampling adjacent pixels of the edge spread function. A similar phenomenon has been reported in our study of performance evaluation of laser film digitizers. In Figure 2, the MTF curve was not smooth because of the high noise in the dark area of the edge spread function.

In a separate study, we digitized a USAF target at a 45 degree angle. Five observers saw the line-bar between 11.3 and 12.7lp/mm for the image digitized by the M4200 machine and saw the line-bar between 22.5lp/mm and 24.2lp/mm when using the M2100 machine. These results were better than the results indicated in Figures 1 and 2. The differences between observable line-bar pattern and MTF measurements were due to the non-optimized edge spread function used in the MTF and the square waves used in the line-bar tests. The users should take the resolving power tests with the line-bar and the MTFs as high and low bounds of the frequency responses of the scanners, respectively.

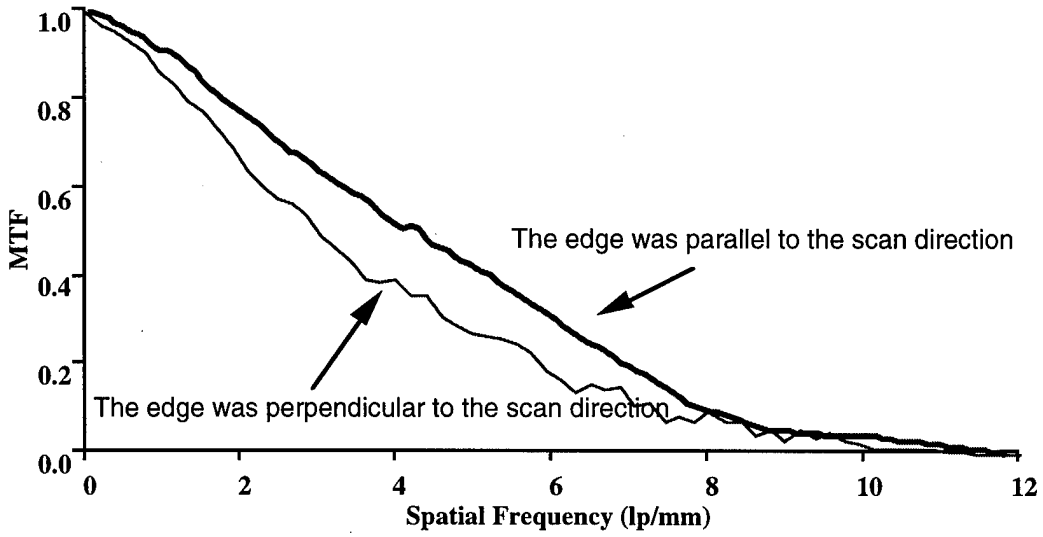

Figure 1. MTFs of the 42mm digitizer.

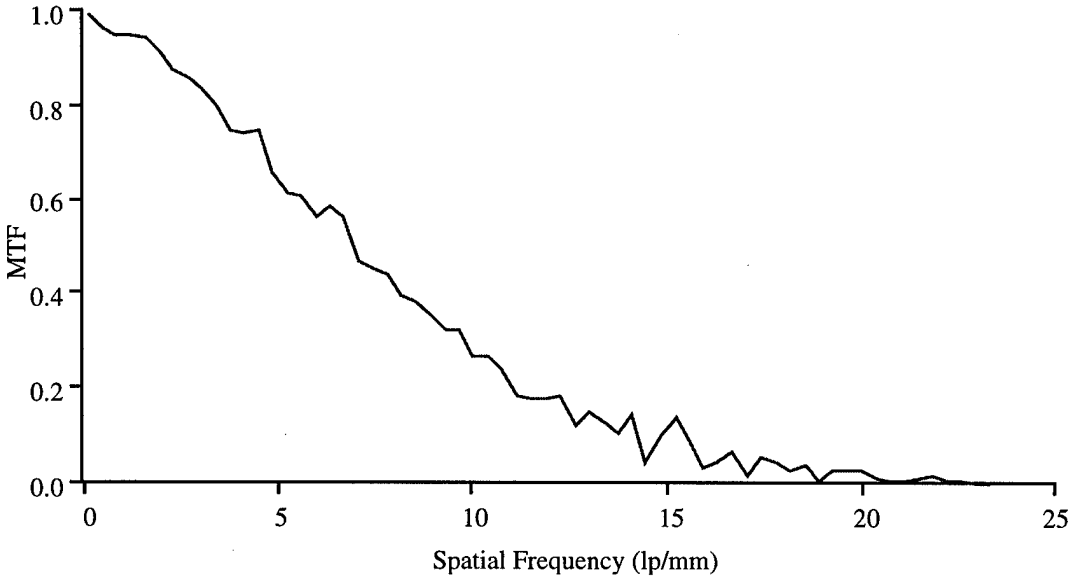

Figure 2. MTF of the 21mm digitizer when the edge was 45 degrees across the CCD array.

D.2 Evaluation of Optical Density Response.

The center region of each step on a calibrated Kodak single emulsion photographic step wedge was digitized onto 10×10 pixels. The mean and standard deviation of the region were computed. Figures 3 and 4 demonstrate the mean gray value and the associated standard deviation versus the optical density (OD) of the 42 μm and 21 μm digitizers, respectively. It is seen that a flat curve rather than a straight line was plotted when the OD was greater than 2.8 for both systems. In fact, higher noises were measured when the OD was greater than 2.8 in M2100 machine. The curves indicated in Figures 3 and 4 show the OD responses and their corresponding standard deviations

when the mean gray values were measured on the step wedge digitized in horizontal and vertical directions, respectively. In Figure 4, it is seen that both the vertical and horizontal gray value measurements coincide. This implies that the system performance was steady and was independent from the orientations with respect to gray response. However, some small variations were observed in Figure 3 where the vertical orientation of the step wedge was inferior to the horizontal one.

The users expect the OD versus gray value response to be linear. However, when the OD has a value greater than 2.8, the digital value can no longer preserve its linear response to the OD values. Moreover, in the non-linear region the signal to noise ratio was approximately 2-4:1 which is clinically unacceptable, especially in the digitization of mammograms. Note that the OD range of 0.2 to 3.5 is considered clinically important density information for mammographic diagnoses. Through many tests, we found that no skin line of the breast could be observed on the digitized GUMC mammograms using both scanners. This was because the optical densities of the skin lines on the tested mammograms were higher than 2.8.

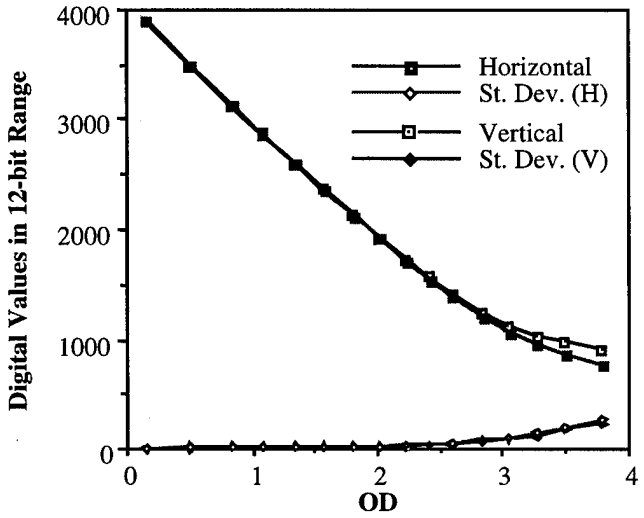

Figure 3. The gray value response of OD with the 42mm digitizer.

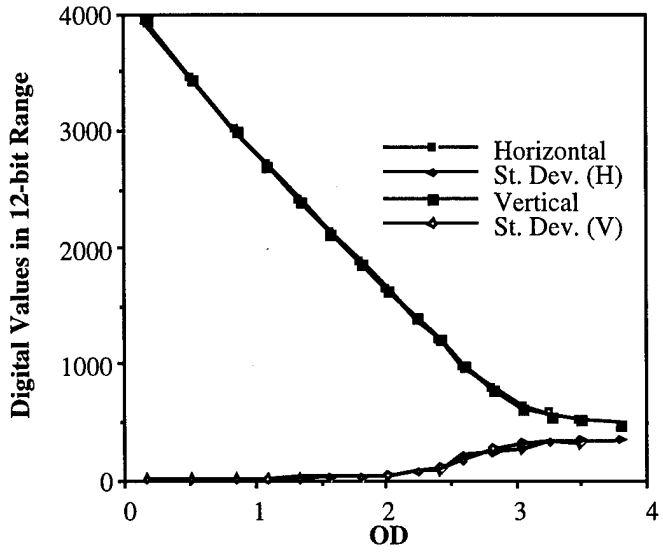

Figure 4. The gray value response of OD with the 21mm digitizer.

D.3 Digitization of Simulated Microcalcifications.

A breast phantom was exposed by an x-ray with routine mammographic examination parameters onto a mammographic film. Bright spots of 120μm and 170μm on the film were digitized by M2100 and M4200, respectively. The digital data of 11×11 pixels were transferred to a DEC workstation using a software called "Khoros". The contrast of the 120μm calcification was not as high as the 170μm one. This is a reasonable result due to the x-ray scattering effect of the surrounding Lucite in the phantom. However, more noise was found in the 120μm image on which the M2100 machine was used.

Based on the 3-D surface display, we found that the half-width full maximum (HWFM) values were measured at 4 pixels (168μm) and 5 pixels (105μm). Despite the high noise in the dark region, the measurements were 168μm with calcification size of 170μm using M4200 and 105μm with calcification size of 120μm using M2100 which were fairly accurate. This implies that the scanners are capable of measuring the size of calcifications detectable by mammography.

D.4 Geometrical Distortion.

Geometrical distortion ratios were also measured by comparing two marks in the real distance and the digitized image. The results indicated that the spatial resolutions for both digitizers were within $\pm 0.5\%$ of the respective system specification of 21μm and 42μm; these small variations were determined to be negligible when the differences were less than 1%.

E. Conclusions

In conclusion, we have evaluated the performance characteristics of two high resolution CCD film digitizers with pixel sizes of 21μm and 42μm. No spatial distortion was found. The performance is better when the edge is scanned in the direction parallel to the scan direction. The gray value response is linearly plotted from OD 0 to 2.8. Non-linear gray response and excessive noises were observed when the OD was greater than 2.8. The vendor is currently working on the noise reduction in the dark region (where the OD is greater than 2.8) and, overall, the system provides the means to clinically diagnose calcifications with spatial resolution and contrast density in higher tissue densities. The inhibition of skin line viewing caused by noise in the dark region diminishes the system's clinical usefulness. This limitation is due to design tradeoffs between spatial resolution and signals in the dark region.

2.2.3 Quality Control on Storage Phosphor Digital Radiography Systems

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A. Significance to the Military MDIS Project and Executive Summary

Computed radiography (CR) has replaced most conventional radiography in the MDIS environment. Optimum image quality is a necessary and critical part of MDIS operation. Quality control standards of CR are not yet fully established. The success of the radiographic imaging system, whether for screening or diagnosis, depends on the production of high-quality images. Achieving this task requires vigilant attention to quality control to produce consistently high quality images. By adopting a consistent program of maintaining and evaluating the equipment where image acquisition or transportation occurs, imaging system performance remains above average while diagnostic image quality is ensured. This becomes critical for remote sites where service is not readily available and the independent function of the medical site is expected. With ongoing evaluation taking place, small problems or maintenance issues are dealt with more effectively without downtime of the system or compromising patient care. By properly evaluating and maintaining the image acquisition system (CR) one also ensures the image quality when that image is transferred to a PACS or out via satellite. QA/QC of the image acquisition device is the starting point of an extensive program to be expanded not only to address hardcopy image quality, but also local and global softcopy display. This report describes the acceptance/QC procedure that is currently being used at Georgetown University Medical Center (GUMC) and is suitable for the MDIS environment.

B. Concept

The complete CR system, from imaging plate and cassette to photomultiplier and laser for the development of the image, to computer algorithms used for image processing and hard copy output devices, must respond properly to the final image. Therefore each section of the CR system should be carefully tested and calibrated. All subsystem components of the CR device such as image acquisition, image processing, and image display are subject to variations in performance that may cause image degradation. The clinical knowledge about quality control (QC) and the standard procedures for CR devices have not yet been established and are still under development. Currently, The American Association of Physicists in Medicine (AAPM) Task Group #10 is working to define acceptance tests and QC procedures for CR systems. The goal is to set standards and to develop a protocol for the CR system. Fuji Medical Systems is the main manufacturer that provides CR systems in an MDIS environment. The protocols are based on several Fuji CR systems and may not apply to other manufacturers' CR systems. The procedure includes the acceptance of the equipment for its image quality, image sensitivity, and overall imaging performance.

The acceptance/QC procedure that has been currently and routinely used at our institution includes:

- Acceptance testing.
- Establishing standard radiographs for comparison based on CR performance.
- Daily, weekly, monthly, semi-annual, and annual checks on system performance.
- Preventive maintenance (PM).

The concept to this approach is as follows: First, make sure that the CR system is functioning correctly. Second, obtain standard images on the correctly functioning system to be used as a baseline for future testing. Third, obtain test images (phantom images), and compare these to images which are considered acceptable at your institution. Fourth, if the images have changed, do additional detailed diagnostic checks to determine the source of the problem. Fifth, run routine densitometry and measure the important parameters (e.g., optical density). The daily, weekly, monthly, semi-annual, and annual PM play a major role in the CR system image quality and will be discussed briefly in this report.

C. Methods

CR is a new technique for obtaining radiographic images. Because of its newness, appropriate acceptance/QC procedures are still under development. Because of its complexity, these control methods are necessarily more complex than those of the conventional screen film (SF) radiography system. The procedure described here is the technique that is currently and routinely used at our institution to assure that the quality of the images obtained from the CR system is acceptable to the radiologist. The QC procedure at GUMC was performed on the Fuji FCR 9000 system.

The equipment needed to perform the complete acceptance/QC test is listed as follows:

- Imaging plates and cassettes of different types and different sizes (14" x 17", 14" x 14", 10" x 12", 8" x 10", 18 cm x 24 cm)
- Densitometer and dosimeter
- 10X or 20X magnifier glass
- Resolution phantoms (at least 5 lp/mm)
- Anthropomorphic phantoms (chest, hip, shoulder, hand, foot, and breast phantoms)
- Anatomical menu and image processing parameter settings.

Before starting the acceptance test, all IPs used in the experiment must be carefully tested for dust, scratches, and cracking around the edges of the plates which may cause artifacts. Plates should be cleaned regularly and should undergo at least primary erasure before the start of a test. This also applies to the cassette; the hinges need to be safe when it is running through the image reader. The lead backing used for the larger plates (14" x 17") must be checked for nonuniformity, which may result in image degradation.

In addition, the exam room should be tested for consistency of the x-ray equipment, accuracy of the x-ray exposure and x-ray tube voltage and current. The dosimeter and the kVp divider are used for the measurements of the exposure dose and the voltage. Our initial experiments were carried out on two different types of imaging plates (IPs): standard resolution (ST-V) and high resolution (HR-V) with different sizes. Fuji GF-1/HR-G (50 speed) film was used for the extremities exams and Fuji GH-1/HR-G (400 speed) film was used for the chest, skull, hip, and shoulder exams. All tests for image quality should be performed at the fixed source to detector

distance (SDD) of 180 cm (71 in). The exposure techniques used for the exams should be at a tube energy of 80 kVp, a tube current of 50 mA, and an exposure time of 0.013 seconds. In our study of resolution/sharpness and the anthropomorphic phantoms, the standard techniques were used. The technique charts for different exams must be available for each institution that is using the CR system.

C.1 Acceptance of the initially installed FCR 9000.

After the CR system is delivered to the hospital for clinical use, the system must be calibrated to perform as recommended by the manufacturer. The protocol for the initial testing of the machine is discussed by the author in a previous publication about the Fuji CR system. In addition, several other tests must be performed on the machine to ensure that the components of the machine are functioning properly before the image quality test. The acceptance of a CR system is briefly discussed in two parts: one related to the CR image reader and the other related to the CR laser imager.

C.2 Acceptance of the CR image reader for initial installation.

After the machine is installed and the installation check is performed, the machine is ready for acceptance testing for image quality such as nonuniformity, sensitivity, and density. In order to perform some of these tests, it is necessary to have access to the service utility function. This must be performed by a highly qualified service person who has been trained on CR equipment, as it is a very complex and sensitive system. An error may cause the machine memory loss. The CR image reader must be properly checked for power on/off, clearing memory operational service, startup/shut down, fan operation, voltage check in different units of the machine, IP conveyance checks, configuration file setting, interlock checks, and finally, full installation of the machine. In addition, if the data management system (DMS) is connected to the machine, it must be verified that the images are stored normally in the DMS and can be retrieved normally from the DMS. The system must also be checked for the external units connection such as a laser printer (LP), image monitor (IM), and identification terminal (IDT).

C.3 Acceptance of the CR image reader for performance and image quality.

After the machine is installed and the installation test performed, the machine is ready for the acceptance/QC procedures. The procedures included the following tests:

1. Nonuniformity
2. Sensitivity and density
3. Jitters, formats, and output characters
4. Preventive maintenance (PM) for the CR image reader

C.3.1 Nonuniformity.

Before starting this test, the imaging plates must be run through the secondary erasure to ensure that no latent images exist on the plates from previous exposures. This option can be performed through the panel located on the left portion of the CR image reader. IPs of different sizes should be uniformly exposed. The exposure conditions should be set at the manufacturer's recommendation at a 180 cm source to detector distance (SDD), tube energy of 80 kVp, current of 50 mA, and exposure time of 0.013 seconds. The images taken in the SENSITIVITY mode from the TEST menu in the image reader are read and recorded, and output images are generated on the hard copies. The images on the output films must be free from nonuniformity. The uniformity of the IPs should be checked to ensure uniform exposure. If any nonuniformity occurs, the service guide should be consulted for appropriate corrective action.

C.3.2 Sensitivity and density. Using the images taken from previous studies, the value of the system sensitivity (speed) indicated on the film output is checked and the film optical density (OD) is measured with the densitometer. The value of sensitivity is about 200, the film density is about 1.2 OD, and the exposure dose measured with the dosimeter is approximately 1 mR. It is

important to verify that there is no density variation in the main scanning direction. Our test was successfully done and the results of the measurement approximately met with the manufacturer's recommendation. If the numbers are found to be incorrect, then corrective action must be taken as discussed in the service guide.

C.3.3 Jitters, image formats, and output characters. *Jitters* - For this test, two 15 cm steel scales are placed perpendicular to each other on IPs of similar sizes as used in previous tests. The IPs are uniformly exposed at the same exposure technique as previously specified. The images are processed in the SENSITIVITY mode from the TEST menu, and hard copies are made. The border of the steel-scale image on the output film must be checked. The output can be made as one-in-one or two-in-one image formats. We examined the border of the steel scale images in all of the output films in two different formats: one-on-one and two-on-one. The borders were all clean and free from jitters. If jitters are found, take appropriate corrective action.

Image Formats - Using the images generated in the previous tests, the image border should be verified to be less than 2 mm with trimming set to 0. We measured the border for different IPs as recommended by the manufacturer. The image size of the steel scales corresponded to the reduction ratio and met the manufacturer's requirements. The reduction ratios corresponded to the requirements and were in agreement for both formats (full image or two-in-one image) and the different sizes.

If the white blank is more than 2 mm in width or if the reduction ratio is improper, the appropriate corrective action must be performed as discussed in the service guide.

Output Characters - Using the image output taken from previous studies, check the contents of the film character format information which is set in the initial installation set up. This is referred to in the manufacturer's service manual for upper and lower portions of the image output.

We verified the output characters as they were written on the hard copy images. The service guide should be consulted if the image output does not satisfy the output film characters.

Error log - In order to ensure that no error occurred during the routine operation, Fuji CR machines have a function that contains entries for an error log during routine operation. To display the error log requires a qualified CR service person. The error log can be shown and verified easily through the maintenance service utility. It is important to review the error log on a routine basis in order to determine that the operations were successful. The error log can be kept in the system at least for a semi-annual PM check. The error log displayed no error during the acceptance/QC operation.

C.3.4 PM for the CR image reader. The procedure for maintenance operations must be performed periodically to preserve good image quality and good machine operation. These operations must be performed by a qualified person trained in CR service. The PM operation is beyond the scope of this work. The descriptions and procedures of the operation are discussed in the manufacturer's service guide.

In addition to the above mentioned tests, the test should also done on the DMS, IDT, and IM to verify the start up of those systems. We also verified that the images were stored and retrieved normally.

C.3.5 Acceptance of the CR laser imager for initial installation. Similar to the CR image reader, the CR laser imager system must be calibrated at the initial installment. The inspection procedure must be performed to verify that the laser imager meets all requirements and specifications of the manufacturer. After the installation, the CR laser imager should be checked

for normal interface connection to the CR image reader. If this is not properly done, then appropriate corrective action must be taken.

C.3.6 Acceptance of the CR laser imager for performance and image quality. After the CR laser imager is installed and the installation test is performed, then the machine is ready for the acceptance/QC procedures. The test must be performed by a qualified service person who is trained in CR system operations. These procedures include the following tests:

a. Performance of the CR laser imager for image quality
b. System function test
c. Preventive maintenance (PM) for the CR laser imager

a. Performance of the CR laser imager for image quality. Performance of the CR laser imager depends on output format, density control function, and image quality tests.

Recording screen format - Use the service utility, perform the FLAT test pattern recording operation, and take the measurements that are required by the manufacturer. The figure of this test is shown in the manufacturer's service guide. The requirement for the dimensions are met for the given accuracy according to the manufacturer's requirements.

Density control function - After the film processor temperature is stabilized and machine start up is normal, perform the density check through the CR laser imager. The density control function must be corrected before carrying out the density control function check. The film density can be checked in two ways:

- Density measurement option is provided
- Density measurement option is not provided

Density measurement option is provided - The density test is performed through the service utility in the following steps:

Step 1. Press the CHECK DENSITY key to check the recorded density.
Step 2. After the density data is displayed on the user operational panel in Step 1., divide the density by 100 and record the data. The required measurements depend on the CR laser imager's maximum density (D_{max}) set up. After the completion of this step, press the YES key to return to normal mode operation.

Density measurement option is not provided - With this option, the 17 step wedge density variation test should be performed. The output will be generated and the optical density will be measured with a densitometer. Note that the maximum density (D_{max}) set up varies from hospital to hospital. The D_{max} can be set at the time of the installation.

Automatic density measurement accuracy - This test shows the accuracy of the density measurement. This can be performed only when the density measurement option is employed. For this experiment, we repeated Steps 1 and 2 three times and recorded the density reading along with the maximum density difference for each step. The difference in measurements met the manufacturer's requirements.

Image quality - After the CR laser imager passed the required recorded optical density test, we performed the following test to ensure that the image quality for the image recorder was checked.

This test is performed in the service utility mode as previously described for density tests. The procedure is divided into five categories as described below:

I. Unevenness and scratches - We entered the service mode and executed the FLAT test pattern record function to check for unevenness and scratches. Generate three test pattern outputs for checking purposes. Number the generated film outputs. Check for unevenness, wave-like stripe, vertical stripes, vacuum cup marks, static marks, scratches, and other irregularities. The criteria are met.

ii. Shading - The test pattern has two built-in resolution phantom, two gradation continuity, and one flat field. The sharpness / shading / gradation test pattern can be generated through the laser imager. In this experiment, check that no shading is seen in the main scanning direction of the test pattern film outputs generated in the preceding check. Measure the density at five points from side and check that the maximum optical density difference among the five points in the test pattern is not greater than 0.1. In our test, the maximum optical density difference among the five points was 0.0 in accordance with the manufacturer's requirements.

iii. Sharpness - Using the service mode we executed the SHARPNESS test pattern. The pattern is clearly visible in both the main and sub-scanning directions.

iv. Gradation continuity - The density variation for the continuous wedge of the test pattern film output generated in the previous test was smooth and no vertical streaks due to the loss of image data bits were present.

The density continuity can be performed in two different experiments:

Experiment 1	Use the test pattern film output generated in the preceding section
Experiment 2	Place the continuous wedge phantom on the IPs of different sizes and expose them with standard exposure technique. In the service utility mode, use the CONTRAST menu and process the images.

The density gradient must be smooth, and there must be no vertical streaks due to the loss of image data bits.

v. Spatial resolution - This test can be done in two different experiments:

Experiment 1	In the service utility mode, execute the SHARPNESS test pattern record function through the laser imager. Check that a 5 lp/mm pattern is clearly visible in both the main and sub-scanning directions.
Experiment 2	Place the resolution phantom (5 lp/mm) on the IPs of different sizes and expose them with standard exposure technique as previously used. For high resolution (HR) plates use higher exposures than standard plates (ST) (approximately 3 times higher). In the service utility mode, use the SHARPNESS menu and process the images.

The following lp/mm should be observed for different sized plates:

At least 4 lp/mm in 18 x 24 cm HR plate

At least 3 lp/mm in 10 x 12 in ST plate
At least 2 lp/mm in 14 x 17 in ST plate

Film processor processing performance - Check that all the film outputs used for the preceding tests are dry immediately after being discharged from the film processor.

b. System function test. This section describes the image recorder acceptance inspection procedures to be performed for the image processing system function checkout purposes. In addition, the system startup and shutdown must be function properly.

c. PM for the CR laser imager. Similar to the CR image reader, PM for the laser imager must be performed periodically by a qualified person in order to maintain good image quality and good machine operation. The items to be checked, the explanation, and the procedures of the operation are discussed in the manufacturer's service guide.

Routine quality control procedures - Finally the routine daily, weekly, monthly, semi-annual, and annual quality control procedure must be performed on the CR machine on a regular basis in order maintain the system's performance for better image quality and better machine operation. These are as follows:

Daily

- system inspection, check chemical levels used in film processor; inspect cassettes and IPs, check film supply, check film density generated from step wedge

Weekly

- clean filters and vents on system and film processor
- clean all IPs with isopropyl alcohol only
- check chemical levels in processor and add as needed

Monthly

- processor maintenance, including chemistry replacement and full cleaning of tanks and racks

Semi-Annually

- full preventive maintenance as described in Fuji Service Manual

Annually

- full preventive maintenance as described in Fuji Service Manual

D. Discussion and Conclusions

A series of tests were performed for acceptance/QC on an FCR 9000 system. The test was divided into two parts: one on the CR image reader (CR-IR317); and the other on the CR image recorder (CR-LP414). The test was based on the overall imaging performance of the system in the clinical environment. The protocol focused on the system's image quality, image sensitivity, and imaging performance. The overall image quality of the system was excellent. The performance of the system was checked for nonuniformity, sensitivity, resolution, and density. The CR image reader, laser imager, as well as the DMS, IDT, and IM performed normally for start up and shut down. No error was observed in the error log during the QC procedure. The performance of the CR image reader and laser imager was excellent. The recorded format using FLAT test pattern

have shown that the measurements are within tolerance level of the requirement. Density measurement was performed on 17 step-wedge using the densitometer for measuring the optical density of different steps. The requirements and the measurements were in excellent agreement. The image quality of the laser imager was also tested in terms of unevenness, scratches, shading, sharpness, gradation continuity, and film processing. The results were in good agreement as listed in the service guide. Finally, the overall CR performance was satisfactory. In addition to the acceptance/QC test, routine preventive maintenance (PM) is needed on a regular basis on the system in order to maintain the system's performance for better image quality.

2.2.4 Performance Characteristics of Storage Phosphor Plates and Cassettes in Digital Radiography

Investigators: Dot Steller, RT (R)(M), Hamid Jafroudi, PhD,
Matthew Freedman, MD, MBA and Seong Ki Mun, PhD

A. Significance to Military MDIS and Executive Summary

More than 60% 0f workload of a radiology department is projection radiography. MDIS convert all or them into computed radiography(CR). Proper use of CR is a cornerstone of MDIS operations. While the operations of CR reader is critical, we have learned that understanding of CR plates and cassettes is also critical. This report documents performance characteristics of CR plates and cassettes.

Projection radiography, based on the storage phosphor (SP) imaging medium, is a promising but challenging technology. SP plates consist of phosphor particles that are embedded in a polymer binder like film and then coated onto a flexible backing. Image quality is dependent not only on the performance of the plate, but also on the handling of the plate-cassette combination by the user and the reading system itself.

The imaging plates included in this study are the 14" X 17" and 10" X 12" standard plates (ST-V) used for general radiography and the high resolution (HR-V) plates used in mammography and for extremity exams. The cassettes or image plate holders correspond to the plate sizes with the 14" X 17" being lead backed. Recorded downtime of the reader due to plate-cassette operation failures, diagnostic image quality affected by plate artifacts, and plate and cassette replacement rates are for period of twelve months. Records are maintained through a detailed maintenance log, the image reader's internal record for plate use, and the system's internal error log for physical malfunctions.

By keeping a detailed log on maintenance and performance of specific system components, communication to the vendor has been timely and effective in solving equipment failures. Plate-cassette maintenance must be an integral part of overall quality control (QC) that includes technologist training, physical plant (clinical environment) changes, and routine evaluation of the operation and performance of CR system components. Quality control combined with equipment improvements have minimized the downtime of the system, image artifacts, and replacement rates of plates and cassettes.

B. Introduction

Computed radiography (CR) using photostimulable storage phosphor plates as the detector is readily becoming an accepted modality for standard radiographs in many radiology departments. Many studies have been performed evaluating the image resolution and the inherent noise of storage phosphor (SP) systems compared to screen-film technology (1). Evaluation of the physical performance and durability of a CR system's components combined with user training will result in the optimal use of system and contribute to better image quality.

A CR system includes many components; however, the imaging plates (IP) and the cassettes or plate holders, are the two pieces exposed to a variety of environments outside of the reader. As these systems constantly improve and newer components are developed and manufactured, evaluation of the physical performance of the components themselves becomes critical for obtaining optimal performance of the overall system Physical performance data has been gathered

on the newest generation of standard (ST-V) and the high resolution (HR-V) imaging plates along with their respective cassettes. The effects that physical plant changes and technologist training have on the repair and replacement rate will also be reported.

C. Materials and Methods

C.1 ST-V AND HR-V IMAGING PLATES.

ST-V and HR-V refer to the fifth generation storage phosphor plates developed by the Fuji Photo Film Co., Ltd. Tokyo Japan. The fifth generation has been created in an effort to decrease inherent noise and improve the contrast of the image detector (2). The phosphor grain of the newest plates is smaller than in previous generations measuring approximately 4 microns as opposed to 5 microns as found in the ST-IIIN plates. In addition to the smaller phosphor grain size, the protective layer thickness has been reduced by 25% relative to the previous generations. The thinner protective layer reduces quantum noise while the higher packing density maintains the image detector efficiency (3). Figure (2a) shows the differences in construction between the ST-V and ST-IIIN plates. The HR-V plates have the same thinner protective layer as the ST-V plates and the same reflective layer; however, the phosphor layer of the HR-V plates is thinner than 230 um, accounting for its higher resolution.

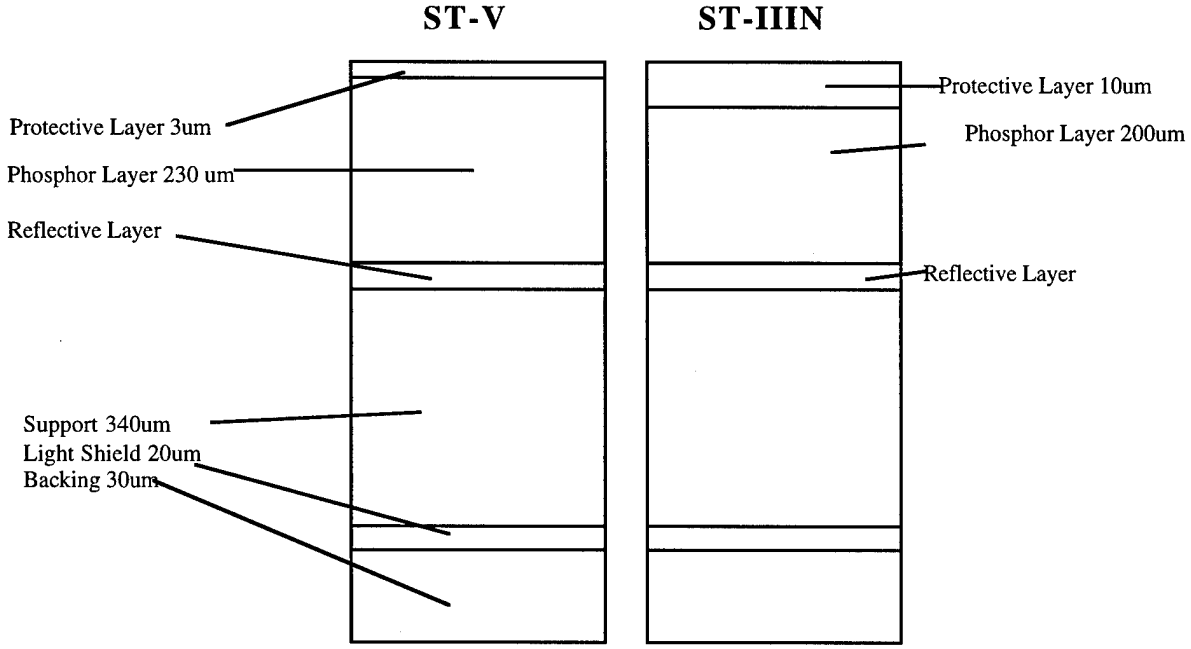


Figure 2a: Plate Cross-section

The plates included in this study are the ST-V 14" X 17" and 10" X 12" SP plates used in general radiography and read in a FCR 9000 laser reader. We also included the HR-V high resolution plates used in mammography and for extremity exams and read in the same reader. The number of uses for each plate is recorded in the identification terminal (IDT) of the FCR 9000. The ST-V plates also replaced the ST-IIIN plates in the AC-1 plus at the beginning of this study. The 14" X 17" plates and the 10" X 12" plates were used in the 9000 and the AC-1 in an interchangeable fashion. Because the older AC-1 plus has no internal means of tracking plate use, the results of this study include only the information we have been able to gather from the IDT of the FCR 9000 and our log book.

One hundred plates were evaluated in the Department of Radiology at Georgetown University Medical Center where the examinations performed routinely include all emergency department exams, all in-house chest radiographs (in department and portable), all in-house muskuloskeletal imaging , and occasional operating room procedures. Approximately 55,000 examinations were performed using the ST-V imaging plates and processed in the FCR 9000 or the AC-1 plus readers. Of the one hundred plates, six of these were HR-V mammography plates used for a limited clinical trial in mammography and other tests involving phantom objects.

The tracking of plate use within the FCR 9000 is accomplished through the IDT. The IDT's primary function within a CR system is to attach demographic information and examination information (image parameters) via a laser-read bar-code found on the back of the SP plate. Other functions of the IDT include two different service menus. The menu that we retrieved plate information from is a service utility menu that allows site-specific settings, software upgrades, and maintenance. Under the IP Use Statistics of this menu, the IDT is able to track the start date of use, last date of use, and number of uses for each plate by its bar-code identification number. We tracked plate use through the IDT for twelve months and at the same time, tracked film use for the FCR 9000 laser printer and the AC-1 plus film processor. Approximately 100,000 sheets of film were used by both CR systems over the one year period.

Length of Study	12 months
Number of SP imaging plates	100 plates
Film use for AC-1+ and FCR 9000	100,000 sheets
Number of examinations	Approximately 55,000

Cracking and chipping of the phosphor layer causing objectionable image artifacts was observed three ways and recorded in a logbook kept specifically for the FCR 9000 system. Chips were easily seen upon routine cleaning of the imaging plates performed every thirty to sixty days and looked like chipped paint. Only the corners of the plates chipped showing the blue backing that the phosphor layer is coated onto. Cracking of the phosphor layer was observed on hard and soft copy of clinical and test images and looked very similar to screen-film artifacts. The cracks looked white on an image and appeared brown upon inspection of the plate outside of the cassette. Observation of the plate cracks on soft copy was accomplished through image processing. We found that by decreasing the frequency factor (RN to 0-3) and increasing the enhancement factor (RE to 5), the plate cracks were easily identified at the CRT of the workstation. All clinical images were then checked daily at the workstation with the edge enhancement factors applied as a quality control procedure looking strictly for IP defects. Plates were pulled from service anytime cracks appeared within the anatomy of a patient's image. Small cracks within muskuloskeletal images could be misinterpreted as a disruption in the trabecular pattern and the same small cracks appearing in a chest radiograph could be misinterpreted as a misplaced line or abnormality. Cracks that appeared within 1 cm of the edge of the plate, presumably caused by being rolled during transport through the reader, were not pulled from clinical use unless additional cracks were seen over the image area.

Pulled plates were accompanied by the edge enhanced hard copy along with the start date and date of last use when being returned to the vendor for replacement. As much information as

possible was supplied to the vendor to assist us, with their expertise, in solving problems.

C.2 CASSETTES.

The cassettes or plate holders used for the study include the 14" X 17" lead-backed, 10" X 12", and the 18cm X 24cm cassettes. The 18cm X 24cm cassette, used in mammography, is made from a stiff molded plastic front and back. The cassette construction ,aside from the lead-backing, for the 14" X 17" and the 10" X 12" consists of a carbon fiber front, aluminum frame and back, and a foam lining for plate protection. The cassettes are very light-weight and closely resemble screen-film cassettes.

The predominant function of the cassette is to protect the plate from the external adverse conditions of daily clinical use. The stress on the cassettes resulted in snapped carbon fiber fronts, broken hinges, and broken bar-code windows. Of the three cassette sizes studied, the 14" X 17" cassettes also experienced internal construction failures. The lead backing in some of the large cassettes curled and completely peeled off of the back of the cassette causing image artifacts and reader downtime. These abnormalities, both internal and external, were observed upon visual inspection of the cassettes and when malfunctions occurred within the laser plate reader, the cassettes were pulled from service. Complete documentation on the reason for pulling cassette from service, repairs, and replacement of the cassettes was maintained through the maintenance log kept for the system and by the vendor.

C.3 PLATE-CASSETTE COMBINATION.

The plates and cassettes were also studied as a combination since problems involving a cassette most often resulted in a damaged IP and/or reader downtime. Cassette problems that resulted in IP damage and/or reader downtime were recorded through the internal log of the FCR 9000 and a maintenance log. Damaged components were immediately pulled from service, examined, and notes made in the log book regarding specific failures, e.g. broken hinges, broken bar-code window, snapped front with internal frame damage to the cassette and any associated reader components damaged. Notes were also made on plate damage ranging from slight indentations in the protective layer to damage resulting in unusable condition of the IP. A log book entry example:

> **3-28-94:** *9000 Fatal Error 0302 at 0904 --called service at 0910. Service engineer returned my call at 0936 and will arrange flight to DC. 1015 service engineer called and will be to GUMC by 1500. When bar-code information is entered through the service panel, the reader wants to double load an imaging plate. Immediately after bar-code information is put in, reader goes into Fatal Error 0302. 9000 rebooted, extra imaging plate held out 0920. Service engineer arrived at 1600 and discovered the problem was cassette related. The whole inside frame at the bar-code window edge of cassette snapped in at least two cassettes causing the IP to slip out of place by 1/8". The reader was unable to read bar-code out of correct position. Service engineer thought this problem specifically related to the horizontal position of the cassette in the 9000. Cleared error log and reloaded all imaging plates back into stacker.*
>
> Similar entries like the one above were made for problems, solutions and new findings.

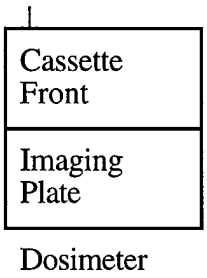
We also conducted dosimeter testing of the plate-cassette combination which we called "sandwich tests." The exposure response of the radiographic equipment, which for all of the testing was a Siemens Polyphos 50 single phase three pulse generator with a standard radiographic tube, was tested first to establish reliable and accurate readings for the "sandwich test."

We chose to use the common exposure factors of 70 kVp and 50 mAs for a 14" X 17" (lead backed) and a 10" X 12" (non-lead backed) plate-cassette. Results are shown in Figure (2b) where a comparison has been made between the two ST-V plate-cassette combinations.

Figure 2b: Sandwich Test at 70 kVp and 50 mAs

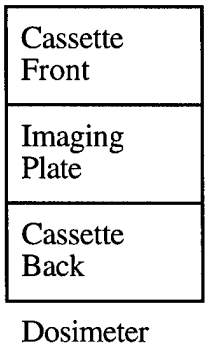
Exit Dose Measurement of Cassette Front and Imaging Plate.

Cassette-Plate Size	kVp	mAs	mR
14" X 17" ST-V	70	50	102.7
10" X 12" ST-V	70	50	102.4



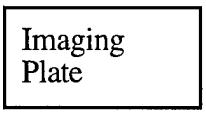
Exit Dose Measurement of Cassette Front, Imaging Plate, and Cassette Back.

Cassette-Plate Size	kVp	mAs	mR
14" X 17" ST-V lead backed	70	50	6
10" X 12" ST-V	70	50	75.2



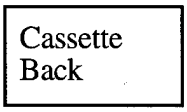
Exit Dose Measurement of Imaging Plate

Imaging Plate	kVp	mAs	mR
14" X 17" ST-V	70	50	104.4
10" X 12" ST-V	70	50	104.9



Exit Dose Measurement of Cassette Back

Cassette Size	kVp	mAs	mR
14" X 17" lead backing	70	50	12.3
10" X 12"	70	50	104.9



Each table indicates exposure direction, object being tested and placement of the dosimeter for the reading. We conducted the same testing using an ST-IIIN 14" X 17" imaging plate and found our results for all the "sandwich tests" were the same except for the exit dose measurement of just the plate which was 113.5 mR. The absorption of the ST-V plate is approximately 10 percent better than the previous generation.

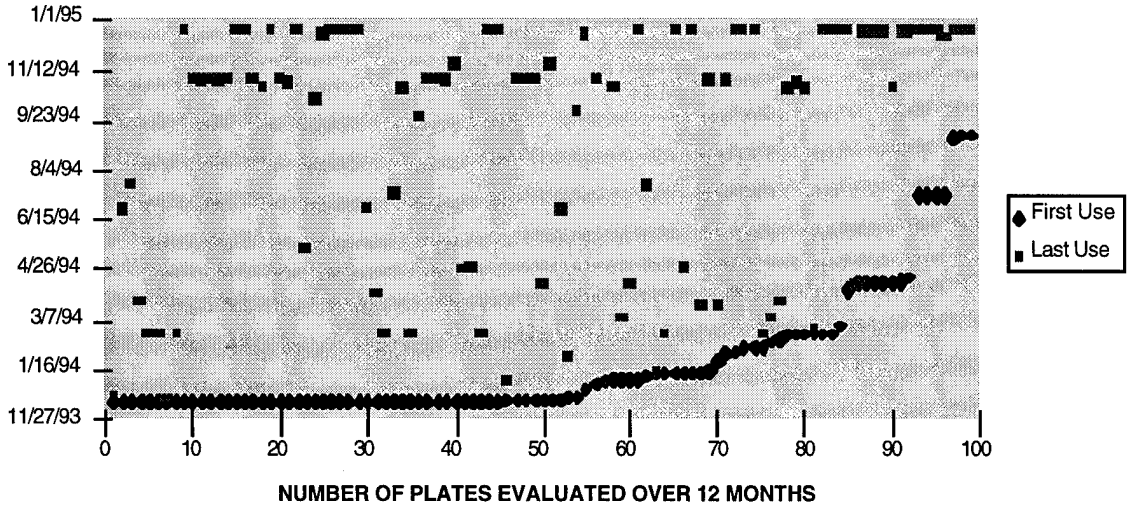
Handling of the plate-cassette by the user, in general, was consistent with the vendor's recommendation; however, the storage of the plate-cassettes, due to space constraints in the clinical area, was not in compliance with the vendor's recommendations. The plate-cassettes should be stored on end to decrease stress on the cassette front and ensure proper rotation of the plates into use, but the plate-cassettes at our institution were stored in stacks laying flat.

D. RESULTS

D.1 PLATE REPLACEMENT.

Our method for tracking plate use through the IDT of the FCR 9000 was found to be insufficient upon reviewing the number of examinations performed in conjunction with the number of films used by both CR systems. Over the course of twelve months, it was determined by reviewing purchase orders, that the FCR 9000 and the AC-1 plus used an average of 100,000 sheets of film. The number of exams performed over that same period averaged 55,000 with the IDT recording only 5597 plate uses for 100 plates. By reviewing the log book, we determined that while the number of uses for each plate as recorded by the IDT was not accurate, the record of the first day in service and last use were accurate. Figure (4a) shows the first and last uses of the 100 plates studied starting December 15, 1993 and ending with the date data was obtained from the IDT at December 22, 1994. Sixteen of one hundred plates have remained in service for the entire twelve months. A total of 50 fifth generation plates were put into service to be processed through the AC-1 plus and the newly installed FCR 9000 in December 1993.

FIGURE 4a: PLATE USE



The replacement of plates over the course of the first twelve months of use are as follows: eighteen of thirty 14" X 17", all 10" X 12" twenty of twenty, and two of six 18cm X 24cm HR-V plates. The estimated average use for one plate, if it remained in service for twelve months, was forty-five exposures per month. The expected number of uses for each plate per the vendor is 1000 uses. In our experience, we should get two years of use for each plate.

Upon reporting initial findings to the vendor, the problem was vigorously pursued and they reported back to us that a manufacturing defect had occurred with the first shipment of fifth generation plates to the USA and all efforts were made to rectify the situation. The replacement plates we received had a very thin strip of clear plastic around the edges of the plate to add strength and prevent cracking.

D.2 CASSETTE REPAIR AND REPLACEMENT.

The FCR 9000's ability to handle a large volume of work per hour (in our experience approximately 100 plates/hr.), makes this unit a work horse within the clinical setting. The amount of handling, therefore, of the cassettes by the user and the reader equals that of a typical screen-film daylight system. The light weight construction of the CR cassettes allows them to be easily handled by the laser reader; the cassette is placed into the reader, opened, plate extracted, new plate loaded, cassette closed and delivered out of the reader to the user in thirteen seconds. We found the necessary light weight construction required careful handling by the user to withstand the stress of daily clinical use.

Initial problems were noted within the first month of use within the FCR 9000. The Plexiglas window in the back of the cassette which allows the bar-code of the IP to be seen and laser read, cracked and broke out of cassettes into the reader causing mechanical failures. Within the first two months of cassette use in the 9000, ten of twenty-six 14" X 17" cassettes were sent back to the vendor for repair of the windows. The same style cassette had been used for two years in the AC-1 plus without this problem occurring.

The second most common occurrence involving cassette construction was the snapping of the carbon fiber fronts. The snapped fronts were able to be detected only if the user felt for the front to "give". The "give" was felt because the internal frame or lip that holds the IP in place would break causing the IP to slip off center. The slight movement of the IP out of place caused the FCR 9000 to fail to read the bar-code on the back of the IP. Without the ID number from the plate the reader

was unable to continue in its process. After being prompted by the error message read from the front of the 9000, the user would manually key punch the ID number of the plate into the reader. An error would continue to occur because the off center bar-code, due to the snapped frame, could never be detected by the reader to correct itself and continue processing the plate. The continuous error eventually required service personnel be called in to extract the faulty cassette, clear the error, and restack all of the imaging plates back into the supply stacker before rebooting the unit. The average amount of time from the reader becoming unusable to being repaired and ready for clinical use was between sixteen and twenty-four hours. After the cause of the problem was determined to be a broken inside frame, all the cassettes were examined. Three 10" X 12" cassettes had broken frames and were replaced. Over the next four weeks, all of the 14" X 17" cassettes were either out right replaced or sent out for repair five cassettes at a time as to not deplete our entire supply for clinical operations. In addition to the front and frame repairs, six 14" X 17" cassettes had hinges break off the back of the cassette. Internal blocks were placed between the frame and carbon fiber front to add strength to the cassette and a new style of rivet was used to repair the broken hinges or replace weakened hinges on other cassettes.

Because of the environment and low volume of use, the rigid plastic cassettes used in mammography showed no failures over twelve months.

When the cassettes were sent out for repair, the lead backing in the 14" X 17" cassettes was also either glued or removed and replaced. Pieces of lead that had peeled from the back of the cassettes were cleaned from different areas of the reader at its six month preventative maintenance check. The lead pieces were found in the lower portion of the reader in the area of the light guide and laser device. The reader experienced downtime once for peeled lead backing when it appeared as an artifact on the light guide causing a wide white stripe to appear on every image processed in the 9000. Again, the same cassette design had been used in the AC-1 plus for two years without this problem occurring. We surmise that the difference in performance is due to the FCR 9000 utilizing a horizontal feeding mechanism as opposed to the AC-1 plus which is a vertical feeding unit.

Modifying the technologist's handling of the cassettes might have reduced the number of repairs necessary over this one year period. The vendor clearly recommends using a grid for all portable chest and abdomen examinations. At our institution, grids are not used for the portable chests; they are used only for the portable abdomen exams. By not using a grid, we have concluded that the cassette is able to twist under the weight of a patient when placed between the patient and a mattress causing the failures we have experienced. Additionally, weight-bearing examinations of the feet have been performed with the patient standing directly on the 10" X 12" cassette. Storing the cassettes flat and one on top of the other adds additional stress to the fronts, frames, and hinges. In essence, everything has its breaking point and cannot be expected to perform beyond its capability. Predictably, when we started using grids for the portable chest exams in the critical care units and began to store the cassettes vertically, the repair rate decreased; the replacement rate is yet to be observed.

D.3 PLATE-CASSETTE COMBINATION.

Plate-cassette operation failure within the reader resulted in system downtime of nine percent. Total downtime of the FCR system over the twelve month period was eleven percent. The most frequently recurring problem causing downtime for service was broken bar-code windows falling into the reader mechanism and in turn affecting plate transport in the reader and most often resulting in plate damage. Four plates have been replaced as a result of damage which occurred within the readers due to mechanical problems causing a plate jam

REPAIR AND REPLACEMENT OF PLATES AND CASSETTES

PLATES AND CASSETTES	IN SERVICE AT INSTALLATION	IN SERVICE AT THREE MONTHS	ORIGINAL PLATES AND CASSETTES IN SERVICE AT TWELVE MONTHS
14"x17" lead backed cassettes	26	16	All repaired
14"X17" ST-V imaging plates	30	30	12
10"X12" cassettes	15	12	12
10"X12" ST-V imaging plates	20	20	All replaced
18X24cm mammo cassettes	4	4	4
18X24cm HR-V imaging plates	6	6	4

Figure 4b: Repair and Replacement Overview

This chart shows an overview of the repair and replacement of plates and cassettes. We began to remove components from service at three months and from that point implemented a quality control step by checking the integrity of the plates daily via workstation and weekly visual inspection of the cassettes.

Findings from the dosimeter testing indicate that while using the smallest IP possible to obtain maximum resolution, using the non-lead backed 10" X 12" cassette for a medium (AP shoulder) to thick (cross-table lateral cervical spine) body part will result in back scatter reaching the plate causing a degradation of the final image quality. The newest cassettes received to augment our plate-cassette supply, have lead backing in all cassette sizes except the mammography cassettes. We have also shown that the thicker and more densely packed phosphor layer in the ST-V plates is more radiation absorbent than the ST-IIIN plates.

E. DISCUSSION

With the use of computed radiography systems on the rise, the subject of image quality as related to resolution and inherent noise is the topic of many studies and discussion. If an institution has chosen CR as its imaging system, then the subject of image quality as it relates to physical performance and durability of components becomes paramount. As a beta test site for the FCR 9000, we became responsible to communicate to Fuji our observations on the clinical operation of the system and its components. By doing so, changes in product design have occurred along with changes in our operations clinically.

The FCR 9000 was designed to be a more efficient high throughput reader while the fifth generation imaging plates were constructed to take advantage of the much improved laser optics found in the 9000. The newest plates have a significantly thinner protective layer and unlike other plate readers, the FCR 9000 rolls the plates in two directions during transport through the reading

and erasure process. The increased rolling motion of the plate with the thinner protective layer resulted initially in hairline cracks appearing along the long axis edge of the plates. We reported this finding within the first three months of use and shortly thereafter started to see cracking in the image area. We began to pull plates from use and the vendor began to investigate. The vendor reported back to us that a "manufacturing defect" had occurred with the first group of plates delivered to the USA and replacement of the plates was forthcoming.

The replacement plates we received had an additional protective strip around the edges of the plate and we have been informed that a new protective coating has been developed to increase the durability of the plates. Of the replacement plates we have received, none have been pulled for cracked edges after five months of use.

The light weight cassettes used in a CR system are fairly robust given the speed at which a FCR 9000 handles them; however, handling and storage of the plate-cassette by the user, if not in compliance with the vendor's recommendation, we found, resulted in a compromise in the integrity of the plate-cassette combination. Contrary to Fuji's recommendation to use a grid for portable chest examinations, we had not used a grid routinely. We have surmised that the broken cassette fronts and frames and the broken bar-code window may have been caused by the cassette "twisting" when placed between a patient and pliable mattress. The addition of a grid strengthens the entire combination. We now use a 6:1 grid on portable chests and have pulled only two cassettes over the last two months; one for a broken frame and the other for a broken bar-code window. In the last month of this study, we changed our method for storing cassettes from laying flat to standing them on end as is recommended by the vendor. We have also been informed of a new cassette design that is currently being tested for improved operation and durability.

The detailed log that has been kept on the maintenance and performance of the plates and the plate-cassette combination has been a critically important and highly reliable method for reporting back to the vendor and solving operational problems. Quality control that includes continuing technologist training, plant changes and daily operations evaluation, show a trend in minimizing the replacement and repair rate of cassettes, thus reducing reader downtime and plate damage. Improvements in the plate and cassette design will continue to decrease image artifacts and improve the overall system performance.

2.3.1 Single Image Hardcopy Display of Musculoskeletal Digital Radiographs

Investigators: Kevin Legendre, MD, Dorothy Steller, RT (R)(M), Matthew Freedman, MD, MBA and Seong K. Mun, PhD

A. Significance to the Military MDIS Project and Executive Summary

One of the frequent complaints of MDIS users is the fact that images must often be manipulated during review by using keystrokes or a mouse. Such activities add time to image interpretation, slow down viewing speed and interfere with the physician's thought processes. It would be ideal to be able to display optimized images that require no further manipulation or handling to a workstation. This report describes our initial effort for skeletal images in a hard copy environment and it will be extended to the MDIS workstation next year. This work will contribute to improving the exam throughput and the level of quality assurance.

B. Skeletal Radiographs and the Utility of Dynamic Range Compression

Skeletal radiographs typically image regions of anatomy containing a wide variety of tissue densities in the field of view. Difficulty is often encountered in simultaneously displaying bony structures of high density and the intermediate to low density structures of adjacent soft tissues, primarily muscle and fat. This problem is compounded by the fact that the region to be evaluated often presents a nonuniform shape and thickness, such as in dorsal plantar (DP) views of the feet. Regions of complex, overlapping bony structures also complicate exposure and visualization such as seen with lateral views of the carpal bones. Thus, compromises are often made by accepting that certain structures cannot be visualized on the same image with other structures that produce a significantly different optical density on film.

In an effort to provide a wide diagnostic field on a single image, a new type of image processing algorithm has been developed. This algorithm, known as dynamic range compression (DRC), represents a new approach to image enhancement that is a distinctly separate entity from its cousins of gradation and frequency processing. The process is based in part on the principles of unsharp masking and can be mathematically demonstrated by Equation 1 and Equation 2 below.

$$S_{DRC} = S_{ORIG} + f(S_{US}) \quad (1)$$

$$S_{US} = \Sigma S_{ORIG} / M^2 \quad (2)$$

First, a smoothed copy of the original image is generated using Equation 2 where M is the mask size, S_{ORIG} is the original image and S_{US} is the resultant smoothed image. This smoothing process is demonstrated graphically by comparing Figure 1A to Figure 1B below. Signal transformation processing is then applied to the smoothed image to raise the optical density (OD) of low density regions and simultaneously lower the OD of high density regions according to a pre-selected sigmoidal curve. The transformation process is shown by Figure 1C below. Original application of the DRC process used only simple curves to affect only either end of the density spectrum. At the request of the senior author, Fuji Film Co., Ltd. has

developed a biphasic sigmoidal curve so that the lookup table values of the smoothed image component are affected at both density extremes.

Figure 1A

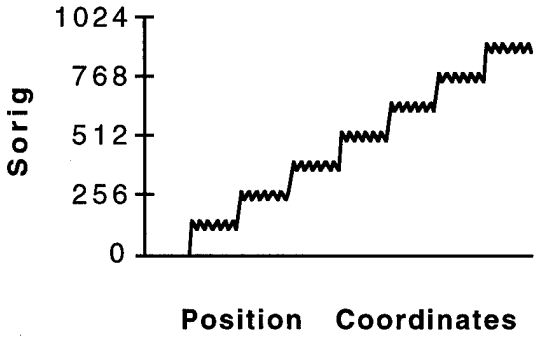


Figure 1B

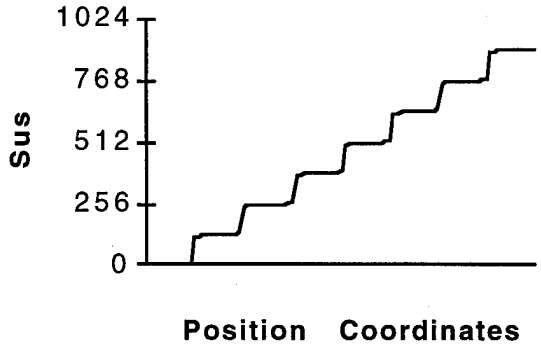


Figure 1C

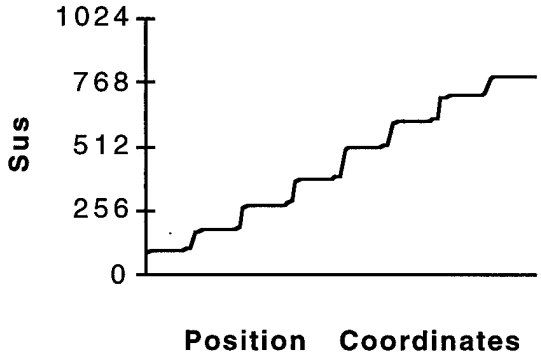
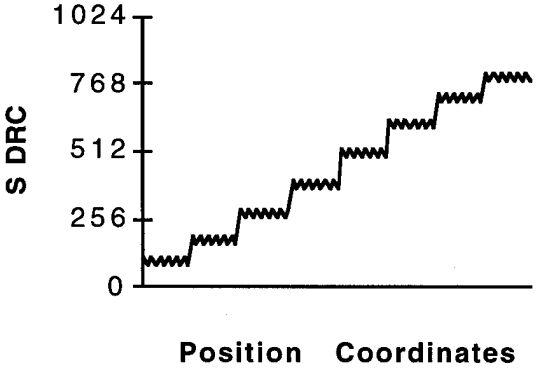


Figure 1 D



The intensity of the DRC effect, known as the DRE, can also be chosen independently ranging from a minimum of 0.0 (no effect) to a maximum of 2.0 (full effect). As shown in Equation 1 above, the transformed smoothed image is then added back to the original image to a degree governed by the DRE selected. The final image signal is shown in Figure 1D. This process allows for the preservation of the spatially fine signal and fine detail present in the original image while compressing the lowest and highest density portions of the smoothed image to yield a resultant image (S_{DRC}) containing OD values more within the optimal interpretative range.

To investigate the effects of the DRC process, the Fuji 9000 CR system was used. In this system, cassettes loaded with a single Fuji ST-V storage phosphor imaging plate (Fuji Photo Film Co. Ltd., Tokyo, Japan) serve as the device for image capture. Following plate

exposure, the technologist enters necessary data into the ID terminal (such as patient name) and chooses the type of exam (foot, wrist, etc.) which determines how the plate will be initially processed. At our institution, we have provided special menu options which allow the technologist to process the plate as a dual format image from a single exposure with standard processing for the left image and DRC processing for the right image. The shape of the sigmoidal curve and value of DRE have been pre-selected and assigned to the individual menu options. The plate is then fed to the image reader (FCR 9000 Image Reader CR-IR 317, Fuji Photo Film Co., Ltd., Tokyo, Japan) and preset gradation and frequency processing is automatically performed as determined by the initial menu option chosen. The images are then assessed on a high resolution CRT monitor where further gradation and frequency processing can be done if needed. Images are then printed using a twin format from a Fuji LP-414 laser printer (Fuji Photo Film Co. Ltd., Tokyo, Japan).

In initial testing of DRC processing, a fourteen level stepwedge was imaged with varying DRE values of 0.0, 0.1, 1.0 and 2.0 and twin format images were printed as above. The OD of each stepwedge level was then measured using a calibrated X-Rite densitometer (X-Rite Inc., Grandville, Michigan). These OD values were then plotted for each DRE value used with the results shown in Figure 2 below.

Figure 2

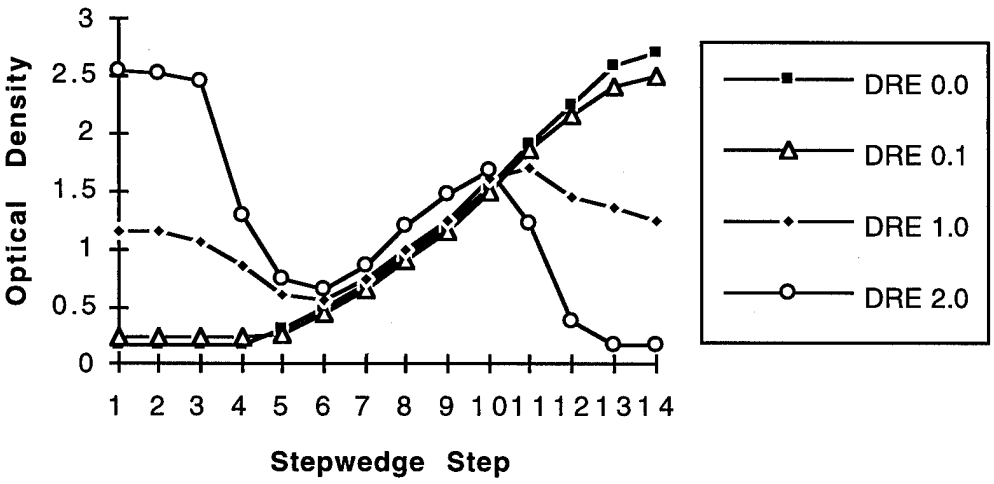


Figure 2: Optical density at various stepwedge levels for varying intensities of the DRC effect.

When the DRE is set to 1.0 or 2.0 it can be seen that lower density regions (thicker stepwedge levels) were darkened (higher OD) and higher density regions (thinner levels) were lightened (lower OD) as predicted. These effects become more profound as the DRE is increased. The DRC process thus compresses the extreme OD values to closer within the interpretable range while preserving optimum midrange OD values along a straight line corresponding to a gamma of 1 for conventional film H&D curves.

C. Clinical Application of DRC to Musculoskeletal Images

The DRC process should be most useful in areas of widely varying tissue density and complex anatomy. For this reason, the process was studied by its application to the DP view of the foot and lateral view of the wrist. The foot is a roughly triangular structure that resembles the shape of the stepwedge used in initial testing and contains overlapping bony structures in the calcaneal region while the wrist presents multiple overlapping carpal bones on lateral exam.

During the trial period of the study, 25 DP views of the foot and 16 lateral wrist exams were obtained, processed in dual fashion by both standard and DRC algorithms and then printed using the twin format discussed previously. The intensity of the DRC effect was applied using a DRE of 0.6 for the foot and 1.0 for the wrist images.

Optical density values were then recorded over selected regions of each image. In the foot, readings were taken over the proximal phalanx of the great toe, the navicular and the posterior calcaneus. In the wrist, readings were recorded from the lunate and soft tissues volar to the distal radius. Figure 3 displays the results of comparing the same anatomical regions of standard and DRC processed images for the foot and Figure 4 demonstrates recordings from the wrist exams. In both instances, the values of OD for DRC processed images lie closer to the midrange of the OD spectrum where optimal viewing conditions exist.

Figure 3

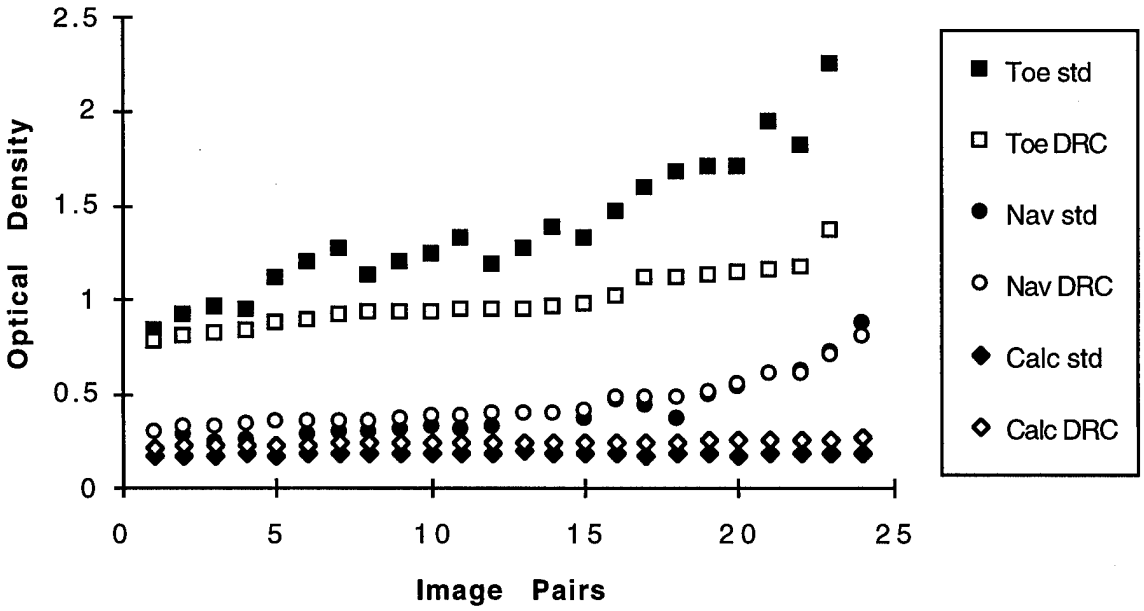


Figure 3: Optical density in regions of the great toe, navicular and calcaneus for standard versus DRC processing.

Figure 4

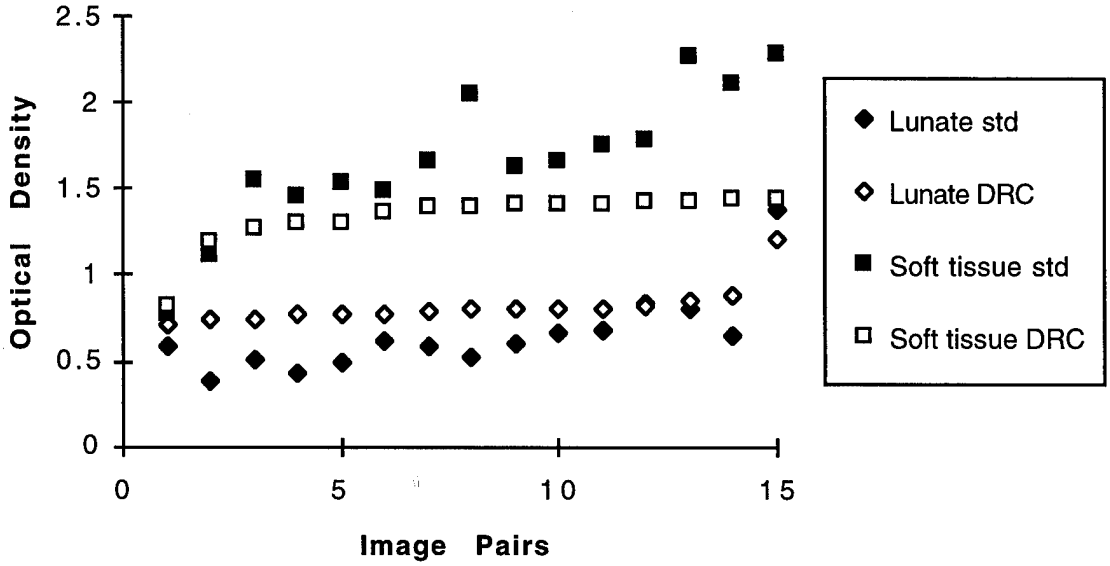


Figure 4: Optical density in regions of the lunate and soft tissues for standard versus DRC processing.

The foot and wrist hardcopy image pairs were then reviewed independently by three radiologists who frequently read musculoskeletal CR exams. Each image pair was assessed and compared with its twin with regard to the degree of various structures visualized on each image. Specifically, the soft tissues of the toes, the tarsal joint spaces and the bone texture of the phalanges and the talocalcaneal region were assessed in the foot. The wrist was evaluated for the soft tissues at the level of the radiocarpal joint, the visibility of the carpal joint spaces and carpal outlines and bone texture within the carpals themselves. Finally, overall interpretative quality for each image was assessed and compared. For each of the above image factors, the reviewer designated a preference for the standard image, the DRC image or no preference between the two. The results are shown in Table 1 below. For each criterion compared, DRC images were favored over the standard except in visualization of bony texture in the carpals of the wrist where the standard imaging was preferred in 31.2% (15/48) versus 20.8% (10/48) for DRC imaging. Visualization of bone texture in the phalanges of the toes showed no clear preference but in the talocalcaneal region DRC imaging was preferred in 92.0% (69/75) of cases. Similarly, the tarsal joints and carpal outlines were much better seen on DRC images as were the soft tissues of the toes. Of note, the soft tissues on DRC images were consistently well seen without the necessity of a bright light. Similar effects in the soft tissues of the wrist were present as well but less dramatic than in the feet. With regard to the overall image, there was a clear preference for DRC processing in the foot and to a lesser degree in the wrist.

Table 1

REGION EXAMINED	IMAGE PREFERRED (TOTAL OF 3 REVIEWERS)		
FOOT	**Standard**	**DRC**	**No preference**
Soft tissues of toes	10	52	13
Tarsal joints	10	35	30
Bone texture-phalanges	23	25	27
Bone texture-talus/calcaneus	4	69	2
Overall interpretive quality	3	50	22
WRIST			
Soft tissues	13	18	17
Carpal outlines/joint spaces	7	18	23
Bone texture-carpals	15	10	23
Overall interpretive quality	11	16	21

D. Conclusion

By evaluating images of the foot and wrist, it is clear that biphasic DRC processing represents a significant improvement over standard processing of CR images in displaying the full latitude of tissue densities present in a region of complex and widely varying anatomy. The process of dynamic range compression allows better visualization of overlapping bony structures that typically yield a low optical density region on film as well as demonstrating darker, high OD regions even without the use of a bright light. This latter benefit is especially apparent in anatomic regions of varying tissue thickness such as the feet. The key to the DRC process lies in compressing the optical density of tissue at the extreme limits of the interpretative range while still retaining sufficient image contrast to distinguish adjacent structures of similar density. That is, because of the biphasic shape of the lookup table, the same optical density on the film can represent different exposure levels. This technique therefore is most likely to be helpful for noncontiguous regions of similar optical density at final output. If contiguous, there would be insufficient image contrast to distinguish the adjacent structures by the interface between them. This anatomic constraint is met in foot and wrist radiographs. Additionally, regions represented by optical density extremes after DRC processing will tend to present somewhat lower contrast so it is desirable that such areas not be of vital clinical importance. Further investigation is still needed to assess the appropriate intensity of the effect to apply to various exams to optimize what could potentially represent a valuable step in the widespread acceptance and usage of digital radiographic examination of the musculoskeletal system.

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2.3.2 A Neural Network Based Computer Vision System Applied to 3D MRI: A Model for MR Image Navigation

Investigator: Y. Chris Wu, Ph.D., Seong K. Mun, Ph.D., Matthew Freedman, MD

A. Significance to the Military MDIS Project

A.1 Executive Summary.

The MDIS technology provides effective ways to integrate various imaging modalities and improve diagnostic performance of radiology. The goals of this research are to develop an interactive three dimensional (3D) image visualization and image analysis system. This system will enhance the radiological capabilities of MDIS. We will evaluate the image visualization system in breast magnetic resonance imaging (BMRI).

We are developing, based on artificial neural networks, a computer vision system that can (a) display interactively 3D images and provide quantitative image analysis, and (b) detect automatically the malignant lesions in the images. It was found that the regions that show strong signal enhancement after injection of a contrast agent may have higher probability of being cancer. Therefore, by analyzing the signal enhancement before and after injection of the contrast agent at different regions, one can detect suspicious regions in each individual image slice. After combining suspicious areas in all of the slices and eliminating false positive findings, the computer system can then identify potential cancer candidates in reconstructed 3D images. Presented with the computer detection results, radiologists can improve the sensitivity and specificity of their diagnoses while reducing the subjectivity and inconsistency that are known to be characteristic of human observers.

B. Background

An image visualization and analysis system that allows interactive three dimensional (3D) image manipulation and qualitative analysis of selected image regions can help radiologists improve the efficacy of examining the massive amount of data. 3D image display using volume rendering will provide radiologists an overview of the patient case without going through each individual slices one by one. By subtracting the pre-contrast image from the post-contrast images in 3D BMRI, the image display system will allow radiologists to identify regions of abnormal enhancement quickly and zoom in to those regions for detailed analysis. Using computerized image analysis tool, the radiologists can obtain quantitative measurements such as the signal intensity enhancement curve and gradient of signal enhancement of the enhanced regions. Interactive image visualization will allow the radiologists to manipulate images efficiently and visualize images from various perspectives. The image visualization system will be evaluated in BMRI. The system can be applied to most of radiological imaging modalities on the MDIS network, however.

C. Objectives

The purposes of this research are (a) to develop an interactive 3D image display and image analysis system to assist radiologists in examining the large number of images in BMRI, and (b) to develop a computer vision system that will automatically analyze and detect breast cancer from

BMRI images quickly and accurately and thus make BMRI a cost-effective procedure with high sensitivity and specificity in the diagnosis of breast cancer.

Technical Objectives

1. To develop a 3D image display and image analysis system based on Data Explorer Tool (IBM) to facilitate interactive image visualization and quantitative analysis of enhancement characteristics of lesions in different regions.

2. To develop an image registration technique to match images obtained in one time sequence at the same slice position so that pre-contrast images can be subtracted from post-contrast images appropriately without introducing structural noises to the subtracted images.

3. To develop an automated image feature extraction technique to extract features from enhancement curves of regions in a 2D image, characterizing the dynamic signal enhancement during the time-sequence in the selected region.

4. To develop an artificial neural network system that includes a self organizing feature map and a back-propagation neural network. This system, utilizing the extracted features, would automatically search through all slice images of an examination and locate suspicious regions with abnormal signal enhancement after contrast injection. The detected suspicious lesions will be presented to radiologists to help reducing the time needed to search through all slices.

5. To develop a region growing technique that would group the detected regions from connected 2D image slices and construct 3D objects.

6. To develop a convolution neural network system that is capable of recognizing 3D image patterns corresponding to benign and malignant lesions in the constructed 3D images.

7. To design an image annotation technique to superimpose the computer-detected 3D objects on the original 3D display to assist radiologists in making a final diagnosis.

D. Methods

Figure 1 shows the overall scheme of the two-step approach that will be employed in this proposal. After the images are acquired, an interactive image display and image analysis will be used to aid the radiologists' examination of the images and initial diagnoses. Meanwhile, the computer vision system will detect the suspicious areas in the 2D slices. The detected lesions at various slice images will then be grouped automatically to form 3D lesions. A 3D convolution neural network will be employed to distinguish the 3D lesions that have shapes typical of malignant tumors from other benign lesions. The final results will be presented to radiologists to make a final diagnosis.

D.1 Image Acquisition and Display.

The BMR examinations will be performed using a bilateral dedicated breast coil operating in the receive mode with a 1.5 Tesla MRI system. The imaging pulse sequence used is a 3D FISP (fast imaging with steady state free precession) variant, a rapid gradient echo (GRE) technique that allows volume imaging of both breasts with 2.5mm consecution slice thickness.

Image slices are stacked up to construct a 3D image object by volume rendering. The 3D object can be rotated and viewed from different angles. The user can also select an arbitrary projection plane and display the density of breasts in the selected plane. We have developed an image registration technique to match image slices at same location during a time sequence so that the pre-contrast image can be subtracted correctly from the post-contrast images. 3D images in one

complete exam before and after contrast injection can be displayed in a continuous loop to demonstrate the dynamic change of signal enhancement in the lesions. The 3D display of subtracted images after contrast injection will reveal regions of strong signal enhancement. Radiologists can then zoom in to those regions of strong enhancement and analyze them with quantitative image analysis tools that will be developed in this system. The image analysis tools can plot enhancement curves at any given location. Other characteristics of signal enhancement such as enhance and washout time, gradients of enhancement curves, and variations among a selected region can also be calculated. Figure 2 demonstrates a display of selected 2D slice images (a), a constructed 3D image (c).

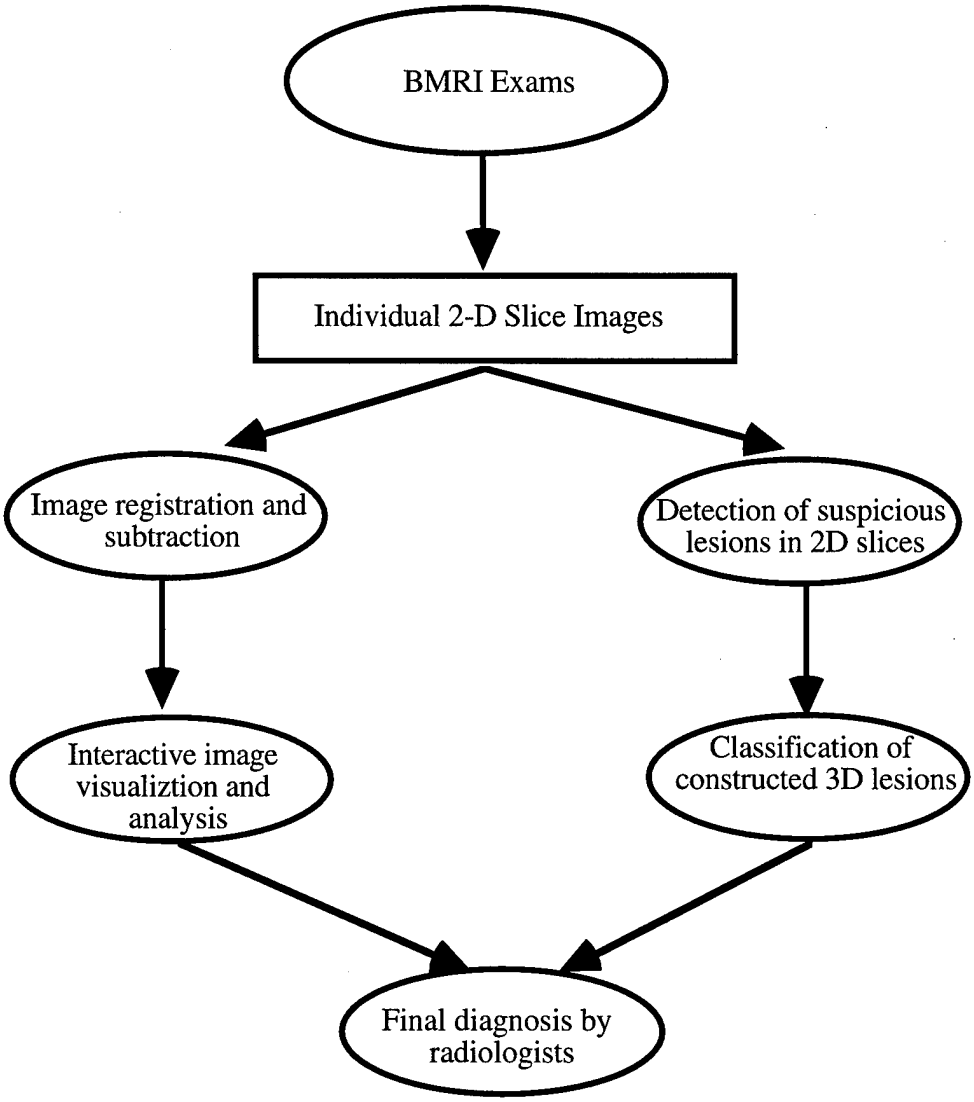


Figure 1. Overall scheme of the neural network based computer vision system.

D.2 Detection of Suspicious Areas in Images of 2D Slice Images.

Enhancement profiles that show the signal intensities at different time intervals before and after the injection of contrast agent will be calculated at each pixel in a slice image. Features characterizing the signal enhancement after contrast injection will be automatically extracted from the enhancement profiles. The features will be calculated based on time derivatives of the

enhancement curve. The feature selection will be optimized by using a self-organizing feature map neural network.

A three-layer, feed-forward, backpropagation neural network will then be employed to recognize pixels with abnormal enhancement profiles. Enhancement profiles will be selected from cancer and normal regions of the breasts to train the neural network. The trained neural network, provided with enhancement profiles of individual pixels of an image, will be able to identify those pixels belonging to a region that could be potentially cancerous. A 2D lesion is formed by connecting all the positive pixels identified by the neural network in a local area in a 2D slice image. The detected lesions in consecutive 2D slice images will be grouped together using a region growing technique to construct 3D objects.

D.3 Classification of 3-D suspicious lesions.

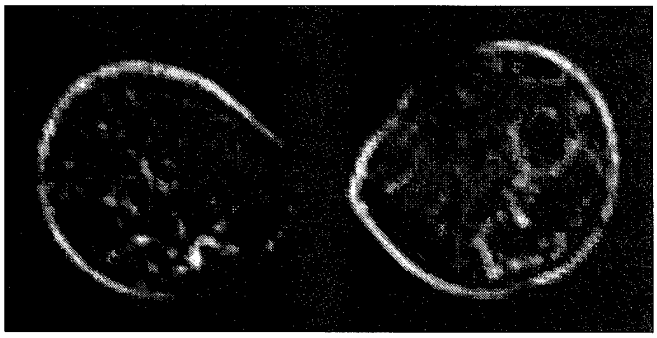
Suspicious regions that are identified in the previous step will include both malignant and benign lesions. Studies have shown that the morphology of lesions may present a clue to lesion origin. The presence of internal septation and lobulation suggest the lesion represents a fibroadenoma, while border irregularity and rim enhancement are highly suggestive of carcinoma. The morphology of lesions is better delineated in 3D than in single 2D slice images. A three-dimensional convolution neural network (CNN) will be employed to recognize image patterns corresponding to benign and malignant lesions. CNN has been shown to be an effective tool for two dimensional image pattern recognition. We have applied CNN in many different applications to classify various image patterns in chest x-ray images and mammograms. CNN has been found to be superior to the conventional fully connected neural networks in processing two-dimensional images of relatively large matrix sizes.

The suspicious areas detected in a slice image are two-dimensional projections on a arbitrary plane of three-dimensional lesions. As discussed earlier, the morphology of lesions may be important information in distinguishing benign lesions from malignant cancers. However, spiculated boundaries of three dimensional lesions may not show up in some of their two dimensional projections. As a result, lesions may not be classified correctly based on their projections on a 2D plane alone. To improve the specificity of detecting cancer lesions, suspicious areas that are identified in each of 2D slice images will be grouped together to form 3D lesions. The 3D lesions will be classified into benign and malignant types of lesions by using a three dimensional convolution neural network. The classification will be based on the three-dimensional boundary information of the lesions.

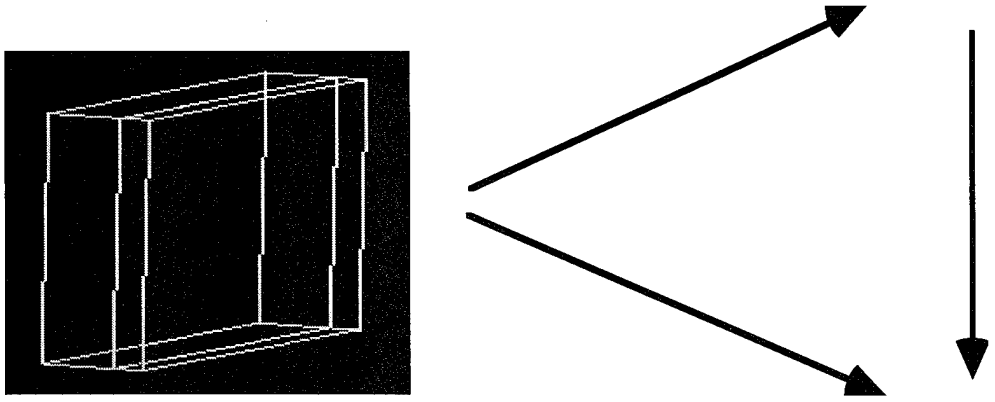
The structure of the 3D neural network is demonstrated in Fig. 3, with the convolution (the connections between the input layer and each kernel in the hidden layer) carried out in three dimensional space. The 3D convolution neural network is developed based on the 2D CNN model that has been successfully applied in pattern recognition of digital mammography. In the convolution neural network, the connections between two layers are grouped into a number of clusters, each functioning as a 3D convolution filter. Therefore, the processing of input signals by the CNN is spatially shift-invariant. The shift-invariance makes CNN suitable for image pattern recognition. Pixel values of the 3D objects will be used as input to the CNN.

E. Preliminary Results

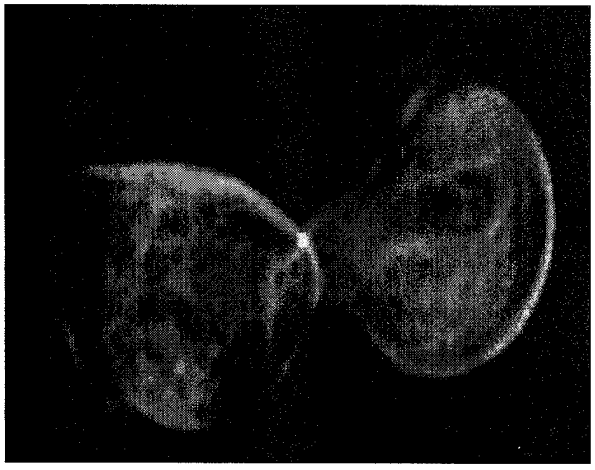
We have developed an interactive 3D dynamic image visualization system. MRI images are reconstructed using volume rendering to produce 3D images. Image slices at different locations from one time sequence can also be played continuously.



(a) 2D slice image



(b) Position of the 2D slice in the breast



(c) Reconstructed 3D image

Figure 2. Image visualization in BMRI.

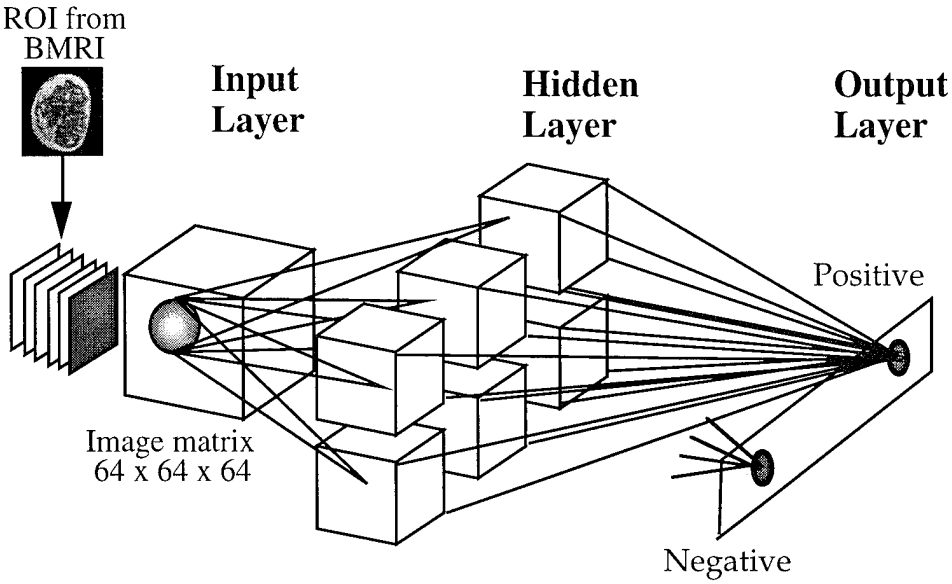


Figure 3. Structure of a 3D convolution neural network.

We have developed a image registration technique that matches image frames from different time interval appropriately such that pre-contrast images can be subtracted from post-contrast images to produce difference images in which the signal enhancement can be visualized. The image registration technique will allow precise matching of frames even when there are patient motion and other misalignment during the exams.

An automated feature extraction technique has been developed to extract features that characterize the signal enhancement in the selected regions. The feature extraction is calculated base on the enhancement profiles and gradients of signal change. A set of features based on the change in intensity between temporally registered images was generated.

A self-organizing feature map has been developed to select the discriminating features from the initial feature sets and therefore reduce the total number of features. The initial 91 features were reduced to 20 by using a forward sequential feature selection algorithm.

A feed-forward backpropagation neural network has been developed to classify the cancer and normal lesions using the automatically extracted image features. Radiologist-supplied truth was given to identify cancer and non-cancer regions. A total of 1144 cancer pixels and 16,703 non-cancer pixels were evaluated. The Backpropagation classifier performed well on both types of pixels, correctly identifying more tan 95% of the non-cancer pixels and more than 99% of the cancer pixels. The false positive percentage was approximately 0.3%; the false negative percentage was minimized at approximately 2.5% when 50% of the database was used to train the neural network.

2.4 Teleradiology over the Internet

Investigators: Darmadi Komo, Betty A. Levine, MS, Seong K. Mun, PhD,
Paul Keezer *, and Howard Cohen

Analogic Corporation, Peabody, Massachusetts

A. Significance to Military MDIS Project and Executive Summary

Teleradiology is important in MDIS around the world. In this area, best speed communication links are necessary to support clinical operation. But a vast number of Medical Treatment Facilities (MTFs) are small and low in volume. The use of the Internet may be a cost effective way to provide teleradiology service because there is no communication cost in terms of post-installation usage. Lower throughput is recognized in current Internet transmission, but it is reasonable to assume that the throughput in the Internet will improve eventually. Therefore, developing tools to support teleradiology over the Internet is significant for the military MDIS program.

B. Background

B.1 Teleradiology.

Teleradiology has a lot of different definitions and may be viewed as radiology diagnosis over long distances. A teleradiology system will allow remote access to a complete set of clinically related information, text and images for a patient and allow remote patient diagnosis and consultation by the radiologist.

B.2 The Internet.

The Internet is a collection of computer networks that uses standardized protocols as a means of communication. The Internet connects government agencies, universities, industries, and private residences. The exact size of the Internet is difficult to determine, but current estimates are 5 million computers in 150 countries, 20 million individual users, and a growth rate as high as 2 million additional users per month.

Access to the Internet varies from analog telephone lines using high speed modems (28.8 kbps) to very high speed direct connections using Ethernet media (from 10Mbps up to 622.08 Mbps). For example, a single magnetic resonance image, which might take around 5 seconds to transfer by Ethernet at 10Mbps, could take as long as 60 seconds with a high speed modem.

Currently most government agencies, universities, and private companies are connected to the Internet. Internet connections are widely available to public users through state/county supported free nets, commercial services like Compuserve, America On Line, Prodigy, or through special commercial Internet connection providers. As an example of a typical university department, an Internet linked computer might first be linked to a local area network in the department; the local network in turn is connected to a university network, which is ultimately connected to the high-speed Internet backbone that links national supercomputing centers.

B.3 The World Wide Web.

The World Wide Web server (also known as the Web) is the most graphical information service on the Internet. It was originally developed at CERN, the European Particle Physics Laboratory in Switzerland, in 1989. The Web is a consortium of computer users which implemented a standardized, nonproprietary syntax called HyperText Markup Language (HTML) for composing documents. HTML provides a method for including links, images, movies, and audio in complex documents that will display on multiple computer platforms. Another feature of

the Web includes easy access to Internet information services using mouse point-and-click techniques. The Web also allows users to access other Internet information services such as Gopher (a text-based only Web), Email (electronic mailing system), WAIS - wide area information server (indexer for information searching), FTP (file transfer utility), etc.

Several Web client or browser software packages are readily available to provide access to the Web server. Popular browsers includes Mosaic, developed by the National Center for Supercomputing Applications (NCSA, Urbana-Champaign, IL) and Netscape, developed by Netscape Communications Corporation (Mountain View, CA).

With these features the Web has been the fastest growing Internet information service in the past three years. In fact, Web usage has outpaced Email usage.

C. Project Description

Project WEBRAD uses the hypermedia capability of the Web to present information and uses the Internet as a communications backbone to transfer medical information. The main reason for using the Web to present medical information is radiology images. While early Internet documents were largely text based, HTML documents provide for the efficient integration of text and images.

When WEBRAD is fully developed, we will achieve two major goals: (1) To make use of the existing information superhighway infrastructure to deliver health care to remote locations efficiently and inexpensively, and (2) To improve the overall health care system by providing diagnosis support for a patient by remote specialists utilizing Internet connections.

C.1 The World Wide Web server.

The Web server is installed at the clinical site and serves as a repository for clinical information about patients. Every document in the Web server is stored in hypermedia format (HTML).

The Web server with the WEBRAD software performs the following functions:

- Standard Web server functions such as http access, server push and pull, access authentication, etc.
- Radiologist validation function management
- Connection to the Resource Gateway System (RGS) server to provide a source for images and minimum patient demographic data
- Radiologists', patients', and images' page assembler
- Image conversion software to convert binary images to a selected image format (jpeg, tiff, gif or another radiology specific format such as DICOM, Papyrus, etc.)

This Web server is always connected to the Internet so that the patient data can be accessed anytime from anywhere on the Internet by an approved radiologist.

C.2 The World Wide Web client.

The Web client contains software installed on a personal computer (IBM PC compatibles, Macintosh or UNIX workstations) that includes an Internet browser and a radiology-specific image viewer which can retrieve and display information from the Web server. This will enable the radiologist to view clinical information, text, and images about a patient and diagnose from this information. Relatively little processing is done on the Web client computer.

A Web client will perform the following functions:

- Standard Internet navigation capability using mouse point-and-click techniques
- Ability to connect to the Web server and access a radiologist's and a patient's page through a login and password validation page
- View radiology images using either standard viewing tools or through radiology-specific viewing tools (such as the Osiris imaging package from The University of Geneva).

C.3 Resource Gateway System Server.

There are two types of medical images: film and electronic images. Images from film have to be transformed into electronic form using a high resolution digitizer. The images (in electronic form) are then transferred to a resource gateway system (RGS) server (Analogic Corporation, Peabody, MA) before being passed to the WEBRAD system. The RGS server acts as an intermediate system which can recognize images in many formats and from different imaging modalities and transform the images into a consistent format which is required by the WEBRAD software.

The RGS server will perform the following functions:

- Detect new files being introduced to the RGS server and recognize them as new image files
- Detect the modality type of the image files (CT, MRI, film digitizer, etc.) and convert them into Film Format Protocol (FFP) format
- Transfer the new FFP file to the WEBRAD database.

D. WEBRAD Prototype

A prototype of WEBRAD (Figures 5 and 6) was developed at the Imaging Science and Information Systems (ISIS Center), Georgetown University Medical Center with the following hardware and software configurations.

Hardware

A very high resolution (50 micron per pixel) medical image digitizer Lumiscan 150 (Lumisys Inc., Sunnyvale, CA) is connected to a high performance host/server computer Sun Sparc 20 station (Sun Microsystems, Mountain View, CA) through a high speed SCSI-2 interface. This computer has 256 megabytes of random access memory and 2 gigabytes of hard-disk storage. Client computers consists of a 486 IBM PC compatible with 16 megabytes of random access memory and 1 gigabytes of hard-disk storage, a Macintosh Quadra with 20 megabytes of random access memory and 500 megabytes of hard-disk storage, and a Sun Sparc 20 station with 256 megabytes of random access memory and 2 gigabytes of hard-disk storage.

Software

On the server side, the Lumiscan 150 film digitizer is controlled by the host computer using SCSI interface software. This software will perform routine checking of the Lumiscan 150 and start digitizing a film. We use CERN httpd version 3.0 (free from Internet) on the Web server. Over the Internet, the Web server is accessible from "http://www.imac.georgetown.edu". This server can be accessed by anyone on the Internet and requires no computer account or password. There is a WEBRAD gateway inside the Web server which requires an account and password. The RGS server and the WEBRAD software are installed on the same host.

On the client side, Netscape version 1.1 (free for educational institutions) is used for the Web client software. Versions of Netscape are currently available for Macintosh, Microsoft Windows, and X Window systems from Netscape Communications Corporation. A radiology-specific image viewer software called Osiris version 2.0 (free from Internet) is used to display and manipulate medical images from the Web server. Osiris was developed at The University of Geneva as part of a hospital-wide picture archiving and communication system (PACS). Currently, Osiris has versions for multiple computer platforms including Macintosh, Microsoft Windows, and X Windows System. Please note that this software is a very dynamic entity. The Netscape browser, CERN httpd and other software mentioned here have gone through several versions in the past years as they continue to be refined and improved by their developers.

D.1 Operational scenario.

At GUMC, film based images are fed into the Lumiscan 150 film digitizer. The user then selects the correct image size and image resolution and enters the patient's medical information. Then the digitizer produces Lumisys formatted files which contain both the patient's medical information and the images. These image files along with the image files from other imaging modalities will be transferred to the host computer running all the server software including RGS, WEBRAD, and Web server. The RGS detects the new files and recognizes the format of the files received. The RGS then converts them into FFP file format. WEBRAD recognizes FFP files and stores them into the database. Once the database has been updated, WEBRAD assembles new radiologist's and patient's pages in HTML format so that the WEBRAD client will always access the most up-to-date information.

On the client side, a radiologist connects to an available WEBRAD server and logs in as a registered user. Once the radiologist enters a correct password WEBRAD will display the radiologist's page (Figure 1) containing a list of available patients. The radiologist can specify how the list of patients is displayed according to name, ID, birthdate, etc. The radiologist will then select a patient of interest and WEBRAD will display the specific patient's page (Figure 2) with all the medical information and images. On the patient's page, the radiologist can choose an image by clicking on it. The image will be transferred to the client computer using FTP and will launch the radiologist-specific image viewer (Figures 3 and 4). This process can be performed continuously with multiple images or different patients.

D.2 Reliability.

All Internet information services including FTP, Email, Gopher, World Wide Web, etc. have been around for a number of years and are being used by millions of people around the world. They have been proven to be very reliable in terms of network connections and very stable in terms of network communications. Workstations and servers that are connected to the Internet will always perform satisfactorily with proper installation and configuration.

E. Conclusion

Project WEBRAD establishes the feasibility of using the Internet for teleradiology and thus delivering health care to patients in remote locations in real time. The patient's clinical, medical record is retrieved and displayed using the Internet as a communications link between remote clinical sites and the radiologist's workstations.

We realize that there are some bottlenecks and limitations in the performance of the existing Internet, but we believe that Internet speeds will increase in the future. Therefore, in order to compensate for the current limitations subsequent steps will include:

- Increasing network bandwidth by using high speed connections such as ISDN, T1, ATM, etc.
- Increasing information transfer rate by implementing compression algorithms at the server side and decompression algorithms at the client side
- Incorporating security information transactions between client and server using data encryption technology
- Developing a more complete radiology specific image viewer on multiple computer platforms.

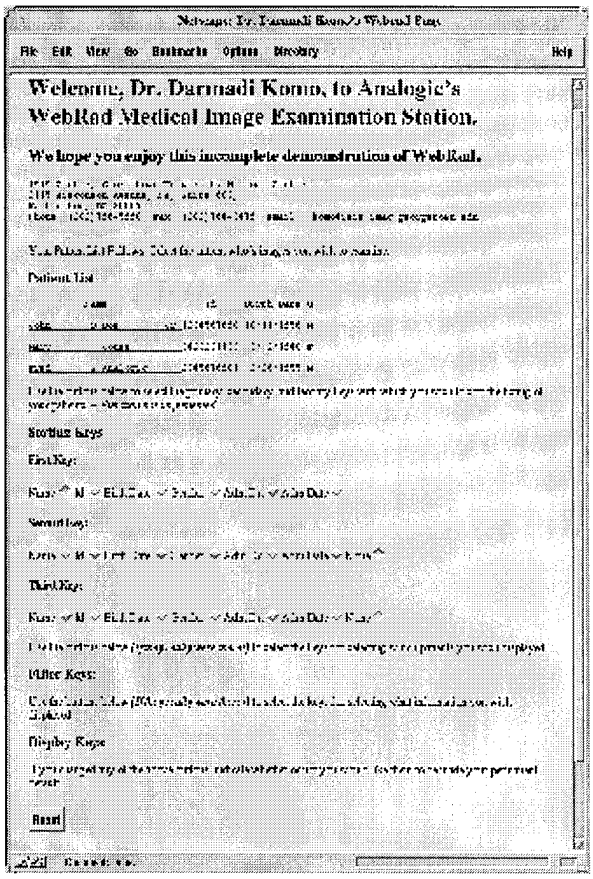


Figure 1. Radiologist Page

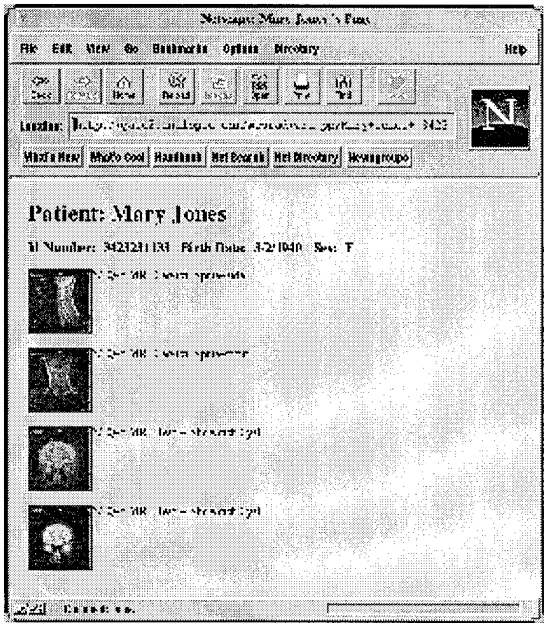


Figure 2. Patient Page

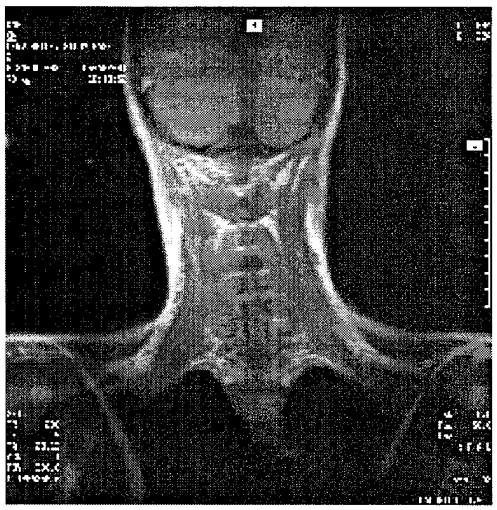


Figure 3. Patient Image 1

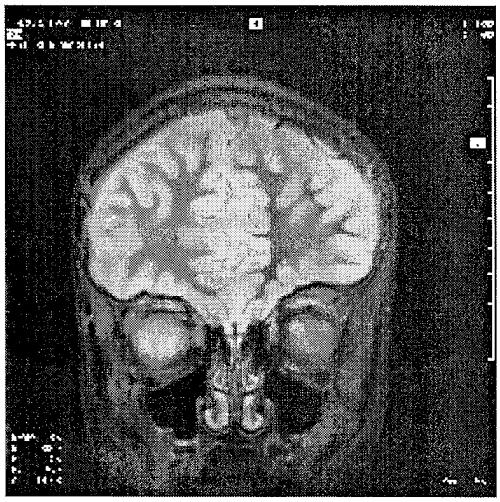


Figure 4. Patient Image 2

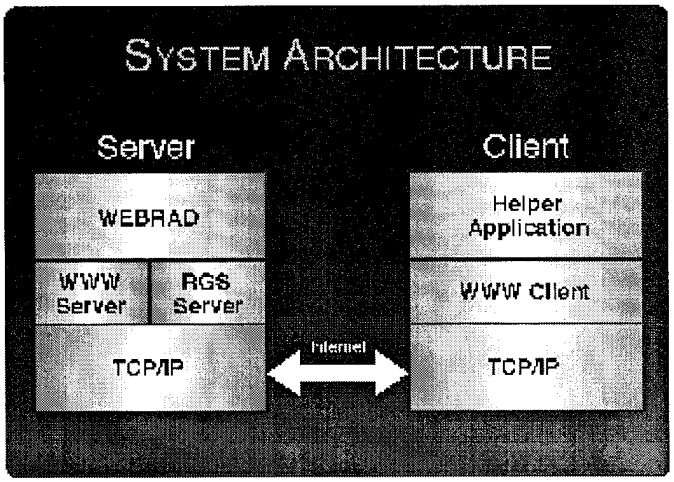


Figure 5. System Architecture

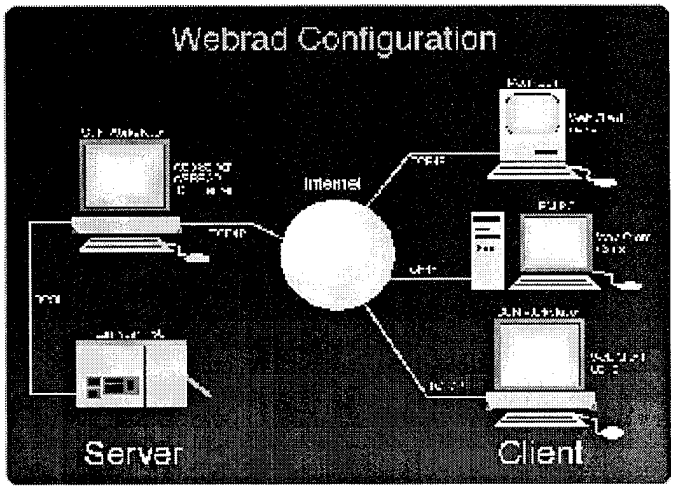


Figure 6. WEBRAD Configuration

2.5.1 Fuji CR link to MDIS Network

Investigator: Betty A. Levine, MS, Matthew T. Freedman, MD, MBA, Gary Norton, RT (R), Marion Meissner and Seong K. Mun, PhD

A. Significance to the Military MDIS Project and Executive Summary

Interfacing CR to MDIS has been one of the most difficult and controversial aspects of the MDIS project. As Loral and Fuji continue to develop future versions of their software, the MDIS sites must be able to utilize new options and enhancements added to the Fuji CR readers. However, in the past, the MDIS sites were required to purchase a special configuration of the Fuji CR in order to be MDIS compatible and therefore send CR images to the MDIS network. Loral is taking a very important step in working with Fuji to allow users to purchase the standard Fuji CR equipment and software so that the MDIS network will successfully match the CR images with scheduled exam folders in the MDIS PACS. This paper, will describe the current Fuji CR - MDIS interface, and describe the next generation interface. It will use the Georgetown configuration as an example of the future Fuji - MDIS network.

B. Loral Options

The Loral interface between the Fuji CR devices and MDIS have relied on the purchase of special configuration software from Loral or Fuji called configuration-S. This software allowed for the connection of the Loral ET and the communication of information to match the CR images with the scheduled exam folders on MDIS. This was special OEM software for interfacing Loral workstations to Fuji CR equipment. However, Loral is attempting to redesign their interface options in an effort to allow users to purchase and use standard Fuji CR devices.

B.1 Fuji IDT - standalone.

The standard Fuji IDT terminal would be connected to the Fuji reader, a SCSI interface would then be connected either directly to the reader or through an HIC-654 workstation, a CRAW would be connected to the SCSI interface and also to the PACS (see figure 1.0). Images would then flow through this path onto MDIS.

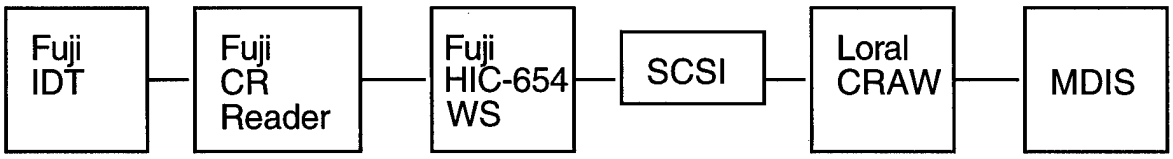


Figure 1.0

"Operationally, the Fuji systems will use the standard IDT to identify the exam information [e.g. Patient Name]. Based on the demographics provided with the image by the CR reader, the CR Acquisition Workstation attempts to match the exam and image data with scheduled exam folders in the PACS and file the images in the appropriate patient folders". (Georgetown University Medical Center Acquisition Plan, Dated: 9/5/95). This requires that all CR exams acquired off the CR utilize Loral's profiling mechanism to match CR exams to the exam text information in the MDIS database. The fields that are used for profiling currently, do not provide enough unique information to allay fears about mismatch of images and exams.

B.2 Loral ET and Fuji IDT.

This solution requires a Loral ET to be connected to the standard Fuji IDT terminal which would be connected to the Fuji reader, a SCSI interface would then be connected either directly to the reader or through an HIC-654 workstation, a CRAW would be connected to the SCSI interface and also to MDIS (see figure 1.1). Images would then flow through this path on to MDIS. Although hardware wise this solution requires the use of an additional computer in the path for getting images from the CR to the PACS, it does provide more security in terms of image and exam folder matching.

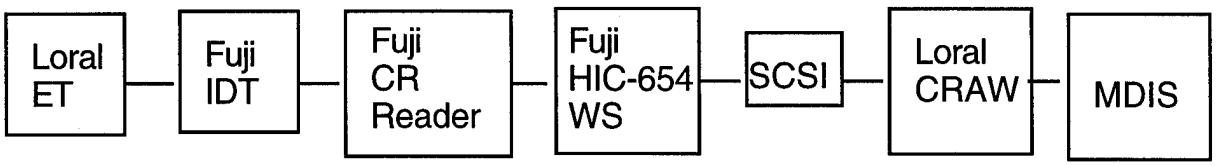


Figure 1.1

Loral is pursuing the use of a documented but not fixed field in the Fuji CR image header to pass a unique identifier to aid in profiling Fuji CR images to scheduled exam folders stored in the PACS. A documented but non-fixed field means that the field will exist in future releases of the Fuji CR software, however its position within the header may change. Thus, for each standalone CR device, Loral proposes an ET, which queries the MDIS database for patient and exam information. The ET is connected to the IDT and thus passes this information, along with a unique exam identifier to the Fuji IDT. This header information gets matched up with the image and is sent through the SCSI interface to the CRAW and ultimately to the PACS. However, since the data comes from the MDIS database originally, and contains a partial exam identifier, the mismatches that could occur with straight profiling are minimized. Although, this appears to be an excessive amount of hardware required to acquire CR images into the PACS, it does solve many problems with matching of Fuji CR images to exam folders on MDIS.

C. Fuji Networking Solution

Fuji has announced their ethernet options for connecting the HI-C654 workstations together so that users can share resources between Fuji CRs. This requires standard ethernet boards being installed in the HI-C654 workstations and an ethernet network installed to connect the workstations. It is our understanding that an HI-C652B cannot have an ethernet board put in it. If one of these were present, it would need to be replaced with an HI-C654.

C.1 Example of networked configuration.

Here is an example of how a hospital can network their multiple CR readers and workstations together to minimize the connections to the MDIS network and also provide a secure mechanism for redundancy in case of system downtime on the MDIS network. The Georgetown University Medical Center (GUMC) Fuji network will connect all the Fuji HI-C654 workstations in an effort to share the ODF, consolidate the purchase of CRAW's and SCSI interfaces, and allow for the movement of CR images between workstations and therefore between laser imagers. The diagram below (figure 2.0) shows how the GUMC network will look when completed.

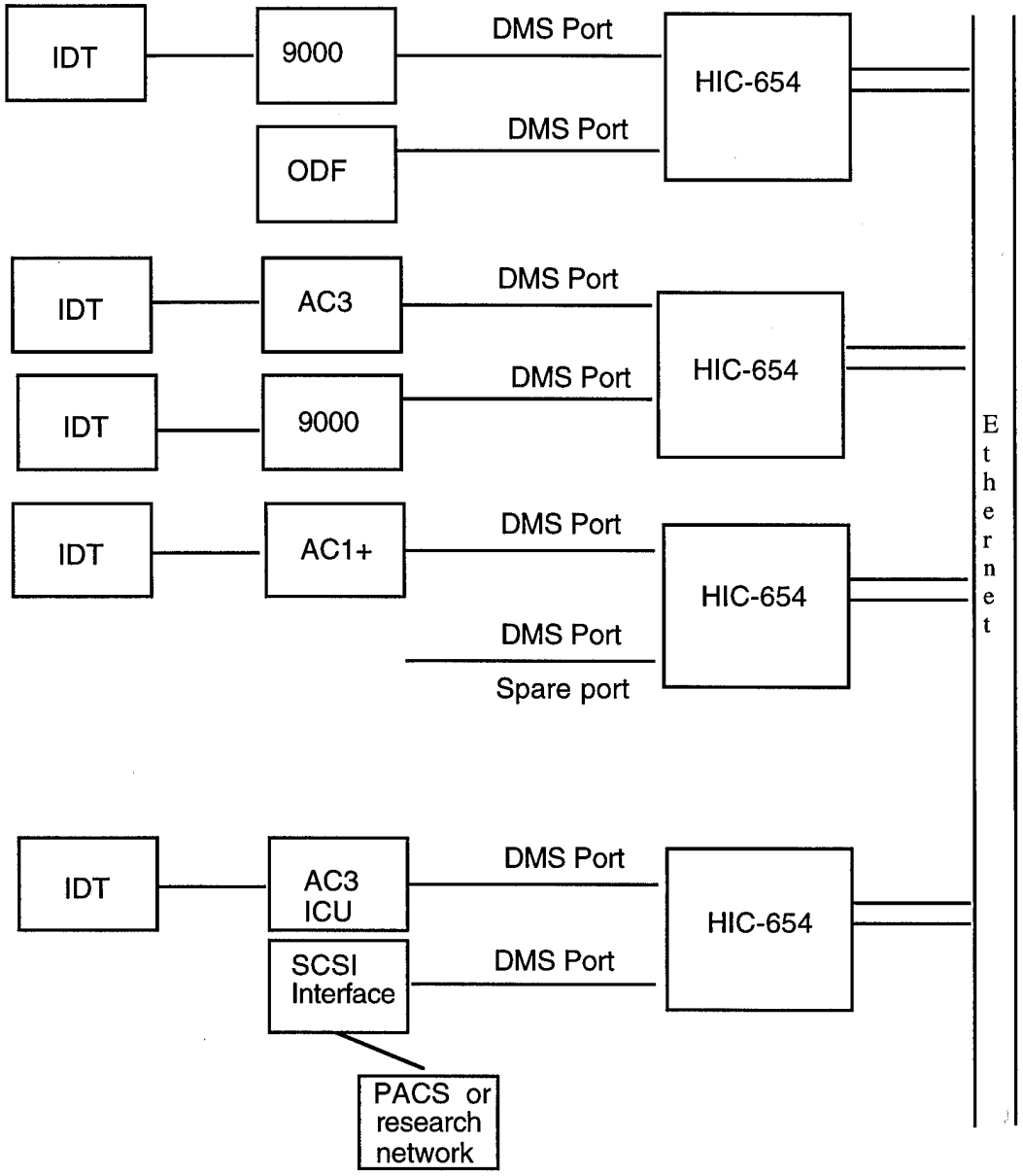


Figure 2.0

C.2 Loral - Fuji CR network interface.

The diagram below (see figure 2.1) shows the total Fuji network interface to MDIS at GUMC. It includes the MDIS hardware that is required, as well as all the Fuji hardware. There are some throughput issues to be considered with this configuration. There will be two SCSI interfaces on the network in an effort to improve throughput so all images do not pass through a single SCSI interface to get to the MDIS network.

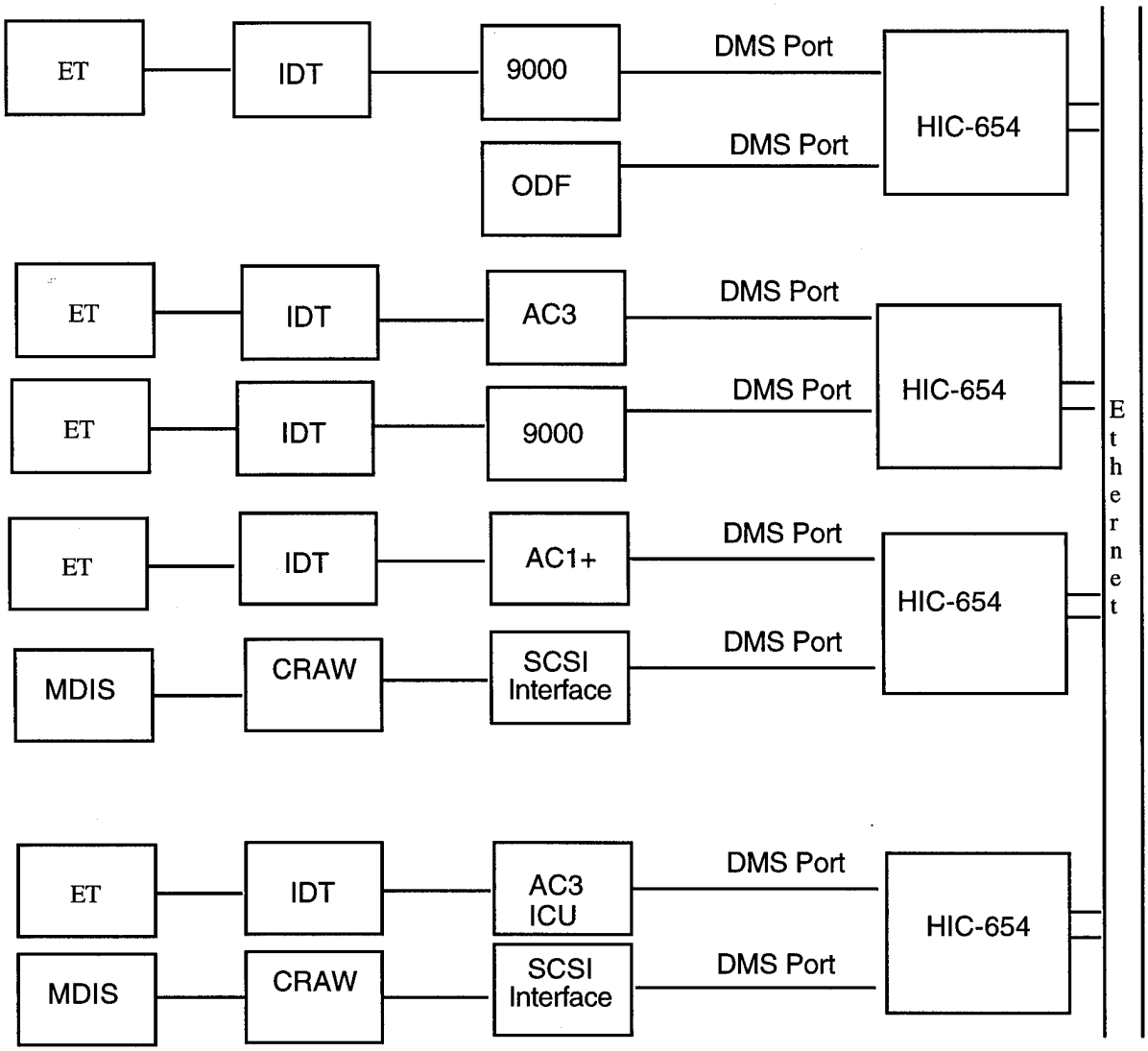


Figure 2.1

D. Functional Requirements

With the introduction of the Fuji CR interface to MDIS, the following is a description of how exams will be acquired into the MDIS network from any Fuji CR devices.

D.1 ET functionality.

The primary function of the ET is to communicate with a Fuji CR plate reader. The ET provides the user with a workstation that correlates patient and examination information, and image processing parameters with a CR imaging plate.

D.2 CRAW functionality.

The CR acquisition workstation (CRAW) is responsible for acquiring the image from the plate reader, storing the image, and allowing the user to perform a quality control review of the

examination before it is read by the radiologist. The CRAW acquires the image using the SCSI interface as the interface between the CR plate reader and the CRAW. The quality control software gives the user the ability to manipulate the image, such as flipping or rotating the image.

D.3 IDT functionality.

The purpose of the Fuji IDT is to accept the patient and examination information and image processing parameters entered at the Loral ET and attach it to the image header. The IDT is required to maintain compatibility with standard Fuji CR devices.

D.4 SCSI interface functionality.

The Fuji SCSI interface is required for images to flow out of the Fuji CR reader or HI-C654 workstation. This is a device that connects via the proprietary Fuji DMS port to the image plate reader or HIC-654 workstation and connects via SCSI to the Loral CRAW.

D.5 Acquisition functionality.

Exams are scheduled into MDIS and bar codes generated via the RIS - MDIS interface and a scheduled exam folder is created in the MDIS database. When the exam has been completed (i.e., the plates exposed) the technologist goes to the ET connected to the CR plate reader and scans the PACS barcode to enter the Exam ID into the ET workstation. The patient and exam information are retrieved from the MDIS database and displayed for the current patient. There are some fields that can be filled in for the exam or patient information. The acquisition data screen is set for the user to select or enter information relating to the current acquisition, including the plate ID. The plate ID can be scanned in using the bar code reader.

Once the patient and exam information has been verified and the plate IDs entered, all the plates for the exam can be inserted into the CR reader. The image plus header information is sent from the current HI-C654 connected to the reader to a HI-C654 workstation that has a SCSI interface over ethernet and is then automatically sent out the DMS port and SCSI interface to the CRAW. The CRAW then matches the exam and image data with the scheduled exam folder in the MDIS and files the images in the appropriate patient folders. This matching is done using profiling as described in section 3.2.

E. Remaining Issues

The most important issues to still be resolved before implementing this type of strategy is to determine the performance of a Fuji CR network interfaced to MDIS through one or two SCSI interfaces and to determine the unique identifier that will be used to help uniquely identify the correct scheduled exam folder in MDIS.

E.1 Performance issues.

Information is needed from Loral regarding the time required to scan a plate and have it arrive at the CRAW. Information is also needed from Fuji regarding the performance of the HIC-654 when it is connected to the ethernet, i.e. what can be done on the workstation while it is sending images out the SCSI interface.

E.2 Profiling.

It is crucial to the operations of the Fuji CR - MDIS interface, that the profiling mechanism correctly match images to the scheduled exam folders at least 98% of the time. Work is required by Loral and potentially the RIS vendor to determine a unique identifier that will guarantee a correct match of images and exam folders. Guarantees are required from Loral and Fuji that this documented but not fixed field that Fuji has approved Loral to use will remain a viable field in future releases of software for the CR devices.

2.5.2 Agfa ADC - MDIS Interface

Investigators: Marion C. Meissner, Betty A. Levine, MS, Seong K. Mun, PhD

A. Significance to Military MDIS Project and Executive Summary

In order for an MDIS network to acquire images, it must either receive digitized images from a film scanner or be interfaced directly with an imaging modality. Currently, the only Computed Radiography (CR) system that has a direct interface to the MDIS PACS is the Fuji CR, as described in Section 2.5.1. The Imaging Science and Information Systems (ISIS) Center of the Georgetown University Medical Center (GUMC) is developing a software interface between Agfa's Computed Radiography system, Agfa Diagnostic Center (ADC), and the MDIS network. This will enable MDIS to access another commercial CR system, enhancing its utility and acceptance and providing a competitive incentive to other CR vendors.

B. Introduction

The ADC currently operates independently of the MDIS network. Image cassettes containing the phosphor plates used in CR are exposed by an X-ray machine. The image cassettes also contain an Erasable Programmable Read-Only Memory (EPROM) chip, on which patient and exam data can be stored. After image cassettes are exposed, they are brought by a technologist to the Agfa ID-Station computer. This is a PC with additional hardware that can read and write to the EPROM chip on the image cassette. At the ID-Station, the technologist selects the option to label a cassette. He or she then types in patient data, such as the patient's name, sex and birthdate, and information about the type of exam/image contained on the cassette. This information is then written to the EPROM chip on the image cassette. After this process is complete, the cassette is taken to the Agfa CR reader, where the digital image is read off the phosphor plate and the data from the EPROM chip is attached to the image file as a header. The image is then sent to a laser imager to generate a film-based version of the image.

Using this approach, images acquired with the Agfa ADC system cannot be used to their full potential. For such images to be displayed, they must first be printed on film using a laser imager and viewed on a traditional light box. In analog form the image cannot be manipulated as effectively as in digital form and its diagnostic value may decrease. A film-based version of the image incurs the same risks of loss and damage as any traditional film-based radiological image. Additionally, the film-based version of an ADC image can be scanned using a film digitizer and thus be imported to a digital display system. This process is unnecessarily cumbersome and some of the originally digital information can be lost. Storage of the image can also be difficult if there is a limited digital storage capacity on the ADC system. These problems can be solved by developing an interface that provides a method of transporting the image in its original digital form to a PACS where it can be displayed and stored digitally.

An interface between the ADC and the MDIS PACS also reduces errors which can easily occur under the current configuration. Currently, when technologists label an image cassette from the ID-Station, they must manually type in text information such as the patient's name and ID number. Due to the isolated nature of the ID-Station, there can be no error checking on the entered data. A wrongly typed patient name or ID number can result in misplaced images or duplicate patient

entries in the hospital's physical or electronic records. If there is an interface between the ID-Station and the PACS database, no data must be re-entered. The technologist can simply choose an existing patient or exam record and be sure that the image will be matched with the appropriate files

Once the interface is in place, the ADC will be able to communicate with the MDIS PACS in a manner transparent to the users of both systems. After a cassette is exposed, the technologist brings it to the Agfa ID-Station and selects the option to label a cassette. Instead of asking the technologist to type in data, the ID-Station will retrieve a worklist of exams waiting for images from the PACS database. This list will be presented to the technologist on the ID-Station screen, who then only has to pick the appropriate exam from the list. The exam and patient information will then be written to the EPROM on the cassette. When the image cassette is processed in the Agfa CR reader, the image and its corresponding header information will be automatically converted to ACR-NEMA format and sent to the PACS without any necessary intervention by a technologist or other staff.

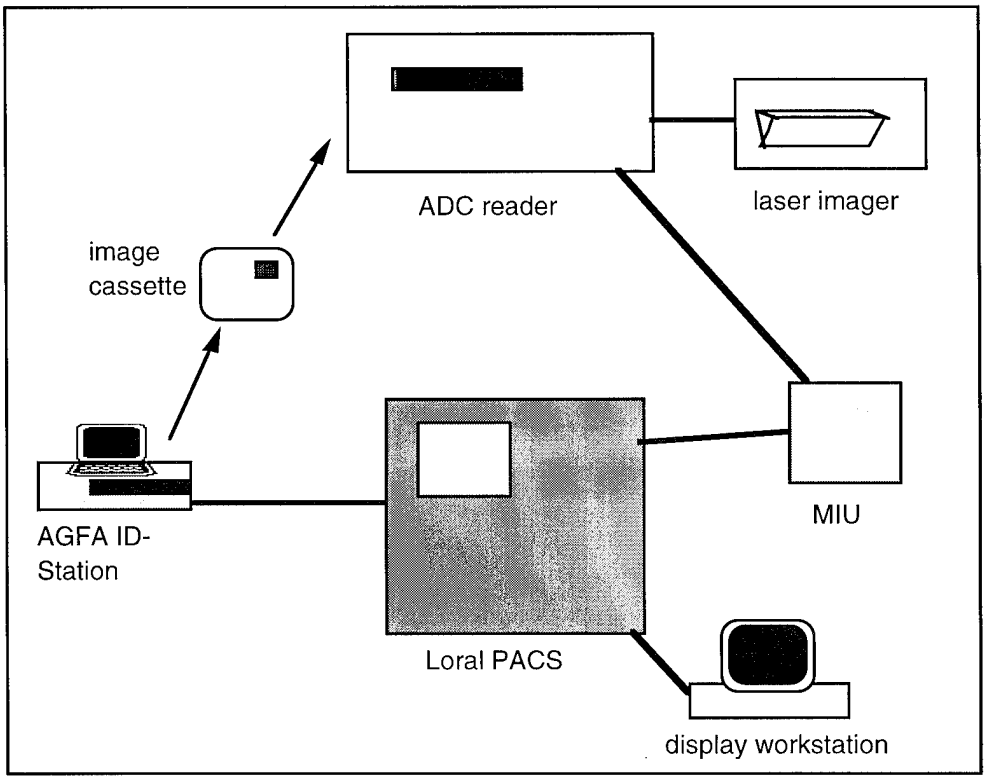


Fig. 1. Configuration with interface.

C. Interface Development

The planned interface between the ADC and the PACS will consist of two discrete parts. The first part of the interface involves querying the PACS database from the Agfa ID-Station for an exam worklist. This worklist will then be displayed on the ID-Station and the technologist can chose which exam corresponds to the image cassette currently being labeled. For the second part, images, complete with headers, need to be sent from the ADC system to the PACS database. The PACS expects images to arrive in ACR-NEMA 2.0 format and provides functions to import data into the database.

Since full-scale PACS and ADC systems are not available for the development of the software interface, we have set up a development configuration to model these two systems and their

interactions. At the current time, we have received and installed the following components from Agfa, Loral and third-party vendors:

a. Hardware:

- ID-Station: PC with EPROM reading/writing hardware to act as the Agfa ID-Station
- ADC reader: Sun SparcServer workstation to model the Agfa ADC reader
- PACS database: Sun Sparc10 workstation to model the MDIS PACS database server
- Litebox: Macintosh Quadra 950 for data entry to the MDIS database; to model a Loral Modality Interface Unit (MIU); to act as a display workstation to display images and patient data from the MDIS database

All of the above components are connected over our departmental ethernet network.

b. Software:

- Agfa ID-Station software package for ID-Station
- Ftp PC/TCP software for ID-Station to communicate with PACS database over TCP/IP
- Agfa RISlink toolkit for ID-Station to integrate interface software with Agfa ID-Station software
- Agfa ADC software package for ADC reader
- SunLink DNI software for ADC reader to communicate with Litebox over DECNet/PACSNet
- Agfa's Softcopy toolkit for ADC reader to extract images from the ADC software
- Siemens spooler for ADC reader to export images to the PACS database
- Sybase database server software for PACS database
- Loral Litebox software for Litebox to display images from the PACS database
- Loral MIU software for Litebox to act as an MIU
- Loral PARIS software for Litebox to act as front end for PACS database
- DECNet software for Litebox to communicate with ADC reader over DECNet/PACSNet

C.1 Querying the PACS database for exam worklists.

To allow customer-developed programs to import data into the ID-Station application, Agfa provides a RISlink toolkit package. This toolkit provides a mechanism to call a foreign program when the "label cassette" option is chosen on the ID-Station. Data from the foreign program can be used by the ID-Station software by reading it from a particular data file. The RISlink toolkit expects certain data fields in that file and they must be in ACR-NEMA 2.0 format.

We have written a program, named IDLINK, that queries the PACS database for the current worklist, presents this worklist to the ID-Station user, allows the user to choose a particular exam from the list, and writes this data to the RISlink data file in ACR-NEMA 2.0 format. In order for our program to communicate with the PACS database server, located on a Sun Sparc10 workstation across an ethernet network, we have installed FTP PC/TCP to implement a TCP/IP stack. Using this package, we are able to issue a command from our IDLINK program to the Sun workstation that executes a program on that remote workstation. This program on the Sun workstation, named ID_SCRIPT, issues an SQL query to the PACS database to retrieve a list of all exams waiting for images, stores the results in a file and formats that file to be easily readable by the IDLINK program on the ID-Station. Once this process is complete, the IDLINK program issues another command that copies the file created by ID_SCRIPT from the Sun workstation to

the ID-Station PC. The file is then read by IDLINK and its contents presented to the user in a list format. The user can choose the appropriate exam from the list. The IDLINK program then takes only the data for the chosen exam, writes it to a new file in ACR-NEMA 2.0 format, and passes control back to the ID-Station software.

Development of this part of the interface is nearing completion. The programs described above are in place and functioning but further work is necessary on testing and integrating them with the ID-Station software.

C.2 Sending ADC images to the PACS.

After an image cassette has been labeled on the ID-Station, it is brought to the ADC reader and the image information is read from the phosphor plate. The exam and patient information from the EPROM chip on the image cassette is attached to the image as a header and the entire image is locally stored by the ADC reader software. When images are to be sent to the PACS, they are exported from the ADC reader software using the Agfa Softcopy toolkit software provided for this purpose. We have written a program, named ADC_PACS, that runs as a background daemon on the ADC reader and continuously checks for the appearance of such an exported image in a certain directory on that system. When an image file is found in the directory, the ADC_PACS program reads the file, extracts the header information, converts the image and the patient and exam information to ACR-NEMA 2.0 format and writes all the data to a new file. Using the Siemens export spooler software, this new file is then sent to the Litebox acting as a Modality Interface Unit. This link occurs over standard ethernet using the DECNet/PACSNet protocol. In a real system, the MIU would then pass an acquired image on to the MDIS PACS database.

We have implemented and tested the ADC_PACS program and shown that it successfully waits for new images and then converts them to ACR-NEMA 2.0 format. We have been able to display acquired images on the Litebox acting in its display station capacity. Currently, we are working on automating the entire process described above.

D. Conclusion

This interface will help integrate Agfa's ADC system with the MDIS network. It will reduce the workload for technologists and eliminate a significant source of errors and duplicate records by allowing technologist to choose an exam from an existing worklist rather than re-typing patient and exam information. Images will be transferred more quickly and easily from the ADC to the PACS, where they can be stored and reliably retrieved.

Despite the many obstacles we have encountered during the development of this software interface, we have made good progress. We anticipate completing the project by the end of the calendar year 1995.

2.5.3 Open Issues in PACS Interface with Imaging Systems Standards

Investigators: Betty A. Levine, MS, Marion Meissner and Seong K. Mun, PhD

A. Significance to the Military MDIS Project and Executive Summary

The use of standards in medical imaging systems networks is critical to the long term success and sustainability of the network. Standards exist in all aspects of system integration and connectivity, however, they aren't always enough. Standards for communications media, communications protocols, and data and message formatting exist, but aren't always interpreted similarly by multiple vendors. The MDIS project needs to ensure that future releases of vendors equipment will be compatible with the MDIS PACS. Without the use of standards, it is uncertain whether compatibility will be maintained with future releases of software. Using standards does not guarantee compatibility, but it does increase the likelihood that systems which can communicate now will continue to do so in the future. This paper will show examples of standards not being interpreted similarly and the problems that this can cause.

B. Background

Georgetown's involvement in the development of interfaces has been long and varied. We have participated in the development of six RIS/HIS - PACS interfaces, performed surveys of many RIS/HIS and PACS vendors as to their use of standards in interface development, and have participated in the ACR-NEMA standards committee. Nevertheless, with each new interface effort, we spend a great deal of time and effort in the initial stages of design.

In general, to begin the development of an information system interface, one must evaluate all aspects of the systems involved. The areas of investigation include: direction of data flow, trigger functions, data element matching, physical media, communications protocols, and message/file formats. If standards are used, many of these questions become easier to answer but the use of standards does not guarantee "easy" connectivity.

In all our experience with interface development, we have used the following "standards": RS-232 and ethernet for physical communications; DECNet, TCP/IP, Kermit, and HL-7 for communications protocols; and ACR-NEMA, and HL-7 for message formatting.

C. RIS/HIS Interface Development

Five of the six RIS/HIS to PACS interfaces we have been involved with have required a separate computer to act as a gateway passing information between the two systems (See Figure 1). This gateway was necessary to reformat data and messages, and to handle the differences in communications protocols. Although many of the vendors used standards for message formatting and communications protocols, no two vendors used the same standards for a given interface.

C.1 Understanding the problem.

In order to begin development of an interface, one must fully understand the problem at hand and what the interface is intended to do. It is often helpful to come up with a written description of the problem. Next it is helpful to describe scenarios of how the systems currently operate independently and then develop scenarios as to how they will work together. These scenarios will make design of the interfaces easier. From these scenarios, the trigger events that will start the flow of information between the two systems and the data available to the interface will become more apparent.

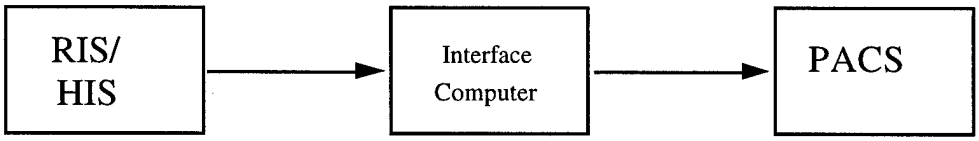


Figure 1. RIS - PACS interface via gateway.

C.2 Direction of data flow.

For any interface project, one must look at the two systems that need to communicate and determine the direction of communication for the interface. That is, does data need to flow from one system to the other and not back, or does it need to flow between the two systems. Once this decision is made, one can begin to understand how the systems are used, and how they will be used in conjunction with each other. For example, if developing an interface between an RIS and PACS, one must decide if a patient will be registered into the RIS first, and then the information will flow to the PACS, or if they should be registered into the PACS and only have data sent to the RIS once the exam has been completed and the images taken.

C.3 Trigger events.

Next the trigger events that will start the flow of data need to be determined. RISs often have many stages of exam creation for the purpose of patient or event tracking. Examples of stages of exam creation or potential trigger events within an RIS interface may include patient registration, exam schedule, exam order, exam confirmation, exam modification, exam begin, exam completion, report dictation, report completion, report signature, etc. At each stage of this process, one must determine if there is a need to pass information between the systems. If at a given stage there is no new information that both systems require access to, then there probably is no reason to define a trigger event at that point. In the above example, if the RIS is the primary system and the PACS secondary, then there is probably no reason to define patient registration as a trigger event, because at that time it is not known whether a radiology exam will be ordered. It also may not be necessary to define a trigger event at the time an exam is ordered, because the order may change before the patient actually has the exam done. Therefore, one might decide to define trigger events at exam confirmation, exam modification, report completed, report edited, and report approved/signed.

C.4 Data elements.

Once the trigger events are defined one can begin looking at the data elements that exist at that point and determine which elements need to be communicated. In determining data element sharing, it is important to understand how data elements are used on each system, so that they have the same meaning on both systems. Some data elements such as "patient name", "date of birth", and "sex" are straightforward to map between the systems, but there are many less obvious elements which must be understood. Some examples of these elements may be "exam start time", or "radiologist". One system might think of "exam start time" as the time when the patient is brought into the exam room while another system might consider it the time the exam is actually performed. The "radiologist" field

can get confusing especially in a university medical center setting. Often, it is desirable to have the resident read an exam first, followed by a fellow and/or an attending physician to verify the results. (There has been some talk that the federal government may impose restrictions regarding reimbursement rate for radiology exams based on who has read the exam, resident, fellow, or attending physician. Therefore, it may be desirable to have both a fellow and radiologist read an exam after a resident has read it and thus one would want all three names on the report.) Unfortunately, it is not always possible to pass all these pieces of information due to a limitation of one of the systems or of the interface. This can be "worked around" by making special considerations and passing data in a comment field or other field that was not intended to be used that way. However, once one starts using fields in ways they were not expected to be used the implementation of a standard becomes nonstandard.

C.5 Message formatting.

If an interface needs to be developed, then the two systems are probably not using the same standard for passing data. Therefore, reformatting of the data from the sending system to the receiving system must be considered. Both the sending and receiving systems should provide a detailed explanation of what the required message format is so that the interface can reformat the data. It is at this point that the interpretation of the message formats is very important, even if the sending and/or receiving system are using standards for the message format. Byte ordering within the messages was a problem with our initial HIS to PACS interface. The PACS vendor interpreted the ACR-NEMA standards differently than we did, so it was not until we started testing the interface that we realized we needed to byte swap our 2 byte data. This was a relatively easy problem to find and fix, but it does demonstrate some of the problems that can be encountered, even when standards are used.

C.6 Lower-level connectivity.

At the time of design, one must also be aware of the physical connectivity requirements, the communications protocols, and the message formats. There is often less discussion between vendors about these aspects of an interface development, because they are usually well defined by one or both vendors. However, using communications standards does not guarantee ease of implementation. Physical media can often follow the standards but not be interpreted the same way. An example of this is our first interface development which was to connect our in-house developed HIS to a PACS. The PACS vendor was attempting the use of standards for their side of the interface. The communications protocol was Kermit over RS-232 serial cables, and the message format was ACR-NEMA V2.0. Although we were using an RS-232 standard interface our serial connection was not working. We then learned that when transmitting over RS-232, there are different configurations for RS-232 cables that are considered RS-232 compliant, but will not work with each other. The PACS required an RS-232 connection that tied pins 5, 6, & 8 to pin 20 (see Figure 2), and our cables did not tie all three to pin 20. These were all considered RS-232 compliant, but the connection would not work. Since we needed a null modem between the devices to make them communicate, we used a null modem that tied pins 6, 8, and 20 together. This problem was difficult to diagnose and determine why the communications would not work. The vendor was unaware of the restriction they had imposed on the cabling.

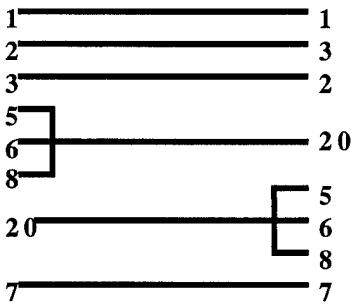


Figure 2. RS-232 null-modem pin configurations.

Besides the examples discussed above, we ran into interpretation problems with interfaces we developed between RIS and PACS. In one case, the version of Kermit implemented by the RIS vendor on an IBM RISC machine was unable to distinguish between a file transfer time-out and a successful transfer. Therefore, we had to develop a fix such that a response file would be sent to the RIS vendor for each file we received properly. A different RIS to PACS interface ran into problems because the RIS vendor needed to write their own Kermit implementation, since their system was written in a nonstandard operating environment. Their initial implementation of the Kermit standard had problems acknowledging packets properly, which lead to miscommunications in the interface. This is a good example of how the interpretation and implementation of a standard can affect the usability of an interface.

Taken individually, such problems are not difficult to overcome, but since they can and do occur often during each interface development project, they can really slow down development.

D. CR Interface Development

We are currently developing a Computed Radiography (CR) to PACS interface. This involves the interfacing of the CR ID station to the PACS for retrieving patient and exam related information, and of the CR processing workstation to the PACS for sending the images and related information to the PACS. To do this we have developed software on the CR processing workstation to reformat the images and related text information and create messages to send to the PACS. We have also begun work on the CR ID station to connect it to the PACS (See Figure 3).

One goal of this project is to retrieve exam related information from the PACS and present it to the user on an ID station connected to the CR. We then associate this information with the images from the appropriate exam and send the package of images and exam related information from the CR workstation to the PACS. This project was tackled as two separate problems, communicating with the PACS database to get the exam data and sending image data to the PACS, and will be discussed that way here.

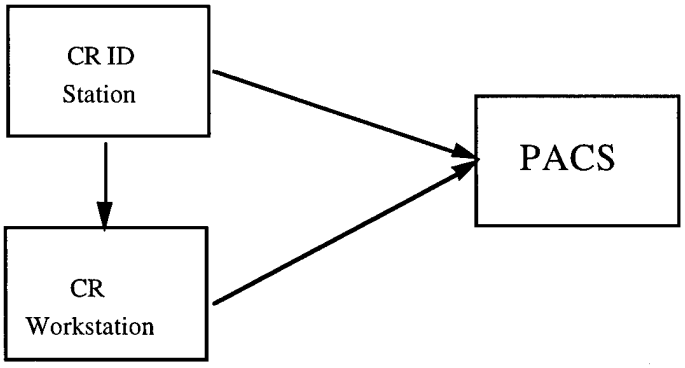


Figure 3. CR - PACS interface.

D.1 Image transfer - low-level communications.

The image transfer problem was addressed first, and to do this we needed to consider the communications protocol differences. The CR is configured for NFS communications, and the PACS requires DECNet communications protocol. Therefore, we needed to configure the CR workstation (a Sun running Sun OS-4.1) to run SunLinkDNI (a DECNet application for Sun computers) and the PACS interface unit (a Macintosh) to run Pathworks (a DECNet application for Macintosh computers). Although the applications we used follow the DECNet standard for communications, we did encounter problems setting up the protocols to communicate. First, we wanted to test the connection between the machines using DECNet by running a loop test. After countless hours of non-communication and phone calls to all vendors, a colleague at another company suggested we set the packet size to 64k bytes. This worked, and we found that although not documented anywhere, this "magical" number was required to get these two systems communicating via DECNet. Once we established that communications worked, we tried to send a file across the interface. This would not work. We finally determined that Pathworks for a Macintosh must have "No Password required" set as an option on the Macintosh in order to be able to connect from the SUN. These two small problems are good examples of how a vendor's interpretation of a standard (SunLinkDNI and Pathworks) can lead to headaches during implementation.

D.2 Image transfer - message formatting.

The next stage of image file transfer was to address message formatting. The CR vendor uses a proprietary message format for image file transfer, while the PACS vendor uses an implementation of an ACR-NEMA V2.0 format. In developing an interface between the two machines, we needed to convert the proprietary messages to ACR-NEMA format. Our interpretation of the ACR-NEMA interface was different than the PACS vendor's interpretation. We began by trying to map all CR data elements to the appropriate groups and elements of ACR-NEMA. This is not so straightforward. There were some data elements that had ambiguous meaning. For example the CR image message has a bits per pixel element which could map to either bits allocated or bits stored in the ACR-NEMA header (28,100 or 28,101 respectively). Also, more clinically, creation date (which contains date and time information) from the CR image message can be mapped to either study, acquisition or image date & time (8,20 & 8,30, 8,22 & 8,32, or 8,23 & 8,33 respectively). Sometimes it is appropriate to send the same information in different data groups, but the receiving systems intention for the data element must be understood to ensure the correct usage on the receiving system.

An inconsistency we encountered with data elements was that the PAC system's ACR-NEMA messages required 16 bit pixel data in the message but the sending system was only passing 8 bit data.

This did not agree with our interpretation of the ACR-NEMA standard and we therefore had to pad all pixel data before creating and sending the ACR-NEMA message.

We also had to determine the ACR-NEMA groups and data elements allowed by the PACS, and which, if any, shadow groups were necessary. Although they claimed to be ACR-NEMA compliant, we found that their interpretation of the standard was different than ours, and that they did not accept a message that contained group 0. We interpreted the standard to require this group. The documentation provided by the PACS for creating the ACR-NEMA message did not state this, and it was only discovered when we looked at example messages provided for other modalities that we realized group 0 was never sent in a message. The PACS also required a shadow identifying group (group 9) that gets sent with elements for the release and version number of their interface, and a unique system identifier that matched one that the receiving system was expecting.

D.3 Exam related information.

The second part of this interface project is to connect the ID station of the CR device to the PACS. A patient worklist will be generated on the ID station with the information obtained from the PACS. This will ensure that the images sent to the PACS will be associated with the correct information on the PACS. The ID station is an application running on a DOS PC while the PACS database is a SYBASE Server running on a Sun host. An SQL client will be installed on the PC to query the PACS database. The communications protocol and physical media will be TCP/IP over ethernet. Although this part of the project is just getting started, we expect that this part of the interface will be fairly straightforward. Where we have started seeing problems is with the actual data that the ID station allows and that the PACS database maintains. Some fields, such as exam subtype and patient orientation, do not exist on the PACS and therefore will not be available to the ID station. Since we are using SQL, message formatting should not be an issue as long as correct SQL syntax is being used.

E. Conclusions

Standards are a necessity if interface development is to be performed in a timely, efficient, cost effective manner. While standards do not answer all our problems, they do go a long way to making interface development manageable. There is much talk about the need for standards and increased interest by vendors and customers for the adoption of standards like ACR-NEMA. In reality, standards cannot solve all our problems until they become widely accepted and tested. The adoption of standards by manufacturers has reduced the complexity of interface development, but it is only the first step. In order to make standards as effective and useful as possible, the problem of manufacturers' differing interpretations of these standards must be solved.

One way to do that would be to develop a suite of validation tools that determine compliance to the standard. This testing suite would need to test all aspects of the standard, and should be modifiable as new issues arise that need to be clarified. The language used when writing the standards must be very specific to avoid interpretation problems. It would also be useful if there were a mechanism to review and change ambiguity in the standards. We realize that it is often difficult to change a standard since it should not negatively impact existing interfaces. However, in order to get "plug and play" connectivity, it is essential to reduce the vagueness in the standards.

Vendors have not been spending enough time looking at the bigger picture when it comes to interface development. They often deal with each interface project individually without looking to the future and seeing the best route to take to limit the number of unique interfaces that need to be developed for their systems. If vendors took more time evaluating the standards that other vendors are

using, and adopted these standards, then many of the remaining problems could be solved. As standards are used by different vendors, the interpretations of these standards should become more similar.

Customers need to insist that vendors begin to use standards so that the cost of interfaces will be affordable, and the time required to connect their systems will decrease. If we pressure vendors to utilize adopted standards and make their systems open systems, it will be better for the vendors and for the radiology community.

2.5.4 Prototype Next Generation Intelligent MDIS Network

Investigators: Brian Krasner, PhD and Seong K. Mun, PhD

A. Significance to the Military MDIS Project and Executive Summary

The current MDIS release enables rapid viewing of radiology images. But the complete responsibility for interpreting exams and organizing them for further action rests with the radiologist. The current MDIS does not provide capabilities for computerized, intelligent, proactive analysis of the images. By having the network analyze incoming exams for pathologies, exams can be prioritized for more efficient and timely treatment in both everyday and emergency clinical situations. Additionally, when the exams are viewed, the network can act as an assistant radiologist or pathologist for interactive analysis of images, which can be important at remote sites when a senior radiologist or pathologist is not available for consultation.

B. Design Overview

A prototype has been designed for the next release of MDIS which will add intelligence to the network. Specifically, the project will develop a system supporting digital radiography for the purpose of investigating:

- intelligent diagnostic agents to identify pathology;
- intelligent agents to classify identified pathology;
- intelligent agents to optimize image presentation, and
- display functions for rapid screening of examinations.

Initially, the system will use as a test case mammography since it encompasses all of the problems associated with an intelligent radiology system. Thus, the system will incorporate:

- acquisition and management of high resolution images from film and commercial digital imaging devices;
- next-generation communications networking;
- computer-aided diagnostic support, and
- specialized diagnostic viewing functions optimized for mammography.

C. Design Requirements and High Performance Computing

The next generation prototype of MDIS envisions enhancements of radiological capabilities and extensions to viewing and analysis of non-radiological images such as pathology. Additional radiological capabilities include interactive analysis of large images such as chest radiographs and batch processing of large numbers of such images. Volumetric presentation and analysis of data sets from CT, MRI and ultrasound would also be included, which requires large data sets and large data processing requirements.
Pathology images can be very large, involve large amounts of processing and possibly 3D reconstructions. These new requirements involve high performance computing.

High performance computing (HPC) signifies order of magnitude enhancements over ordinary workstations in terms of speed of computation, data handling and networking. An ordinary workstation performs floating point computations at about 100 MFlops, moves data in the Mbytes/second range and networks at data rates from 10-100 Mbits/second. For many medical applications such as simple viewing of CT, MRI and ultrasound images, these workstation requirements are sufficient. However, viewing large sized images such as chest radiographs, applying image analysis and understanding techniques such as computer assisted diagnosis (CADx), enhanced viewing capabilities (3D viewing of pathology specimens) and real-time, interactive telemedicine applications require HPC.

D. Methods

To test the impact of HPC on medical computing, a prototype has been designed and developed to integrate the components of HPC into an effective clinical tool. This prototype consists of integrated HPC hardware components from many vendors and custom software designed and created at GUMC to take advantage of this hardware.

The following two sections describe these hardware and software components.

HPC hardware components (see Figure 1)

PsiTech HFB360-24 frame buffers - These frame buffers are 2K x 2K x 24 bit deep, double buffered video frame buffers which drive Imaging Systems high resolution 150 ft.-lambert monitors. The unique feature of these frame buffers is a high speed communications link (HIPPI interface - see below), which allows networked interfacing with one or more hosts.

High Performance Parallel Interface (HIPPI) Network - This network consists of a HIPPI ES-1 switch from NSC and interfaces to the CRAY supercomputer and the PsiTech frame buffers. The ES-1 switch supports up to 16 input/output channels with each channel providing transmission rates of 800 Mbits/second. The channels can be active simultaneously for a total switch capacity of 12.8 gigabits/second.

ATM network - This network consists of an ATM ASX-200 ATM switch from Fore Systems and network adapters for the CRAY, DEC Alpha workstation, Sun SPARCstation and Silicon Graphics ONYX workstation. The network is configured to support the TCP/IP networking protocol. The switch supports 16 155 Mbits/s OC-3c/STM-1 connections for a maximum possible non-blocking throughput of 2.5 Gbits/s. The network also contains a LAX-20 LAN access switch for internetworking the various other research networks to the ATM networks at high speeds and without bottlenecks.

CRAY J/916 Supercomputer - 4 processor CRAY with 512 MBytes of memory and 10 Gigabytes of disk storage. It can process neural network procedures at a rate of up to 1 gigaflops. It has a high speed HIPPI interface for access to fast peripherals and an ATM interface.

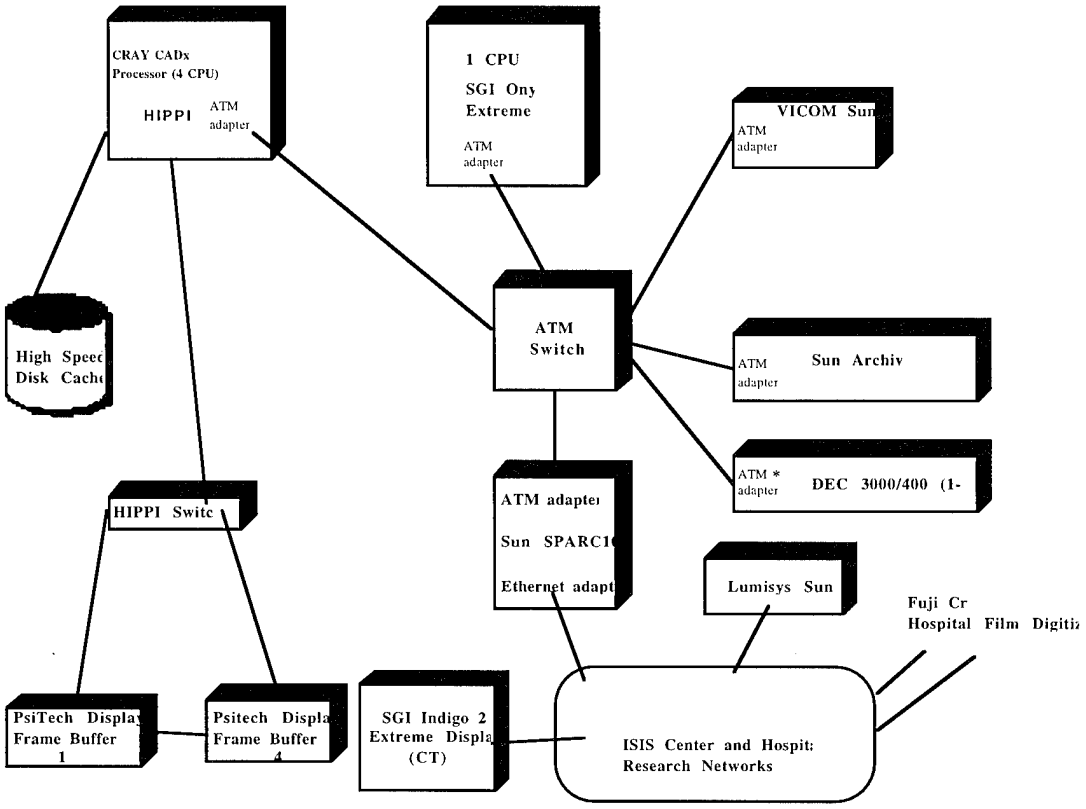
Silicon Graphics Onyx workstation with Extreme Graphics Board provides 300 MFlops processing power and interactive 3D visualization. It has an ATM interface to the network.

VICOM 4 screen, high-resolution workstation also is capable of displaying 2Kx2K digital radiographs. It is currently being used for quality assurance testing for CR and film digitized chest images.

Lumisys film scanner attached to a Sun provides the current means to digitize radiographs for research purposes. It is located in the GUMC Radiology Department. This scanner can digitize film at a resolution of 50 um.

GUMC Radiology Department Network is currently Ethernet based and is connected to the ISIS center network at 10 MBits/second rates. In the near future, this network will also be ATM based and be connected to the ISIS center with fiber optic lines (ATD net).

Figure 1



HPC software components

Computer aided diagnosis (CADx) programs for detection of lung nodules have been ported to the CRAY supercomputer, and have been shown to run 40 times faster on the CRAY than on a DEC ALPHA workstation, which is one of the fastest of the desktop workstations. The digitized images and the CADx results can be displayed on a 4 screen display subsystem attached to the CRAY, running X Windows. This standard windowing system allows the use of many available tools for designing an easy to use interface for the clinician. A current project currently being developed involves integrating these capabilities into a clinical prototype called INet-2000.

The scenario for use of this prototype is as follows:

A technologist scans in a film using the Lumisys Film Scanner and enter patient and exam information which is stored in a Sybase database.

- A process on the CRAY periodically queries the database and constructs a worklist of unread cases, which is displayed on a window in the CRAY 4 display subsystem.
- By using a mouse interface device the radiologist can select the exam to view, whose images appear at 2Kx2K resolution.
- By using pull-down menus and simple mouse motions, the radiologist can edge-enhance the images, change the brightness-contrast, etc.
- Finally, the radiologist can open a text window, enter a report and save it in the database.

As is well known the radiologist needs rapid response when viewing images. The workstation takes advantage of the 512 Mbytes of memory by preloading the next exam to be viewed. When the radiologist clicks on the next exam it is loaded into the frame buffers at throughput rates of 40 Mbytes/ second, so that all four screens can be loaded in less than 2 seconds.

E. Results

E.1 Current Status

- Finished prototype on CRAY using X Windows interface for displaying chest radiographs and caching images for rapid display. This prototype is able to let the clinician select images from a list for interactive manipulations and region-of-interest analysis. Using the CRAY's vector processing capabilities, various filtering operations such as edge enhancement can be performed in less than a second even on large radiographs. The prototype is able to display ROIs and text information such as would be produced by the CADx analysis of the images.

- Finished CADx programs for detecting microcalcifications in mammograms and lung nodules in chest radiographs. These programs output the locations for localized pathologies and reliability estimates for the suspected pathology. In the prototype, these estimates are saved along with the exam images. Worklists of exams to be screened are constructed with images containing pathologies grouped together at the top of the list with the first case already in cache memory so that it can be reviewed rapidly. When the images are displayed the pathology locations are initially overlayed on the image and can be toggled on and off. By clicking on the overlay, reliability estimates and any other descriptive information derived by the CADx such as presence of clusters is displayed. Preliminary studies have shown that these CADx programs are sped up by up to 40 times by the CRAY's vector and parallel processing capabilities. The main advantage to this speedup is that the initial evaluation of the patient can be made with the patient still in the medical evaluation site so that further testing, if necessary, can be performed immediately. The increase in efficiency for treating personnel and the reduction of stress while awaiting results is clear.

- Finished database schema for supporting clinical prototype. In addition to the standard patient, exam and image records, new relations supporting computer diagnosis were added. These fields include the type and location of suspected abnormalities, description of the

abnormality and confidence level of the abnormality. These fields then become associated with key patient diagnostic images, so that when the image is recalled, the display subsystem is able to present the CADx results.

- Finished high level designs for INet 2000 subsystems. These designs include data flow diagrams, scenarios, subsystem interfaces and user interfaces for all the major components of a clinical prototype. These subsystems include digital film acquisition, database library and schema, graphical user interface including all major menus, dialogs and worklists, image manipulation and display, and CADx which generates the diagnostic information presented by the display subsystem as described above.

E.2 Future Developments

- Integration of CADx programs with image display programs in an exam oriented evaluation system. The current prototype is primarily image oriented.

- Completion of INet 2000 subsystems. The individual pieces are working but there is still too non-automated procedures involved in the acquisition, analysis and storage of diagnostic exams.

- Completion of installation of ATM networks.

F. Conclusion

The prototype next generation intelligent MDIS network will provide a unique testbed for the delivery of medical services by high speed networks. The foundations for this system have been laid. In the next year, a working clinical test system will be functioning.

2.6 A Training Workshop in Computed Radiography (CR)

Investigator: Wendelin S. Hayes, DO, Hamid jafroudi, Ph.D.
Dot Artz, RT, Matthew Freedman, MD, Seong K, Mun, Ph.D.

A. Significance to the Military MDIS Project and Executive Summary

In the MDIS program, all conventional radiography has been converted to computed radiography (CR). CR is a complex technology requiring additional training of technologists, engineers and radiologists. Training provided by vendors has not been satisfactory. The three-day program we have developed has been tested several times and the team is ready to provide training to all CR users. This will make the introduction of CR and the MDIS system more routine.

B. Introduction

Computed radiography (CR) is a relatively new technology utilizing a photostimulable phosphor plate as the x-ray detector. The technology of CR is based on a storage phosphor screen chemically similar to a conventional intensifying screen. The photostimulable phosphor plate is exposed using conventional radiographic technique and stores some of the x-ray energy as a latent image. The latent image of activated electrons can be recovered during a readout process by scanning with a high-resolution laser and by detecting and digitizing the emitted visible light with a photo multiplier and A/D converter (1).

CR has evolved from conventional screen-film radiography with the following advantages: (1) improved detector efficiency; (2) linear detector response; (3) the capabilities of digital processing for image enhancement, display, retrieval, storage and transmission; and (4) the potential for a filmless radiology department. Due to these advantages, it is anticipated that the use of digital techniques will increase rapidly over the next two decades particularly in the field of conventional radiography imaging of the chest, abdomen, skeleton and breast.

C. Literature Review in Computed Radiography

Over the past few years there have been a series of articles in the literature, some of which presented concerns that specific diagnosis might be missed on CR and other articles that answered the potential objectives with new studies. There has been a slow evolution in the quality of the equipment over time and an improved understanding of image processing of CR so that, in general, the more recent articles are more favorable than the older articles. As clinical users of CR for bedside chest, in department chest, abdomen, skeleton and pediatrics, the Georgetown University Medical Center radiologists believe that CR correctly used is suitable, and is at least the equivalent to conventional screen-film radiography in all situations except for use in premature infants in the first few months of life, newborns, and in the detection of the earliest signs of hyperparathryoidism.

The diagnostic performance of CR depends on the clinical question and the use of image processing. For evaluation of the adult chest, CR is superior to conventional film radiographs for evaluation of the mediastinum, retrocardiac region, subdiaphragmatic recess and coronary artery

calcification. CR is reported to be generally superior or equivalent in the detection and evaluation of pulmonary nodules and larger pulmonary opacities. Evaluation of fine line detail (high frequency information), including interstitial infiltrates or pneumothoraces demonstrated equivocal results(2). CR based on photostimulable phosphor has replaced conventional screen-film imaging in bedside imaging (3).

For the evaluation of the musculoskeletal (MS) system, CR provides an alternative to conventional screen-film without significant differences in diagnostic quality (4). The wide dynamic range of CR offers distinct advantages in the parts of the body that have a large variation of body thickness and subject contrast (osseous and soft tissue) (4). This is particularly important in skeletal imaging when high-contrast, narrow-latitude screen-film combinations and low-kilovoltage technique are used with little margin for exposure error. The wide range in body and extremity thickness may result in underexposure in one part of the image and overexposure in another part (5).

D. CR Training

The Division of Imaging Sciences and Information Systems (ISIS) of the Georgetown University Medical Center, Department of Radiology, in cooperation with Fuji Medical Systems, has designed a training workshop in CR. The course is an intensive three-day program which provides an overview of CR technology and clinical applications, film interpretation sessions, and laboratory workshops. The course is given four times during the year and is limited to 12 participants to provide for dedicated individualized instruction and 'hands-on' workshops.

The course will be of interest to radiologists, medical physicists, radiologic technologists, radiology administrators and others who are active in advanced technology in the field of computed radiography and image processing.

E. CR Training Schedule

Day one of the course is devoted to the technical aspects of CR and comparisons to screen-film technology, image quality and image processing. An introduction to laboratory procedures is given defining CR equipment, the various components, and operation. Following the formal lectures, the participants engage in two laboratory workshops with 'hands-on' experience dedicated to exposure techniques and a plate reader session. Exposures are performed on phantom cases.

Day two of the course is devoted to the clinical aspects of CR. Image processing and clinical applications from the radiologists are discussed in formal lectures followed by a view box review of teaching cases on films including the clinical applications in chest, skeletal, abdominal and breast imaging. QA/QC (quality assurance) examples are also included. A post-processing laboratory of clinical and phantom cases on the workstation allows the course participants to apply the techniques of image processing to selected cases. The participants also tour the radiology department at Georgetown University Medical Center to observe the clinical experience of CR technology in both the inpatient and outpatient departments.

Day three of the course is devoted to Quality Assurance lectures and laboratory workshops. Film critique is performed of the phantom cases imaged on the first day of the course. An invited guest radiologist from Fuji Medical Systems provides a lecture and teaching cases of their subspecialty using CR technology.

F. Training Facility

A dedicated training facility for this course has been established in cooperation with Fuji Medical Systems at the Imaging Sciences and Information Systems Center. A dedicated x-ray room and an AC-1 Plus image reader and processor with a HI-C 654 workstation has been installed. In addition, Georgetown University Medical Center, Department of Radiology is equipped with two Fuji 9000 image reader-Laser imager with a HI-C 654 workstation.

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3.1 Experiment with the NASA Advanced Communications Technology Satellite

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A. Significance to the Military MDIS Project and Executive Summary

NASA has developed the ACTS satellite to test the applications and usefulness of high performance wide area networks. The US military has been testing the use of the ACTS through several experiments simulating battlefield scenario. In order to test the usefulness of this type of technology in the civilian medical field, Georgetown has undertaken several efforts to use and test the ACTS satellite. During the first National Forum Conference held in Washington, DC in March 1995, Georgetown undertook a great effort to test the NASA ACTS satellite between the conference site in McLean, VA and the Tripler Army Medical Center (TAMC) in Honolulu, HI. This section reports the results obtained and experience of the Georgetown University Medical Center with the ACTS (Advanced Communication Technology Satellite).

B. Introduction

Along with TAMC, GUMC conducted an experiment to evaluate the role of the T1-VSAT (Very Small Aperture Terminal) mode of operation of the ACTS satellite. The baseband processor mode used in conjunction with a T1-VSAT earth station provides speeds of up to 1.5 Mbps The other mode of operation is the Microwave Switch Matrix (MSM) mode which will make OC-3 (155 Mbps) available. Georgetown is also undertaking efforts in that field and this is reported elsewhere.

This experiment tested the use of the ACTS satellite under new conditions. NASA's experimental satellite operates with fixed and hopping beam antennas covering the continental US and one steerable beam antenna covering Hawaii. The important aspect of this ACTS project is that it is one of the few viable alternatives to access remote, isolated regions, such as Hawaii, with speeds equal or higher than T1 since fiber optic communications are not widely available there.

The experiment entailed a period of test simulations conducted at Mitre, Bedford, MA as well as a series of loopback tests before the actual demonstration. This paper reports on the simulation test results and conclusions, and the demonstration test results including the Phase One tests at NASA Lewis and the Phase Two at TAMC.

C. The T1-VSAT Experiment

C.1 Objective.

The teleradiology/telemedicine experiment was set up to test the communication infrastructure support. This experiment linked a conference site at the Hilton in McLean, VA to the Tripler Army Medical Center (TAMC) for transmission of Magnetic Resonance (MR) images. This was planned during the National Forum: Military Telemedicine On-Line Today: Research, Practice and

Opportunities conference in Washington, DC on March 27-29, 1995 which attracted more than 1,000 DoD participants. The goal was to test the feasibility of medical image transmission as well as video, voice and data over the NASA ACTS at T1-VSAT rates through our medical image workstation.

C.2 Clinical Relevance.

The usefulness of having a multimedia teleradiology workstation is to allow the physician not only to view the patient images such as x-rays, MRs and CTs but also to view and talk to the patient while interacting and examining him/her, exchange with the referring physician images/comments or previous data/images over the white board and annotating them. This would also allow the receiving physician to monitor other patient related data such as EKGs through a document camera or even heart beats through a remote stethoscope

C.3 Simulation Test Results.

The initial simulation tests were conducted at Mitre, Bedford where two of our multimedia KLT Telecom workstations were installed and tested. The simulation tests used a satellite link simulator provided data for characterizing the performance of the medical imaging workstation under conditions of different channel data rates and link bit error rates (BERs). The performance measures were:

* The ability of the system to establish the connection
* Maintain local and end-to-end synchronization
* The quality of the transmitted image
* Efficiency of the file transfers

The same hardware configuration was used for all tests; the parameters for the ViewShare multimedia videoconferencing software and the channel service units (CSUs) were modified as necessary.

The two phases of the testing involved measurements of the file transfer efficiency achieved with the ViewShare software as well as a qualitative evaluation of the video quality for different channel data and error rates. The test data would identify any potential problem areas and characterize the performance of the system prior to its being connected to the ACTS terminal. Table 1 summarizes the tests results. The entries in the transfer time and efficiency columns are average values based on approximately four runs for each case. There were only small variations in the results among the runs for a given set of parameters. Note that the minimum delay used in the tabulated results is 10ms. This is due to the fact that it was not possible to achieve synchronization for the entire system when the 0 ms delay was used.

The transfer times are in minutes and seconds. The transfer time was derived by obtaining the maximum value of the elapsed time counter of the ViewShare application reached during the transfer of a single file (647114 bytes). It should be noted that the transfer efficiencies reported in Table 1 were computed using a 64 Kbps data rate regardless of the configured channel data rate in the ViewShare setup and the CSU/DSU configuration. This is due to software and hardware design limitations. This is compliant with H.320 standard that allocates one 64 Kbps channel for audio data and the remaining 64 Kbps channels of the video conference channel to the video data. Some informal test were conducted in which the channel data rate was changed between 128 Kbps, 192 Kbps, and 256 Kbps, with all other parameters kept constant, for which the average transfer times were 2'22", 2'47", and 2'15" respectively. For each data rate, the transfer times were distributed in a small range around the corresponding average values. It was not clear what accounts for the discrepancies in transfer rates given that the actual transfer rates are 64Kbps

independent of the channel data rate.

Table 1

Simulation Test Results

Delay (ms)	Error Number	Error Frequency	Transfer Time	Efficiency
10	0	1x108	1'46"	75.5
250	0	1x108	2'03"	65.8
250	4	1x106	2'03"	65.8
250	10	1x105	2'03"	65.8

C.4 Demonstration Test Results.

A Phase One test was established from NASA Lewis to Mitre in Reston VA where a T1-VSAT earth station terminal resides. A loopback test was successfully achieved. During the initial over-the-air tests, there was a timing synchronization deficiency in the medical workstations. The workstations could establish connections at data rates up to 384 Kbps when working with the ACTS system.

C.5 System Configuration and Set-up.

The Phase Two demonstration was undertaken during the conference. The configuration set-up in Figure 2 shows how the link was made from the McLean Hilton site to the earth station located at the Mitre site in Reston, VA through a dedicated T1 line. From there the connection was made to the ACTS through the T1-VSAT earth station to the TAMC where a T1-VSAT earth station is located on-site. The images were captured from the MR machine through the network LAN at TAMC and a file transfer protocol (FTP) . An alternative to this was provided which was to retrieve the images through an external hard-drive connected directly to the medical workstation.

The National Forum Conference Link-up

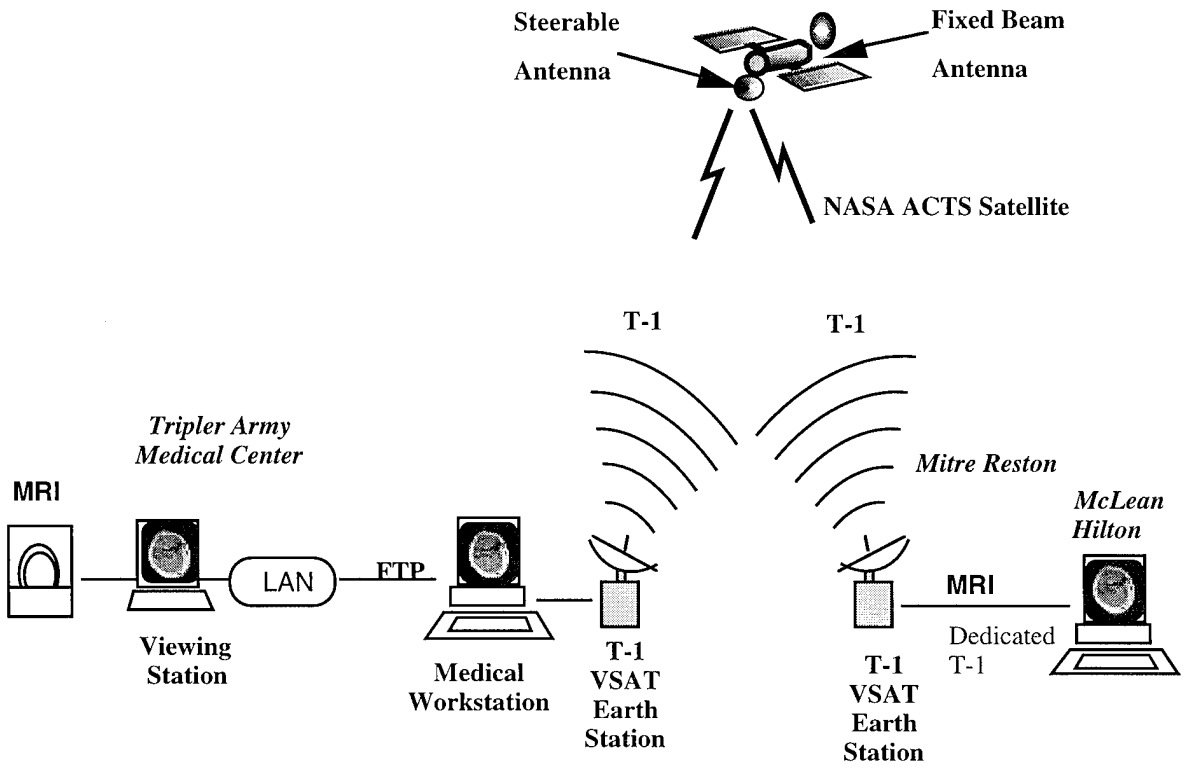
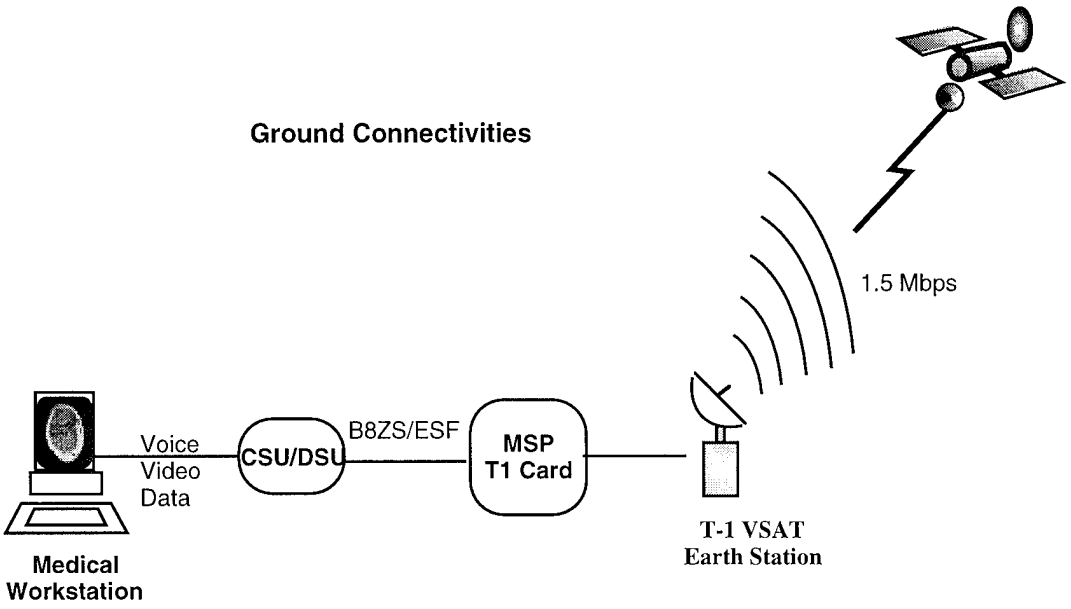


Figure 2

Detailed ground connectivities and equipment used are shown in Figure 3. A Channel Service Unit/Data Service Unit (CSU/DSU) at the McLean Hilton in McLean, VA was connected to the T1 line with Binary 8 Zero Substitution and Extended Super Frame Coding (B8ZS/ESF) to the Modular Switching Peripheral (MSP) T1 Card at the Earth Station location at Mitre in Reston, VA. The same connectivities were repeated at the Hawaii end except for the T1 line since the Earth Station was located on-site. The medical workstation, known as a ViewShare model, was connected through a high density interface and an RS449 cable to the TyLink ONS400 CSU/DSU.



CSU/DSU: Channel Service Unit/Data Service Unit
B8ZS/ESF: Binary 8 Zero/Extended Super Frame
MSP: Modular Switching Peripheral

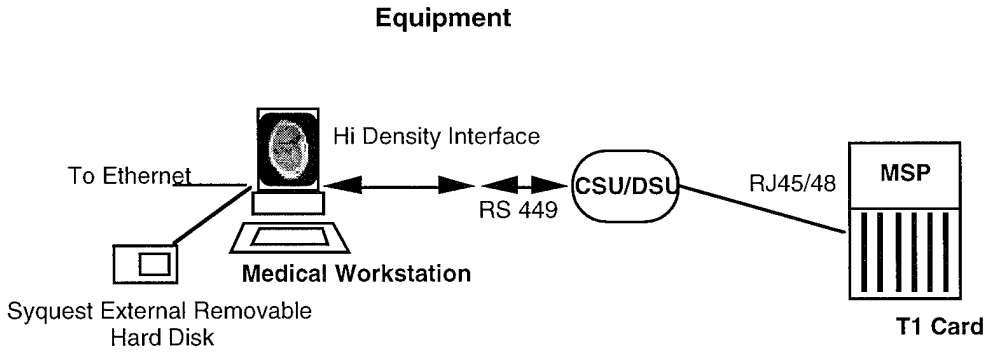


Figure 3

D. Conclusion

The experiment allowed the testing of the T1-VSAT between the Washington, DC area and the Tripler Army Medical Center during the National Forum Conference. Some of the lessons that were learned will help a lot in future demonstrations or tests of the T1-VSAT mode of operation of the satellite. While the satellite earth station terminal failed at TAMC one day before the demonstration because of an internal power amplifier failure, the experiment had several positive aspects and challenges that lay ahead. Some of those challenges related to Standard Compliance

and Proprietary Systems. For this experiment, images transmitted were MRI data which usually constitutes a much smaller matrix than x-rays. The data channel limitation is due to the fact that video conferencing standards such as H.320 only allow for 64 Kbps channel for data file transfer no matter how wide the available bandwidth is. Therefore, while one can construct additional data channels to overcome this problem, the underlying problem becomes one of a trade off between open-system architecture and proprietary systems. Also System Redundancy was an issue. The internal power amplifier is most vulnerable piece of equipment for the ACTS satellite. Unfortunately, with the outgrowth of the NASA experiment very few back ups are available for redundancy. This is an essential feature to ensure experiment support and routine clinical support. Finally. it is essential that the type of signaling standard(Most often either USOC or AT&T) at each interface be known. If different standards are in use, adapters will be required.

In general, the experiment was a success because our design for the system has shown to be operational, and with minor modifications, full T1 rates can be achieved in order to transmit higher bandwidth intensive applications such as teleradiology of chest x-rays. The redundancy we provided on our end of system in terms of image acquisition sources proved to be very useful since imaging format problems and network configuration issues were avoided.

3.2 Progress in R&D to Develop Image Capable Telemedicine Network

Investigators: Darmadi Komo, Walid G. Tohme, PhD and Seong K. Mun, PhD

A. Significance to the Military MDIS Project and Executive Summary

Telemedicine network as a part of the MDIS telemedicine program has been used for many years in military sites around the country and other parts of the world. One MDIS program is the enhancement in telemedicine applications to incorporate an image capable MDIS telemedicine network. The Imaging Science and Information Systems (ISIS) Center of the Georgetown University Medical Center (GUMC) has incorporated a powerful and multi-platform, yet simple medical image diagnosis software called Osiris from The University of Geneva into a commercially available two-way video conferencing application software called ViewShare from KLT Telecom, Inc. The result of the combination of these two applications is a prototype of an integrated image capable telemedicine application software package which allows both video conferencing and medical diagnosis operation on one single application. We believe that this integration can be a possible solution for the MDIS image capable telemedicine network.

B. Introduction

Telemedicine can be explained as the delivery of medical care to patients from one or more remote sites by combining communication links with medical expertise. It should provide patients and practitioners access to primary of special care at remote sites thereby increasing the quality of medical care while minimizing the costs.

Telemedicine applications ranging from simple telephone calls from patients to primary physicians to the more sophisticated remote patients' diagnosis. At the ISIS Center of GUMC, in order to enhance telemedicine applications to remote patients' diagnosis we design and incorporate two software applications: Osiris, medical image diagnosis software and ViewShare, video conferencing software into an image capable telemedicine package.

B.1 Osiris.

Osiris software is designed as a general medical image manipulation and analysis software. The design is mainly based on the following criteria:

- Portability
- Extendibility
- Suitability

Osiris is designed to deal with images provided by any type of digital imaging modality to allow physicians to easily display and manipulate images from different imaging sources using a single generic software program.

Portability ensures the software implementation on different types of computers and workstations. Thus, the user can work in the same way, with exactly the same graphical user interface, on different stations. The current version of Osiris runs on Unix workstations, Macintosh, and IBM PC compatible.

Below is a summary of features and tools available from Osiris software:

1. Features:
   - General digital medical image manipulation and analysis software
   - Handle single or sets of images
   - Handle images from all imaging modalities

- Available on Unix, Macintosh, and PC/Windows environment
- Standard image file format PAPYRUS and DICOM
- Developed in C++
- Easy development and integration of new analysis and processing tools

2. Tools:
   - Image manipulation tools: stack/tile/movie modes, zooming and panning, windowing, rotation, flipping, reordering images
   - Image processing tools: filters, isocontours, multiplanar reconstruction, segmentation
   - Graphical overlays: text annotations, region of interest, caliper, angle, profiler
   - Standard analysis tools: coordinates, angles and local intensity measurement, region of interests with both display of statistical data as well as histogram

B.2 ViewShare.

ViewShare is the video conferencing system that integrates existing hardware, programs, and networks into the most user-friendly system. ViewShare provides the functions of larger, more expensive systems. It implements the latest international standards, insuring maximum global interoperability with other systems (Figure 1).

In terms of hardware and networking, ViewShare uses IBM PC compatible computers to enable one person or many people video conferencing with clear sound and picture. It is a world face-to-face conferencing which operates over a variety of telecommunications medium including:

- LAN
- Modem
- ISDN
- Switch-56
- Fractional T1
- Full T1

ViewShare permits an instantaneous exchange of images with some sharing of text, graphics, annotations, sketches, and charts. In overall, ViewShare has the following features:

- Slide album presentation made simple:
  Slide folders provides an easy way to arrange and keep track of images because images can be combined into slide folders.
- Captioned, floating tool bars during conference:
  When user is having trouble determining which button to push to perform certain function, moving the mouse cursor onto the button will display the function for the button.
- Synchronism of images:
  Image will be display on both workstations. In order to let users at both workstations have the same viewing positions at the image, there is a function in ViewShare to perform synchronism of the image.
- Remote controlled cameras:
  User at one workstation can control the movement of other workstation's camera while in videoconferencing session.
- Unlimited whiteboards for drawing, notes:
  For sharing images, there is a multi function whiteboard with unlimited size, drawing, or notes.
- PowerPoint and Harvard Graphics integrated into system:
- ViewShare is designed to import files from both PowerPoint and Harvard Graphics software.
- Panning of large images and a total view mode:
  If the image is too big to fit into a default screen configuration, user can select a total view mode which gives a whole screen of image with navigation capability such as scroll and panning.

plus the following:

- Ported for scanner or any visual presenter
- Ability for each side to adjust picture and sound
- Near full motion video with user able to balance resolution and motion
- Screen capture of images on screen for future use
- Full screen video
- Varied configuration of screen
- Printer interface for instant printing of on-screen images
- Zooming in on (magnifying) image or text
- Choice of font sizes
- Color printing from computer
- Self explanatory software

C. Process of Integration

There are a lot of issues to be solved between Osiris and ViewShare. We divide those issues into two aspects of consideration and will be addresses separately below:

C.1 Software Consideration.

To integrate two software applications into one application requires careful planning and considerations about the integration specifications. This means that every compatibility issues between two software have to be solved before the integration process begins.

The main issue to consider in terms of compatibility is the running platform. Osiris is a multi platform software application that runs on Macintosh, PC with Windows 3.x and Windows NT, and Unix workstations while ViewShare runs only on PC with Windows 3.1x. So it is very reasonable to use the common platform that both software support, PC with Windows 3.x.

In terms of software coding structure, whether it is a functional driven, procedural driven, or object-oriented, is also a major consideration. Fortunately, both Osiris and ViewShare are using the same C++ object-oriented structure in building their classes including member functions and data. In the process of software code merging. Osiris classes are melted and combined with ViewShare classes to form integrated classes which has both communication and medical image diagnosis functionalities. In software engineering terminology, this is done by incorporating all classes, with their member functions and data into ViewShare classes. In other words, we can imagine that ViewShare is a general purpose communication part of the final software and Osiris is a specific medical image diagnosis part of the final software. When Osiris is integrated into ViewShare it means that we add medical image diagnosis capabilities of Osiris into the communication capabilities of ViewShare to form a final software which has both communication and medical image diagnosis capabilities (Figure 2).

There are some redundancies between two software features, such as digital glass magnifier, text annotations, region of interest annotations, etc. To solve this issue, an approach is taken to incorporate the features from one software which have more functionalities and discard the same features from the other software that has less functionalities. Obviously, the advantage of using the approach is a more powerful final software which has the combination of best features taken from Osiris and ViewShare.

File format for medical images is also an issue. Osiris can read standard medical image formats (Papyrus2, Papyrus3, and DICOM 3) file format whereas ViewShare can read commercial non standard medical image formats (TIFF, JPEG, EPS, etc.). In order to incorporate some degree of backward compatibility to both Osiris and ViewShare, the software will allow file formats from Osiris and ViewShare. This will greatly increase the flexibility of the software in terms of its file format capability.

C.2 Performance Consideration. Performance of the new software compared to the original software before the integration are determined based on the following criteria and will be discussed separately:

- Input and Output Image Format
- Speed of File Transmission Over The Network
- Speed of Image Loading

- Image Tools
- Image Optimization Capability
- Ease of Use

From the previous section we know that the new software will be able to read file format from both Osiris and ViewShare. Thus, new software will have greater bandwidth in terms of input and output file format than either Osiris or ViewShare.

File transmission over the network only depends on the communication software, ViewShare. Integrating Osiris into ViewShare code does not add any complexity in ViewShare code in terms of its communications functionalities. So the speed of file transmission over the network is the same as the that of ViewShare.

When Osiris loads an image, it will perform the basic image file parameter retrieval (image format, image size, image dimension) and advanced image file parameter retrieval and calculation (file integrity verification, image window and level, image minimum and maximum pixel's value, patient demographic and clinical information, regions of interest etc.). In contrast, when ViewShare loads an image, it will only perform the basic image file parameter retrieval. Based on that difference, the new software will need longer time to load an image compare to the same operation on the same image with ViewShare. The new software will, however, use the same amount of time in image loading as that with Osiris.

As we mentioned in the previous section about the redundancies of features from both Osiris and ViewShare. Since the functionalities of the new software are incorporated from the combination of the best feature of Osiris and ViewShare, it is reasonable that the new software has better features than Osiris and ViewShare.

ViewShare is a merely video conferencing software and does not include any image optimization features (image window and level, brightness and contrast, image flip and rotate, etc.). Incorporating these features from Osiris really enhance the capability in terms of image optimization.

Both software runs on Windows 3.x and share the same look and feel of Windows 3.x user interface in some common dialog operations such as file open, file save, print dialog, etc. Thus, it will be a benefit for users who are familiar with these Windows 3.x operation because they do not have to learn a new set of user interface and be familiar with it.

D. Results

In general, integration of Osiris and ViewShare into an image capable telemedicine application enhance the capability of existing video conferencing software. This will allow remote patients diagnosis by primary physicians thereby increasing the quality of patient care while minimizing transportation costs for both patients and physicians. Also, with this new features of telemedicine application running on PC platform it proves that image capable telemedicine solutions on PC platform is possible and might be a potential investment strategy in the near future especially for small and remote sites where financial issue is always the main bottleneck of implementing new facilities.

E. Conclusion

ISIS Center of GUMC has integrated medical image diagnosis software and video conferencing software into an image capable telemedicine solution on PC platform to enhance the current telemedicine applications as part of improving MDIS program. Several operations especially on the speed of file loading, image resolution, features enhancement, features addition, etc.. is currently being pursued and improved following the review of the system's overall capabilities and performance.

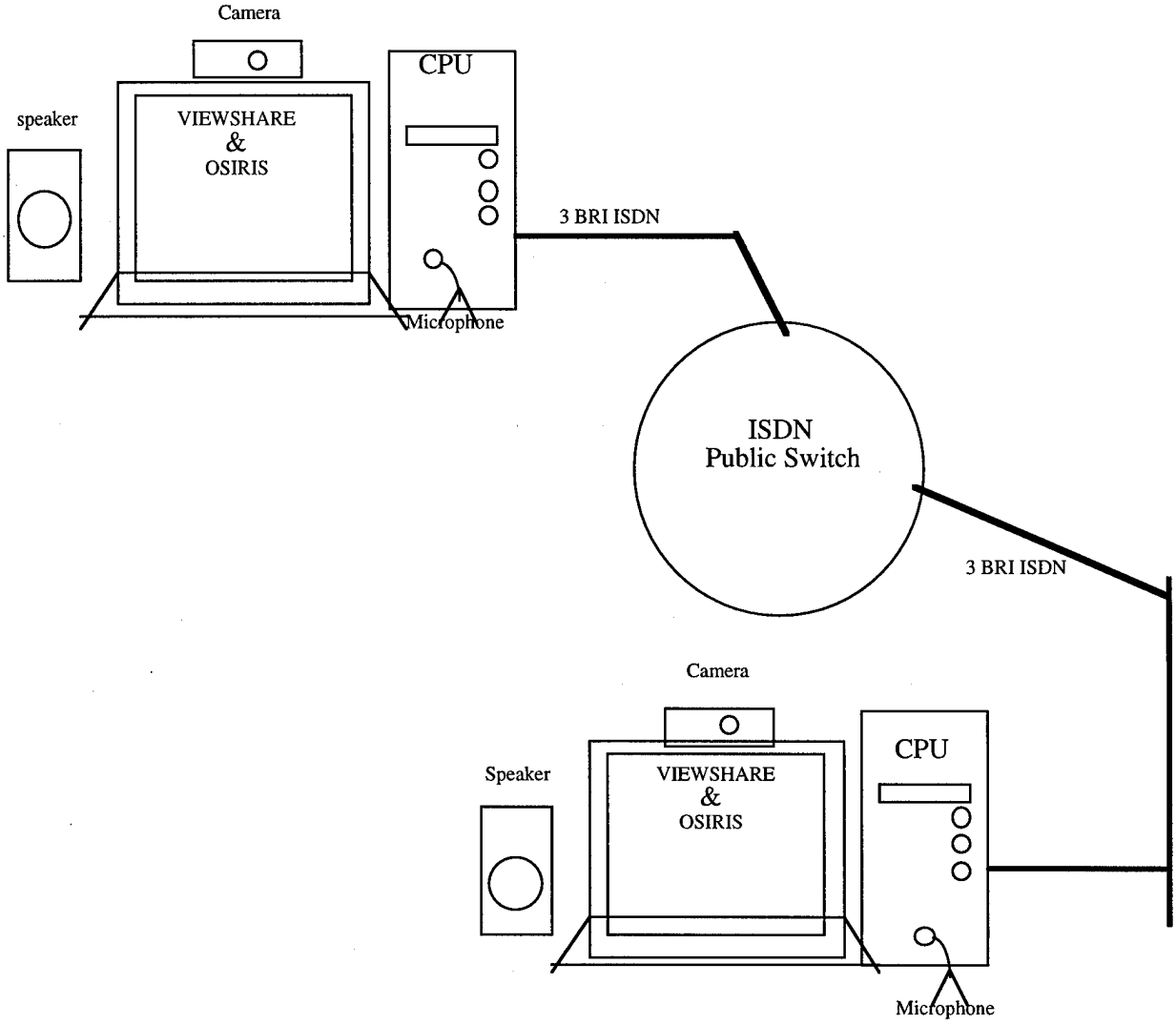


Figure 1 Hardware Diagram of ViewShare Videoconferencing System with Integrated Osiris Image Analysis Software

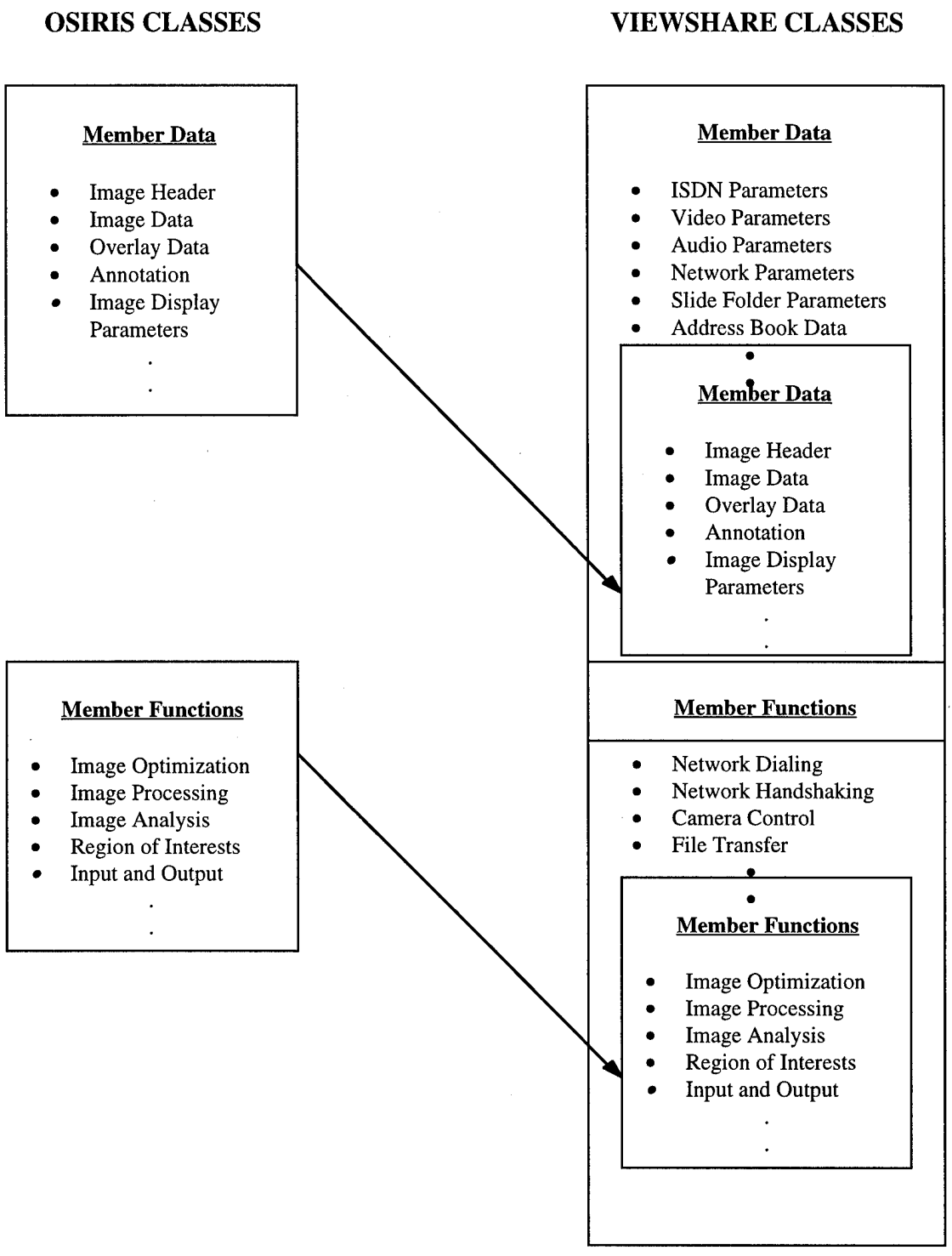


Figure 2 Osiris and ViewShare Classes Integration

3.3 Designing a Common Telemedicine Evaluation Platform for Three Different Medical Applications

Investigators: Walid G. Tohme, PhD, Wendelin S. Hayes, DO, Seong K. Mun, PhD, Darmadi Komo and Marion C. Meissner

A. Significance to the Military MDIS Project and Executive Summary

Telemedicine is an attractive technology that can be useful for the military. It promises a number of advantages over conventional means of health care. The technology of telemedicine has not been studied as thoroughly as that of MDIS. This report focuses on the development of technical requirements for several applications of telemedicine.

This project investigates the design and technical efficacy of a common platform for three different medical applications. This platform will be used for each project with different configurations depending on the clinical needs. The efficacy of a common Telemedicine platform has not been evaluated in the literature. The first application, with the Department of Surgery, Division of Urology, tests the utility of a telemedicine platform including radiology images for a surgical stone disease consultation service from an off-site location in West Virginia. The second application, with the Department of Internal Medicine, Division of Clinical Pharmacology, investigates the usefulness of Telemedicine when used for a clinical pharmacology consultation service from an off-site location. The third application, with the Department of Pediatrics, will test telemedicine for clinical subspecialty pediatrics consultation service from an off-site location in Virginia as well as allowing the resident to 'attend' grand rounds at GUMC.

B. Introduction

Telemedicine has many definitions and can be viewed as providing medicine from a distance. It should provide patients and practitioners located at remote sites the possibility to access primary or specialty care thereby increasing the quality of care while minimizing costs. Telemedicine takes advantage of the tremendous growth in the telecommunications industry.

Telemedicine is not new. It started in the late 1950s and continued with sporadic implementations until the mid 1970s. Most projects did not continue after the initial funding ended. However, there has been a clear rebirth of telemedicine since the early 1990s. Today most video conferencing vendors concentrate on business applications, but there has been a growing interest in health care and telemedicine applications in particular.

Most definitions of telemedicine include teleradiology but some of the underlying technologies used in both applications are different. Most workstations that combine both video conferencing with digitized film transmission are based on high end workstations and are not necessarily cost effective. At the ISIS Center of GUMC, we are testing a common PC platform for telemedicine applications used for three different medical specialties with the Clinical Pharmacology Division within the Department of Medicine, the Urology Division within the Department of Surgery and the Pediatrics Department. Those are the first three projects among a number of forthcoming ones with various clinical departments at GUMC.

C. The Clinical Applications

C.1 Multimedia Teleradiology with the Department of Surgery - Urology Division.

The first application tests the utility of telemedicine combined with teleradiology for a surgical stone disease consultation service from an off site location in City Hospital in Martinsburg, West Virginia [Figure 1]. We refer to this as multimedia teleradiology as the physician not only has access to the patient's images, but also can view and discuss the case with the referring physician as well as the patient at the remote end. While the physician in West Virginia provides initial patient evaluation, the urologist at GUMC makes a clinical decision for treatment based on the consultation through Telemedicine. The goal is to investigate whether having access to the patient's x-rays as well as interacting with him/her through the system will help the urologist in making a clinical decision for treatment through telemedicine. This protocol will undergo evaluation through satisfaction surveys of the patient, consultant and the referring urologist. In addition, those patients who are referred to GUMC following the telemedicine consultation for treatment of their stone disease will bring their original radiographs to be reviewed by the urologist at GUMC and compared to his original interpretation utilizing telemedicine.

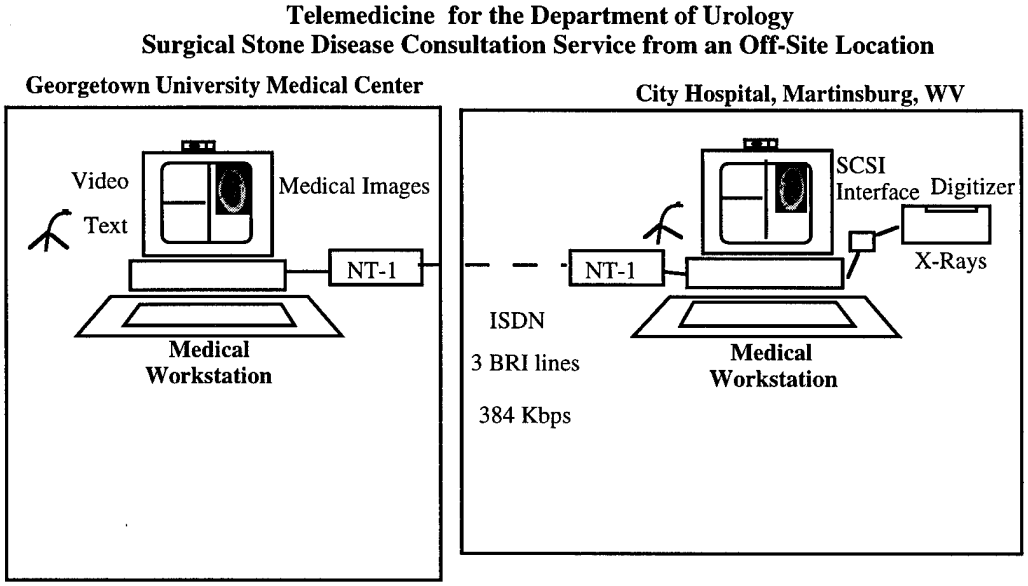


Figure 1

C.2 Tele-Proctoring with the Department of Medicine - Clinical Pharmacology Division.

The second application investigates the usefulness of telemedicine in the Department of Medicine by establishing a clinical pharmacology consultation service from an off-site location through Telemedicine [Figure 2]. The need is based on the increasing challenge of maintaining a high quality education in the principles of rational therapeutic decision making. This is especially difficult as training programs move toward multiple ambulatory care sites. This is why new educational models are needed. Tele-proctoring to multiple sites potentially increases faculty efficiency and emerges as a promising new models. Here the clinical consultation occurs between the consultant clinician of the Department of Clinical Pharmacology located at a remote clinic and the internal medicine resident as well as the medical student. The goal is to evaluate the impact of telemedicine on the medical decision making process for residency training. Tele-proctoring refers to the fact that the physician is directing the resident or the student from an off-site location on how to proceed with the clinical care of the patient. The consulting physician also has the opportunity to discuss the clinical case and evaluate the patient through the telemedicine system. This project will

require evaluation of patient's reaction to various drug therapies which are often manifested in various skin reactions. In this protocol, this will be evaluated with the use of a dermascope. This will allow for magnification of the suspicious area and will aid the consultant in their differential diagnosis. Additionally, the use of a remote stethoscope will be a dedicated part of this evaluation as both the cardiac and pulmonary status assessment of the patient is needed for appropriate evaluation. Radiographs will be digitized prior to the consultation as clinically indicated.

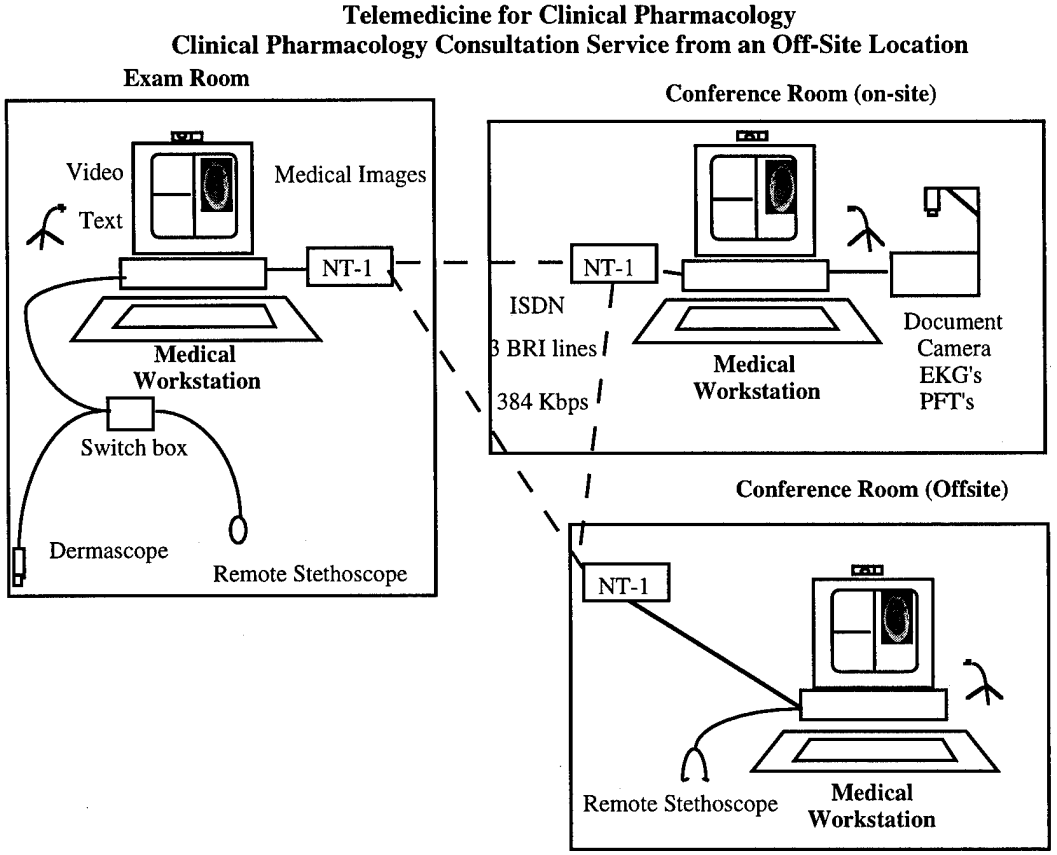


Figure 2

C.3 Tele-Education with the Department of Pediatrics.

The third application will test telemedicine in tele-education for clinical subspecialty pediatrics consultation service from an off-site location [Figure 3]. The off-site hospital staff based in Arlington, VA attends grand rounds at Georgetown University Hospital through the telemedicine system. Also selected patients at the remote site are examined and discussed by the experts present at GUMC through the telemedicine system for diagnosis, treatment and for assessing whether or not transfer of the patient is required for specific patient care. At the present time, the pediatric specialists at GUMC evaluate the pediatric patient either at Arlington Hospital or the patient is transferred to GUMC based on the recommendation of the pediatric resident and general pediatrician at Arlington Hospital. Through telemedicine, the specialist will meet and examine the patient and review radiographs and documents as indicated.

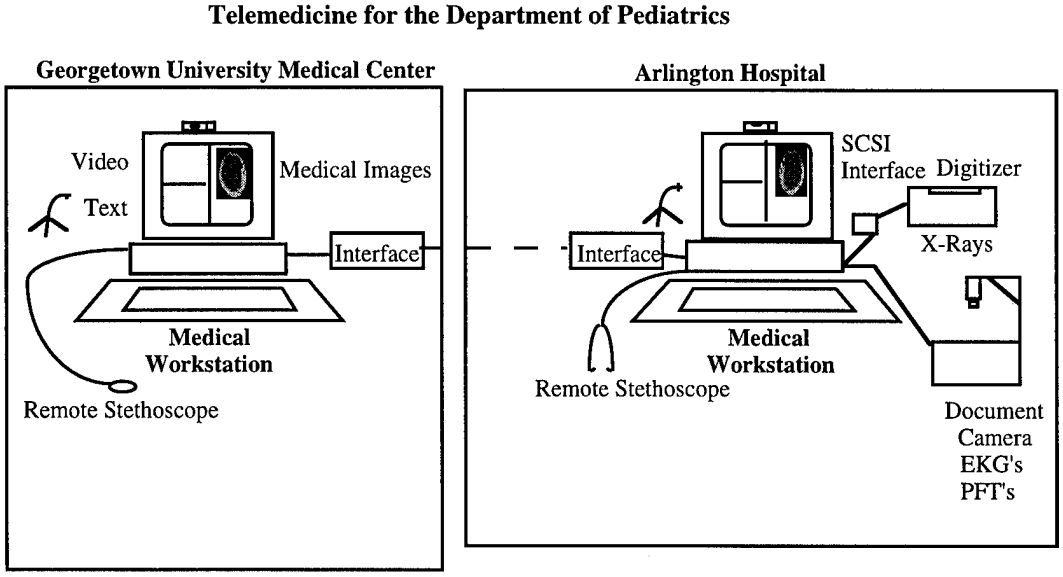


Figure 3

D. Defining the Focus of the Evaluation Studies

Evaluation studies can encompass many different aspects of technology assessment. The scope of the studies cannot be such that one study covers every single aspect of this multi-disciplinary effort. Each project is unique in that it looks at some aspects not necessarily shared by others, yet there is an underlying commonality for all the projects. This is why we have developed a living multidimensional model or matrix that will include the aspects of each effort within a certain dimension (Figure 4, 5). This matrix is likely to grow, expand and be transformed as new projects are added or new dimensions are examined. For the present time, we have selected five dimension to look at for each of the three projects under consideration.

Communication Paths: The West Virginia project is geared towards specialist to subspecialist consultation where a urologist in West Virginia is consulting with a specialist in lithotripsy. The Clinical Pharmacology project involves communication between a specialist and a resident or medical student. The Pediatrics projects looks at an emergency room physician or resident consulting with a pediatric emergency room specialist at Georgetown. The communication paths are therefore different for each project and our focus will be to determine how the communication paths for each of those projects are changing.

Project scope: (inter-state, inter- or intrahospital) This implies that we are looking at inherently different concerns. For example the interstate project will tend to look at credentialing and licensing problems which of course are not a concern for intrahospital projects.

Goal: The goal for each project is different. Consultation for treatment is the main goal for West Virginia while education and teaching is the main goal for Clinical Pharmacology. Trauma care is the main goal for the third project.

Impact of interest: The impact of interest include outcomes that need to be studied. The impact on the organization as well as financial considerations such as reduction in the cost of treatment through avoided transportation (in the case of West Virginia and Arlington) are important for some projects. On the other hand, the Clinical Pharmacology project is not interested in financial consideration as much as the utility of a multi-site educational effort. Of course the impact on the

medical decision making process is of interest to all the projects. However, changes in referral patterns are most relevant in the West Virginia project.

Operational Setting: The main operational setting for each project will differ whether it is mainly consultation with occasional emergency cases (Urology), mainly scheduled consultation (Clinical Pharmacology) or mainly emergency room settings (Pediatrics).

Focus of Evaluation Studies

Clinical Application	Communication Paths	Project Scope	Goal	Impact of Interest	Operational Setting
Urology	Specialist -Subspecialist	Inter-State	Consultation	Organizational Financial Referral Patterns Treatment Options	Scheduled Consultation Emergency
Clinical Pharmacology	Specialist-Resident/ Medical Student	Intra-Hospital	Teaching	Educational Multi-Site	Scheduled Consultation
Pediatrics	ER Physician-SubSpecialist	Inter-Hospital	Trauma Care	Organizational Clinical Financial	Emergency

Figure 4

E. Defining the Technical Requirements for Clinical Applications

Telemedicine technology has been based on teleconferencing technologies that revolve around analog to digital converters or codecs (coder/decoder) for transmission. Video codecs have revolutionized the video technology and its transmission because they allow for video compression. Without compression, video transmission would require around 90 Mbps of bandwidth to transmit the signal while today compression techniques allow video to be transmitted over significantly lower speeds down to 56 Kbps.

Varying technical requirements are expected to support different clinical applications. For example, telepathology, teledermatology, teleradiology, telepsychiatry and others will have different requirements. While there will be large area of common requirements for many applications, each specialty applications will have unique requirements.

Our telemedicine platform is based on a 486-PC platform with 21 inch Super Video Graphics Array (SVGA) monitor, 16 Megabytes of Random Access Memory (RAM), 1 Gigabyte hard drive

and an audio/video board as well as an integrated Inverse Multiplexor (IMUX) that is needed when more than one Integrated Services Digital Network (ISDN) line are present. For each clinical application, we are testing the same platform but with different configurations.

Each clinical applications will require different technical specifications and the challenge is to design a platform that will be able to integrate all of those needs through expansion of its basic configuration. Figure 5 details the different technical requirements based on the three clinical applications.

E.1 Surgical Stone Disease Technical Needs.

When patients are seen in Martinsburg Hospital in West Virginia, urologists located off-site at GUMC need to look at their radiographs. Digitized urology radiographs require 1024x1024x10 bits of resolution. However, commercially available codecs do not allow the full resolution to be displayed on the monitors. The images will therefore be initially acquired as radiographs, digitized through a digitizer and through a SCSI interface board transferred to the medical workstation where they will be read in TIFF format [Figure 1]. Although we have not established the diagnostic accuracy of such a process, a preliminary review by our radiologists indicated that this provides adequate resolution if images are used for consultation purpose for evaluation of renal stone disease.

Previous efforts have been reported that document teleradiology for PC applications. These were not however using urology images. Teleradiology for specific urology applications has been tested but not for PC applications. Furthermore, neither of those efforts included the video portion of the communication since they concentrated on strict transmission of digitized images. This added feature will help us evaluate the utility of full telemedicine consultation when dealing with remote lithotripsy consultation.

E.2 Clinical Pharmacology Technical Needs.

One need specific to clinical pharmacology is the ability for the clinical attendings to assess the patient's skin reaction to a specific drug therapy. In such a case, a dermascope is added [Figure 2] that provides the ability to view to the third cell layer. However, for most clinical pharmacology applications, the physician located at the remote site will only need to look at the general appearance of the patient's skin such as observing the distribution of a skin rash over the entire body. Therefore, in those cases, the level of detail offered by commercially available dermascopes may not be needed. This is a case where matching the level of technology to the clinical needs is very important to make telemedicine cost-effective.

Furthermore, internists need to assess the patient's cardiac status. Remote stethoscopes hooked to the codec were not judged adequate by the clinicians. This shortcoming is due to the fact that codecs available on the market handle a range of frequencies much smaller than the frequency spectrum of the human ear (25 to 16,000 Hz for codecs vs. 50 to 7,000 Hz for the human ear). One way around this problem is to allocate a certain portion of the bandwidth so that those frequencies can be carried independently from the primary codec using an audio analog/digital encoder/decoder and requiring 48 to 128 Kbps of bandwidth just for that purpose. If T-1 (1.5 Mbps) capability is available, this would not affect the quality of the transmission. However, stripping away 128 Kbps from a 3-BRI line (Basic Rate ISDN), providing 384 Kbps, might deteriorate image quality and should be considered carefully.

E.3 Pediatric Department Technical Needs.

The third application linking pediatric residents at Arlington Hospital to Georgetown Hospital will require high quality motion video since the physicians can gain a considerable amount of information by watching the child's motion. This implies the possibility of having to add a T1 line instead of 3 BRI ISDN in order to increase video resolution. Physicians need to look at chest x-rays of the children so the resolution requirements of the digital images will need to be higher than

that of urology for example. Also a remote stethoscope will be needed to assess the child's cardiac status as well as pathology slides. Finally, grand rounds can be integrated into the system through the addition of a large screen monitor for grand rounds. This does not represent any technical difficulty since most systems have NTSC (National Television Standards Committee) outputs that can be readily connected to a large projection screen or TV monitor.

Primary Technical Requirements for Clinical Applications

Clinical Application	Motion Video	Still Video	Digital Images	Integration w/ Text, Graphics	Audio
Urology	Consultation	Snapshot	Mod Res	Yes	Voice
Clinical Pharmacology	Consultation	Dermatology	Lo Res	Yes	Voice + Remote Steth
Pediatrics	Evaluation	Pathology Dermatology	Hi Res	Yes	Voice + Remote Steth

Figure 5

F. Conclusion

This project is a new concept in the design of telemedicine systems. Through the use of a common platform, three different medical applications are being undertaken; each one with different clinical requirements. The challenge is to be able to design a system that responds to the different clinical needs of the applications by incorporating new technologies into systems but keeping the same common platform. Varying technical requirements are expected to support different clinical applications. For example, telepathology, teledermatology, teleradiology, telepsychiatry and others will have different requirements. While there will be large area of common requirements for many applications, each specialty applications will have its unique requirements. We are testing the different technical parameters in order to develop technical specifications for a global telemedicine system of the future.

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4.1 Telepathology Over the Internet

Investigators: Al M. Elsayed, MD, Armed Forces Institute of Pathology, U.S.A.
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A. Significance to the Military MDIS Project and Executive Summary

Pathology is a specialty area with many subspecialties. There is a great need for expert consultation in pathology. The Armed Forces Institute of Pathology (AFIP) has been a world leader in pathology consultation using conventional means of glass slides and paper. In the military, there are many medium size medical treatment facilities that can use expert pathology consultation. This project aims to develop low cost telepathology capabilities using Internet, in which there is communication no cost.

Georgetown has been involved in developing digital pathology research under the guidance of Dr. Al Elsayed of the AFIP. The AFIP has developed a prototype telepathology capability over the Internet in collaboration with the Japan Cancer Center, Oxford University and Nikon Corporation in Japan. Recently Georgetown made an arrangement to have the Chief Engineer of the project from Nikon Corporation come to Georgetown for one year to implement an expanded version of telepathology capability based at Georgetown.

The Phase-1 network will link AFIP, Wright Paterson Medical Center, Japan Cancer Center and Oxford University. It is expected that once the system is operational, experimental services will be extended to DoD and other sites. This report describes operation protocol and technical capabilities of a next generation telepathology system that the AFIP developed and that Georgetown plans to implement it.

B. Operating Procedures for Telepathology

The purpose of this Global Standard Operating Procedure for Telepathology (GSOP-TP) is to establish a systematic procedure for receipt, accession and processing of mutual case exchange/consultation between international centers via telepathology. These guidelines have emanated from the collective experience of our centers and are intended as recommendations for information exchange in telepathology.

B.1 Receipt and acceptance of cases:

a. All case acceptance is dependent upon mutual agreements between consultation centers.

b. The contributor will initially telephone the receiving center to coordinate the initiation of the process, and will thereafter telefax the following information:

Patient identifier (e.g. Name, Hospital Number, Surgical Pathology Number, etc.)
Nature of specimen
Site of lesion

Preliminary diagnosis
Sending laboratory name.

c. In addition, the following information should also be submitted if available:

Clinical history of patient
A copy of pathology report
Any additional remarks and/or requests.

B.2 Accessioning of cases:

a. Upon receipt of the contributor and patient information by telefax, the receiving center will accession these cases in accordance with its own standard operating procedure. The generated accession number will be communicated back to the contributor.

b. Upon receipt of the images, the receiving center will arrange for professional pathology review.

c. If deficiencies are detected, the contributor will be contacted and asked to make corrections.

d. All images will be adequately labeled, either as a packaged case or individually. If individually labeled, the images will be labeled according to the scheme below or in a similar fashion.

"entire_1" will show a naked eye view of the entirety of the case slides. If the case is comprised of so many slides that they all can not fit in a single image, additional "entire_2", "entire_3", "entire_4", etc. images must be included in order to contain a naked eye view of the entirety of the case.

The entire section on every glass slide sampled will be captured as a separate image and labeled "slide_1", "slide_2", "slide_3", "slide_4", etc., accordingly.

Microscopic images will be obtained in a manner that enable appropriate orientation of the viewer to the area being sampled by progressing from a low magnification to higher magnification in a step fashion. The area magnified in the image can be marked by a box in the lower magnification view.

Microscopic images from each slide will be labeled according to a format that will enable identification of the histologic slide it was obtained from, objective lens magnification and the image number in a series of similar images. This format can be represented as S##M##_#. As an example, "S02M40_3" would indicate image number 3 in a series of images obtained at 40 magnification from slide number 2.

Auxiliary images (e.g. radiographs, endoscopic images, gross images, sampling diagrams, etc.) accompanying the case will be labeled with the image content and number. As an example, "rad_1", "rad_2", endo_1", "endo_2", "gross_1", "gross_2", "diag_1", would indicate radiographs

1 and 2, endoscopic images 1 and 2, gross images 1 and 2, and diagram 1 respectively.

B.3 Reporting of results:

a. Upon review of the images, the pathologist will issue an opinion. This can be a tentative diagnosis, conditional diagnosis, case specific advice, etc.

b. A hard copy final report will be forwarded to the contributor in a systematic pre-agreed upon manner, if requested.

c. The reviewing center will annotate the opening image with the reviewer's name and diagnosis.

d. If additional materials, such as histologic glass slides, paraffin blocks, and/or fixed tissue specimens, are received with or after the case images, the image files will be flagged as "glass slides also present", "paraffin blocks also present", etc.

e. In teleconferencing systems with "white pages" capability, the white pages will be used as a framework to convey identification summary and diagnostic images.

C. The Internet as a Consultation Medium for Telepathology

The Internet was evaluated as a medium for diagnostic telepathology between the AFIP in Washington, D.C., U.S.A. and the National Cancer Center Hospital in Tokyo, Japan.

For this application we utilized Unix based computer systems. The hardware used consisted of two Silicon Graphics IndySC workstations, MIPS 4400 cpu running at 150 MHz with 32 MB of RAM and 430MB hard drive, connected to the Internet by commercial Internet providers in the United States and Japan using CISCO 7000 routers. The software used consisted of IRIX v.5.2 operating system and InPerson software package v. 1.1A. All of the used equipment and software are off the shelf products of Silicon Graphics Corp. This setup enables: 1) Two way voice link at 16 KHz. 2) Two way video link with 280x160 pixels at a rate of 1-3 frames/sec.
3) Simultaneously viewed "white pages" area of 1200x700 pixels with dual pointer and annotation capability. 4) Two way file transmission capability. In the multipage white pages, several 640x480 pixels 24 bit RGB images can be pasted and annotated.

The communication link between our two institutes are based upon TCP/IP and UDP/IP for the U.S. and Japan, respectively. Our analysis of a sample communication is provided below.

1. Number of relay points US --> Japan = 18 relays total.
2. Weakest/Strongest link delay within communication chain = 200.
3. List of relay stops, geographic site and communication delay in msec for each:

3.1	indy1.ncc.go.jp	Tokyo	2

3.2	nttky-cisco3-s214.conc.imnet.ad.jp		17
3.3	kdd-im-cisco1.noc.imnet.ad.jp		16
3.4	sl-stk-7-s315-512k.sprintlink.net		241
3.5	sl-stk-5-F0/0.sprintlink.net	Tokyo	323
3.6	icm-fix-w-H210-T3.icp.net	Hawaii	197
3.7	fix-west-cpe.SanFrancisco.mci.net	San Francisco	156
3.8	border3-hssi2-0.SanFrancisco.mci.net		126
3.9	core-fddi-0.SanFrancisco.mci.net		127
3.10	core.hssi-2.Denver.mci.net	Denver	151
3.11	core.hssi-3.Washington.mci.net	Washington, D.C.	191
3.12	border1-fddi0-0.Washington.mci.net		205
3.13	suranet-wtn-ds3.Washington.mci.net		205
3.14	wtn8-wtn-cf.sura.net		218
3.15	sura9-wtn-c3.sura.net		201
3.16	sura4-sura9-ce.sura.net		194
3.17	afip.sura4ck.sura.net		209
3.18	Tele1.afip.mil	Washington, D.C.	199

We prepared the cases to be exchanged, relayed them by FTP, and subsequently held interactive teleconferences centered on the transmitted cases. We observed the following steps in our preparations:

1. Record documentation of the sessions.
2. Schedule four 15 minute segments for each weekly session. The sessions are conducted every Wednesday evening, Washington, D.C. time; Thursday morning, Tokyo time.
3. Acquire the images and write files to local workstation and FTP files to remote workstation.
4. Conduct scheduled teleconference session.

From our experience, the Internet appear to be a promising medium for providing a low cost vehicle for international inter-institutional consultation and pathology case exchange.

4.2 Segmentation and Analysis on Pathology Images by an Adaptive-Sized Hybrid Neural Network

Investigator: Akira Hasegawa, PhD, Al M. Elsayed, MD and Seong K. Mun, PhD

A. Significance to the Military MDIS Project and Executive Summary

The MDIS is a vast network, but it is mainly handling only radiological images. For the purpose of the diagnostic support, we must take advantage of MDIS infrastructure to handle images other than radiological images such as pathology, cardiology, ophthalmology and dermatology. As a potential expansion of imaging capability of the MDIS, we have started developing a digital pathology network. As a part of the digital pathology network, this project is to develop CADx of pathology images to make the digital pathology network eventually more intelligent.. The technology of CADx is significant enhancement of the capability of MDIS, and we have already been developing CADx for radiological images. In regard to enhancement and expansion of the current MDIS technology, this project is in compliance with the goals of the MDIS technology project.

B. Overview

Diagnosis of breast cancer based on pathology images is commonly done to identify malignancy of suspicious tumors or microcalcifications. Fig. 1 shows an example of a breast cancer pathology image, which has colors. Tissue sections of breast cancer are stained, and magnified by a microscope. In Fig. 1, the rounded cell indicated by the white arrow is an epithelial cell, which is a cancer cell, a long cell indicated by the black arrow is a stromal cell, and the small black dots overall the image are insulin-like growth factor-II (IGF-II) mRNAs. Generally, IGF-II mRNA is a potent mitogen for a variety of cell types and is considered an important regulator of breast cancer growth. This means that cells overlapped with clustered IGF-II mRNAs are active and growing. In the treatment of breast cancer, it is important to recognize and count active cancer cells. However, without the help of computers, counting cells is time-consuming work. Currently, most pathologists make a diagnosis based on a rough estimation of the number of cells on an image. Because of the rough estimation, the diagnosis is not objective. To assist pathologists to make a consistent diagnosis, it is necessary to develop a computer system to automatically recognize and count several kinds of cells. The system will provide pathologists with not only a consistent but also fast diagnosis.

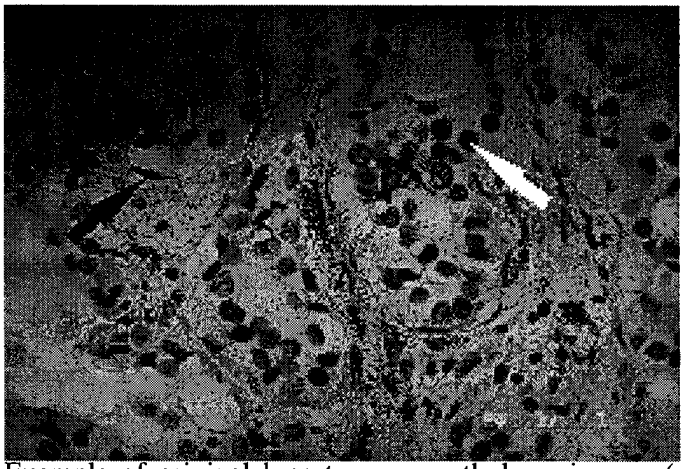

Fig. 1 Example of original breast cancer pathology images (color). The image has 733¥491 pixels and each pixel consists of RGB colors.

Combining the computer-assisting system with telepathology, which is a potential extension of the medical diagnostic imaging support (MDIS), is expected to extend the potential of telepathology systems. The main function of telepathology is transferring digital pathology images over a satellite or Internet to other institutions for diagnostic help. If a telepathology system has the computer-assisting system that recognizes and counts cells automatically, not only original pathology images but also computed analyzed data can be transferred. By transferring the analyzed data with the original pathology images, the diagnosis is expected to be more effective and speeded up. A study on automatic segmentation of breast tissues by a back propagation neural network has been reported by Okii *et al.* However, they used input images with a notable difference only in brightness, but not color. In addition, the number of the training examples used for training of a back propagation neural network was so small that the trained neural network's performance was not expected to be generalized. Generally, it is said that to get a generalized performance of a back propagation neural network, the necessary number of training examples is more than ten times of the number of connection weights in the neural network; nevertheless, Okii *et al.* used only 48 training examples for training a neural network with more than 360 connection weights.

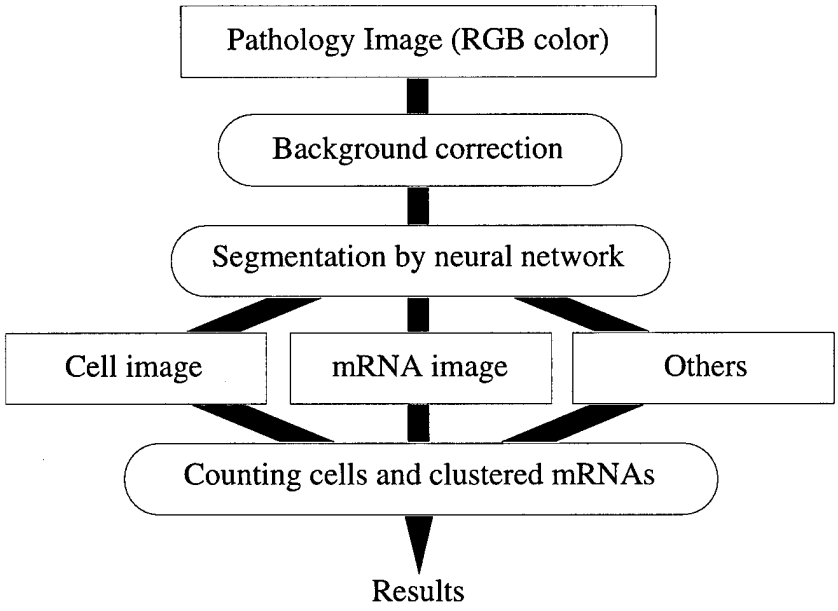

Fig. 2 Overall approach for automatic segmentation and analysis on breast cancer pathology images.

For the image segmentation of general color images, several techniques have been reported. Methods based on the thresholding of image histograms have been proposed. In these methods, on each color axis, color space is divided by means of histogram thresholding, similar to a technique used for the segmentation on gray-scale images. Other techniques based on the *K*-means algorithm and the least sum of squares criterion have been reported. Recently, a method using neural network has also been proposed. The basic idea of this method is a vector quantization, which is done by a competitive learning. Image segmentation is done by clustering color space by the vector quantization. In these methods, however, the number of segments is usually not

specified and depends on the pathology image. On the other hand, in segmentation on pathology images, the number of segments is assigned.

In this project, we proposed a novel neural network model, an adaptive-sized hybrid neural network (ASH-NN), for the segmentation of breast cancer pathology images. The ASH-NN is based on a supervised learning method, and connection weights between the input and hidden layers are self-organized. The ASH-NN has the capability to self-optimize the number of hidden units. As a result, the user does not need to perform trial and error to find the optimal network structure, which is necessary when back-propagation neural networks are used. In addition, as the ASH-NN's learning process is not based on the error back propagation algorithm, the learning process is not time-consuming. When a back propagation neural network is used, the time-consuming learning process is a serious problem; nevertheless, back propagation neural networks generally need an enormous number of training examples.

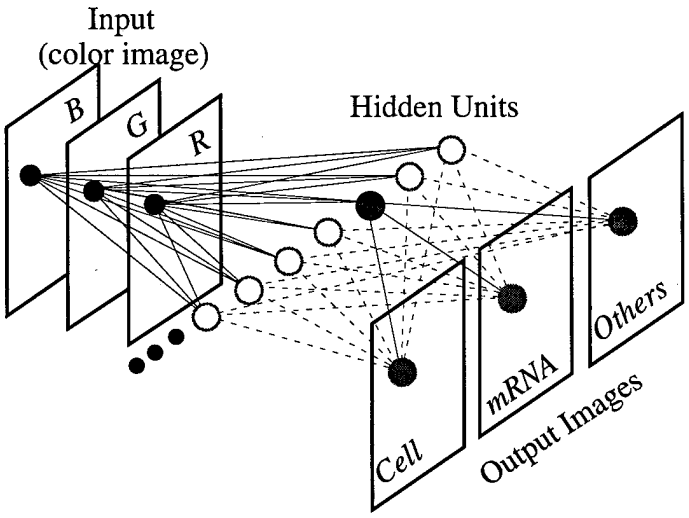

Fig. 3 Adaptive-sized hybrid neural network model for automatic segmentation on breast cancer pathology images.

C. Methods

The proposed overall approach for the automatic segmentation and analysis on a breast cancer pathology image is illustrated in Fig. 2. An original pathology image has 733¥491 pixels and each pixel consists of RGB colors. All breast cancer tissues to be used in this project were stained by the same chemicals, but there is some difference in both color and brightness between images. In addition, brightness varies with location in an image: the pixel values around image edges are usually darker than around the image center. To reduce these differences, it is necessary to employ background correction as preprocessing. The background corrected image is processed by a novel neural network, an adaptive-sized hybrid neural network, that has already been trained on training samples. The neural network segments cells, mRNAs, and the other structures from an original color pathology image. In the next step, each cell and cluster of mRNAs are recognized and counted from each segmented image. In the current stage of this project, we have been working on segmentation of cells and clusters of mRNA, but we have not finished recognition and counting of them. In the following section, the algorithm of the adaptive-sized hybrid neural network is described.

C.1 Adaptive-Sized Hybrid Neural Networks (ASH-NN).

The proposed adaptive-sized hybrid neural network (ASH-NN) is illustrated in Fig. 3. The ASH-NN consists of an input, a hidden and an output layer. When the ASH-NN is applied to the segmentation on a breast cancer pathology image, the input layer consists of three units that correspond to pixels on red, green, and blue frames. In our application, the output layer also has three units correspondent to "cell," "mRNA," and the other structures. When a set of RGB signals is presented to the ASH-NN, each hidden unit's output is calculated, and a hidden unit that has the largest output value is selected as a "winner". Only the winner hidden unit contributes to the output layer and no other hidden units take part in the neural network output.

In the mathematical expression, the output signal of the ASH-NN is written as follows: When $\boldsymbol{p}^i$, where i=1,...,M, denotes the ith n-dimensional input signal and $\boldsymbol{w}_j$ is the n-dimensional connection weights vector between the input units and the jth hidden unit, the jth hidden unit output signal H_j is represented as

$$H_j = \left\| \boldsymbol{p}^i - \boldsymbol{w}_j \right\|, \tag{1}$$

where $\|\cdot\|$ indicates the Euclidean norm. After calculation of each hidden unit output, H_{win} is selected as a winner:

$$\text{win} = j \left| H_j = \max\{H_1, H_2, \cdots, H_N\}, \right. \tag{2}$$

where N indicates the number of hidden units. Then, the final output of the cth output unit is represented as

$$O_c(\boldsymbol{p}^i) = v_{\text{win},c}, \tag{3}$$

where $v_{\text{win},c}$ represents the connecting weight between the winner hidden and the cth output unit.

In the initial stage of the ASH-NN training process, there is no unit in the hidden layer. When a first training example is presented, a hidden unit is created:

$$\boldsymbol{w}_1(0) = \boldsymbol{p}^1. \tag{4}$$

At the same time,

$$M_1(1) = \cdots = M_1(C) = 0. \tag{5}$$

In Eq. (5), $M_1(c)$ $\{c$=1,...,$C\}$ indicates the memory counter for the class c and C is the total number of classes that training examples include. Each hidden unit has a memory counter that add up the number of winning.

To generalize the learning algorithm, we assume that the neural network has N hidden units at tth learning epochs. When the ith training example is presented, a winner hidden unit is chosen based on Eqs. (1) and (2), and then the winner's weight vector is updated:

$$\boldsymbol{w}_{\text{win}}(t+1) = \boldsymbol{w}_{\text{win}}(t) + \lambda \cdot \left[\boldsymbol{p}^i - \boldsymbol{w}_{\text{win}}(t) \right], \tag{6}$$

where l is the learning rate. The learning rate is exponentially decreased as

$$\lambda = \lambda_0 \cdot \exp\left(-\frac{t}{10}\right), \tag{7}$$

where l_0 is the initial learning rate.

After the updating, the winner's memory counter is incremented:

$$M_{\text{win}}(s^i) \equiv M_{\text{win}}(s^i) + 1, \tag{8}$$

where s^i is the target signal of the ith training example $\boldsymbol{p}^i$, which indicates the class that $\boldsymbol{p}^i$ belongs to. If $\sum_{c=1}^{C} M_{\text{win}}(c)$ is larger than a frequency threshold F, a hidden unit is created and

$$\boldsymbol{w}_{N+1}(t+1) = \boldsymbol{w}_{\text{win}}(t+1), \tag{9}$$

$$\left.\begin{aligned} M_{N+1}(1) = \cdots = M_{N+1}(C) = 0 \\ M_{\text{win}}(1) = \cdots = M_{\text{win}}(C) = 0 \end{aligned}\right\}. \tag{10}$$

Whenever the neural network goes through all training examples, connection weights between the hidden and output units are calculated as

$$v_{j,c} = \frac{M_j(c)}{\sum_{c=1}^{C} M_j(c)}. \tag{11}$$

After this calculation, all hidden units' memory counters are reset, and the next epoch starts. After every epoch, the total error is calculated as

$$E = \sum_{i=1}^{M} \left| O_c(\boldsymbol{p}^i) - \delta_{c,s^i} \right|. \tag{12}$$

In this equation, δ_{c,s^i} is the Kronecker delta symbol:

$$\delta_{c,s^i} = \begin{cases} 1 & (c = s^i), \\ 0 & (c \neq s^i). \end{cases} \tag{13}$$

D. Experimental Results

Examples of resultant images before and after background correction are shown in Fig. 4 (a) and (b), respectively. In Fig. 4 (a), it is obvious that brightness is not uniform: the center area is brighter than the image edge area. On the other hand, in Fig. 4 (b), after background correction, brightness of the image is uniform. However, it cannot be seen in Fig. 4, the colors after background correction differ from those before because a uniform background is added to the image instead of an ununiform background, which is removed by the background-correction process. By the addition of the same uniform background to every image, colors in every image after background correction become similar. This process is indispensable because colors vary with different images, which may cause the mis-segmentation in unknown pathology images.

Fig. 5 shows an example of training sets used in the training process of the ASH-NN. Each training set consists of four images: (a) an input image, which is already background-corrected, and its target images representing (b) cells, (c) mRNAs, and (d) the other structures. The target images were hand-drawn. Each image consists of 64¥64 pixels. Each pixel in the input image is an input datum and the corresponding pixels in three target images are the target signals. Only one of the corresponding target pixels is highlighted. Only the highlighted pixel is relevant: For example, when the highlighted pixel is in an image that represents cells, the training signal indicates that the corresponding input pixel is a part of cells. It is noted that there are zero, two or more highlighted pixels in a corresponding pixel area in Fig. 5 (b), (c), and (d). These pixels are excluded from training sets.

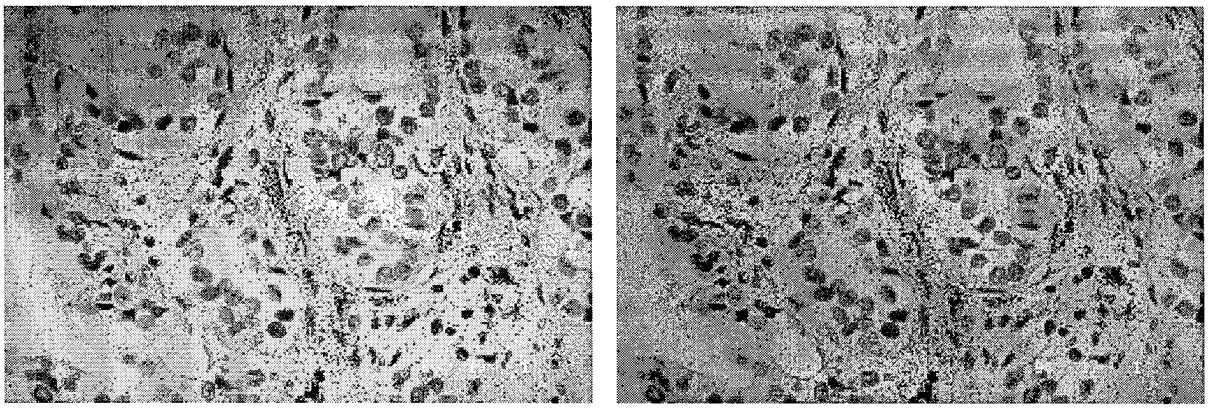

Fig. 4 Effect of background correction: (a) before and (b) after background correction process.

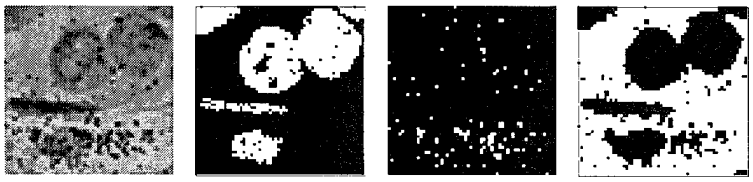

Fig. 5 Example of training sets. Each image consists of 64¥64 pixels. (a) Input color image, and its corresponding target images (b) indicating cells, (c) indicating mRNAs, and (d) the other structures.

In the training process of the ASH-NN, two 64¥64 pixel images were used as training sets, which were extracted from two different original images. In the training sets, a total of 7,255 effective training examples were included. The initial learning rate l_0=0.1 and the frequency threshold F=50 were used in the training process. After 25 training iterations, the training error was converged into 555.9, which is equivalent to about 2.6% error per pixel. During the training process, a total of 223 hidden neurons were created.

After the training, the ASH-NN was tested. The performance of the ASH-NN on a training example shown in Fig. 5 (a) is demonstrated in Fig. 6. Fig. 6 (a) is the same image as Fig. 5 (a). Fig. 6 (b), (c), and (d) are corresponding output images to Fig. 5 (b), (c), and (d), respectively. As shown in Fig. 6, cells, mRNAs, and other structures such as backgrounds, are successfully detected, although there is some difference between the resultant images of Figs. 5 and 6. Fig. 7

shows the resultant image on a whole image. Cell, mRNA, and the other structure images are detected in Fig. 7 (a), (b), and (c), respectively. The original image had an uniform background, however, similar results were obtained in both image edge and center areas because of background correction followed by the ASH-NN processing. Currently, we do not have an objective evaluation method, however, promising results were obtained on the other five images which included four unknown images.

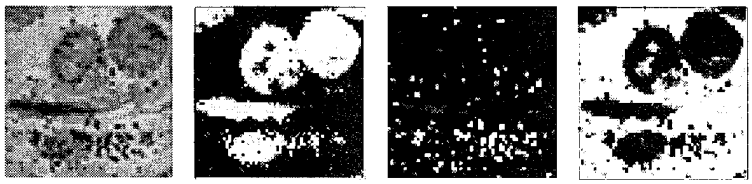

Fig. 6 Testing results on training sets: (a) is the same image as Fig. 5 (a). (b), (c), and (d) are output images of the ASH-NN, which are correspondent to the target images shown in Fig. 5 (b), (c), and (d), respectively.

We have tried the same process without background correction. As mentioned above, without background correction, brightness in each image is not uniform and there is some difference in colors among images. After training on the same areas we used in the above experiment, but without background correction, the neural network was tested. In an image with uneven background, acceptable segmentation was obtained only around the center of the image. In an image with different colors from those of training examples, segmentation failed on almost the whole image. This experiment suggested that background correction is necessary for segmentation.

E. Conclusions

In this report, we described an automatic segmentation and analysis on breast cancer pathology images. For the segmentation, we developed an adaptive-sized hybrid neural network that can quickly learn training examples and self-adjust the number of its own hidden units. The neural network trained on two image blocks and was tested on several unknown images. The testing results suggested that the developed neural network has generalized performance. Currently we have done only the segmentation on breast cancer pathology images but not the analysis and counting. However, the performance of the segmentation might significantly control the results of the following analysis and counting, and it is important to get good segmentation performance. In future works, we need to develop methods to evaluate segmentation performance and to recognize each cell and mRNA from segmented images.

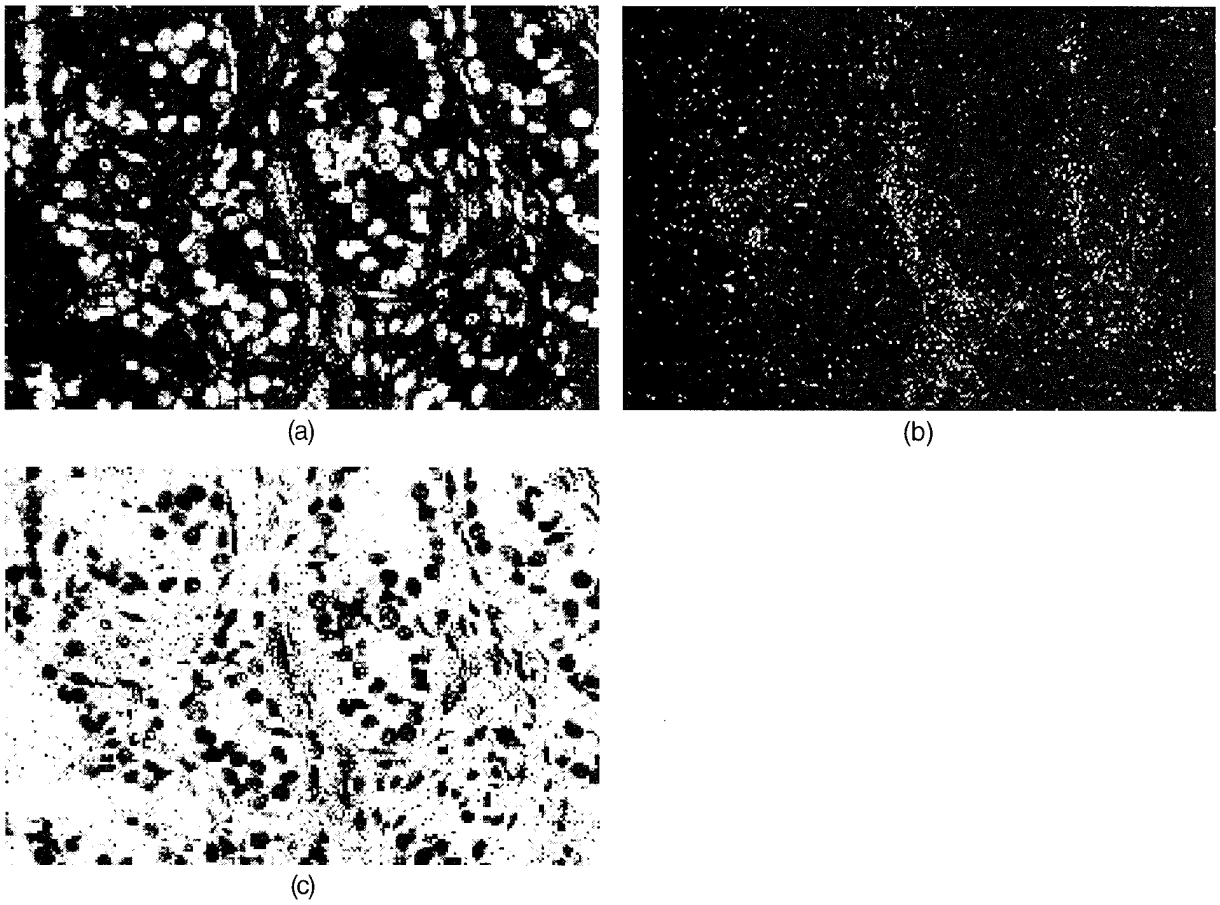

Fig. 7 Results of the ASH-NN on a testing image: (a) detected cells, (b) detected mRNAs, and (c) the other structures.

5.1 RIS/HIS and PACS Interfaces: Trends in Compliance to Standards

Investigators: Marion C. Meissner, Betty A. Levine, Seong K. Mun

A. Significance to the Military MDIS Project and Executive Summary

This study extends a previous survey on available standards of data communication and interfacing in the RIS and PACS industry. We sought more detailed knowledge about such interfaces and contacted a greater number of RIS/HIS and PACS vendors. We also wanted to determine if interfaces had changed in the last two years and in what direction the industry is moving. This information is of great significance to the development of an image-capable HIS. In order to acquire, store, and distribute images and related data, an HIS must be able to interface with imaging modalities and other systems dealing with image data. To the extent to which such other systems communicate via standards, an image-capable HIS must be able to adhere to these standards. It is important to know which standards are commonly supported among RIS and PACS vendors and what trends the industry is following.

B. The Need for Standards

As computer systems have become more and more important in health care data management, the need to transfer data efficiently and accurately between different computer systems has increased. In radiology departments and imaging centers, Radiology Information Systems (RIS) and more generally Hospital Information Systems (HIS) have been firmly established as the method for storing and managing patient information. Picture Archiving and Communication Systems (PACS) are seeing increased clinical use, storing and displaying image information for radiological exams, reports and some patient demographics. In order for a PACS to be effective in clinical applications, it is necessary to connect it to an existing RIS or HIS. Such a link should ensure that patient images are correctly matched with the appropriate patient demographic information and results from other departments and exams. It can also reduce redundant and potentially erroneous data entry.

When a new computer system is installed in a clinical setting, an interface must often be developed between the new system and existing systems. Since there are currently well over 50 vendors of Radiology and Hospital Information Systems and many PACS solutions of varying sizes, there are potentially hundreds of interface combinations. Designing a custom interface for each installation would lead to huge development costs as well as the potential for repeating errors in every interface implementation. To make interface development easier and faster, various organizations have developed standards for the formatting and transfer of clinical data. These include the American College of Radiology and the National Electrical Manufacturers Association (ACR-NEMA), and the Health Level 7 (HL-7) Working Group. The ACR-NEMA and HL-7 standards also provide protocols for lower-level communications. Lower-level communications protocols are needed wherever data is communicated electronically. Among the most common of these standards are Ethernet, developed by XEROX, DEC and Intel and defined as an international standard by IEEE (Institute for Electrical and Electronic Engineers), and TCP/IP (developed by the academic community using ARPANET), DECnet, Kermit, XModem, etc. At the level of physical

connections, two of the most common standards are Ethernet and the older RS-232 or serial line. High-speed options such as the T1 protocol, most often used over telephone lines, and fiber-optic wiring and protocols have more recently come into use.Interface development is financially costly and labor-intensive for several reasons. Because many vendors build RIS/HIS and PACS, there are many possible interface combinations. Conversely, there are few instances of each particular interface. Without the use of standards, many different single-use interfaces are needed. Furthermore, when an interface is developed, many parties are involved. The two main vendors must communicate with each other and with various groups at their customer site, such as administrators, technologists, radiologists and other users. They have to decide how to map data items between the two systems and resolve any inconsistencies. For example, both systems might store a unique exam ID but one system might consider an exam a complete set of images of one body part while the other system thinks of an exam as several sets of images that were ordered together. There are many other examples of such discrepancies between different computer systems that use the same data elements but have different meanings attached to them.

Medical communications standards like HL-7 and ACR-NEMA go a long way toward solving this problem. Nevertheless, different vendors can interpret ambiguities in the standards in different ways and these differences must be reconciled during interface development.

C. Surveys Performed at ISIS

In 1992 we performed a survey at Georgetown University's Imaging Science and Information Systems (ISIS) Center of some RIS and PACS vendors to see how vendors dealt with the need to communicate data between their systems and other computer systems. We contacted 25 radiology software vendors who were ranked highest by number of clients in a 1991 Health Week article. Nineteen of the 25 vendors replied with information about the physical connections, communications protocols and message formats they used in their interfaces to other systems. While many vendors used lower-level data communications standards and well-established cabling options, very few conformed to the ACR-NEMA 2.x standard for radiological data transfer.

Last year we repeated the survey, expanding our list of RIS and PACS vendors. We also added more detailed questions about the interfacing procedure, the type of data transferred, error checking and reasons for the choices made. Our aim was to determine how interfaces had changed in the two years since our previous study and in what direction the industry is moving. We also sought more in-depth knowledge on current methods of data communication and interfacing in the RIS and PACS industry.

We contacted all of the vendors surveyed in 1992 as well as many others listed by market consultant Ron Johnson in the 1993 National Report on Computers & Health. Of the 54 RIS vendors and 6 PACS vendors surveyed, 19 and 4 vendors responded, respectively. The survey included the following sections: interface type, interface procedure (what types of systems are interfaced, how is a data transfer initiated and completed), physical connections (wiring, direct link or intermediary computer), communications protocol, data format, data content, data integrity checks (low-level and high-level) and where applicable, reasons for choosing particular options. The responses were tallied by category and the number of vendors who checked each option calculated as percentages of all the respondents.

D. Survey results

D.1 High-level communications.

A comparison between the two surveys indicates that more vendors now support standard methods of medical data communication and networking than two years ago. Support for the HL-7 and ACR-NEMA standards seems to have increased significantly. While 60% of RIS vendors still

maintain proprietary message and data formats, 80% now also support the HL-7 standard. This is an increase of over 20% from the previous survey. 40% of the RIS vendors supported ACR-NEMA in 1994 compared to none in 1992. Although proprietary or custom interfaces seem to have stayed about the same, this may be misleading. ASCII-delimited messages and printed reports tend to be customized as well and there seem to be large increases in these types of interfaces. In general, it appears that RIS vendors are now supporting more varied options than they were two years ago and they are making some effort to create interfaces using the standards.

For the PACS vendors, it is important to note that we only had four respondents for each of the surveys. Nevertheless, some changes seem to have occurred over the past two years in the way these vendors do interfaces. Among PACS vendors, the support of HL-7 and ACR-NEMA seems to have increased while proprietary formats do not seem to be very popular. ACR-NEMA may be the standard of choice for these vendors. With the introduction of DICOM, conformance is likely to remain high. This is plausible because many PACS vendors were and still are involved in the definition of the DICOM standard and ACR-NEMA (DICOM) is the most prominent medical standard that deals with image data. Our results show very little support among PACS vendors for ASCII delimited messages and printed reports, which are generally customized.

D.2 Communications protocols.

Communications protocols determine the format of lower-level packets of information and the procedures used at the lower level to ensure error-free transmission and receipt of these packets. Among the RIS vendors, there may be an increase in the use of TCP/IP and HL-7 protocols which were already popular in 1992. There also seems to be more support for other standards like Kermit and ack/nak. Unfortunately, the use of proprietary and customized protocols also seems to be quite high. The PACS vendors seem to be using mostly TCP/IP and HL-7 as their communications protocols. None of these surveyed vendors use proprietary protocols. In general, vendors seem to be supporting a wider variety of options as they offer interfacing to more and different systems.

D.3 Physical connections.

At the level of physical connections, vendors also seem to have shifted to using more current standards. In 1992, all of the RIS vendors and most of the PACS vendors used RS-232 cabling as the physical medium for their interfaces, while only 53% and 50% used Ethernet, respectively. Now, 75% of the RIS vendors and all of the questioned PACS vendors support the more modern Ethernet cabling and networking standard. RS-232 is still widely supported but its use has declined somewhat among both RIS and PACS vendors.

The use of modems and T1 lines seems to have gone up as well. Although T1 is not a physical standard, we have included it in this category because it is a technology usually associated with telephone lines. One reason for the increase seen might be that more hospitals have sites that are geographically separated. Modems provide a relatively inexpensive way of communicating between remote computer systems, whereas a T1 link can be very fast.

There also appears to have been a significant increase in the use of fiber optic cabling. This might be because prices have gone down and this high-speed option has become more widely available in the last few years. The change in the use of fiber is probably not as dramatic as it looks from our survey. It is more likely that in the 1992 survey, vendors did not include their interfaces to imaging modalities which would have to use high-speed cabling. Our most recent survey was broader in scope and PACS vendors probably included not only interfaces to RIS but also to imaging equipment and other systems. We should also note that in many PACS, primarily image data is transmitted through fiber while the text data and commands go through the slower Ethernet or RS-232 media.

D.4 Direction of communication.

As part of both surveys, we also asked vendors whether the interfaces they had developed are bi-directional or uni-directional and in what direction information is transferred. We found some interesting results. Most of the RIS vendors indicate their systems send and receive data and only 15% have unidirectional interfaces. Of those three systems, all receive only. For the PACS vendors, we found the same trend in direction of communication. Most of these vendors describe their system as supporting bi-directional interfaces.

We have found that vendors mean different things when they say they support bi-directional interfaces. A true bi-directional interface has patient data moving in both directions. Often, each interfaced system will provide different types of information to the other system as it becomes available. A bi-directional interface might also be defined as one where data such as commands, requests and acknowledgments flows in both directions but patient data moves only in one direction. Probably, not all of the systems described as "send and receive" are truly bi-directional.

D.5 Intermediate computer vs. direct connection.

Besides the comparison between the two surveys, we found some other interesting results in the most recent survey. One of the questions concerned the use of an intermediary computer between the two systems to be interfaced. This is sometimes necessary to implement an interface if the two system are not compatible physically or send and receive incompatible messages. Often, for proprietary reasons, vendors do not allow third-party interface software to be run on their systems. If processing is needed to convert a message from one system before it can be understood by the receiving system, this processing must take place on a third computer placed between the two interfaced systems. This type of connection is more common in interfaces developed by a third party, often because of limited access to the RIS/HIS or PACS source code and database structure. If the interface is not designed by one or both vendors of the systems to be interfaced, these vendors must provide a facility to import data to and export data from their system or make their source code available.

Using an intermediary computer has the advantage of more flexibility for the development and maintenance of the interface software. The intermediary machine can supply the necessary processing power and memory. A third party can develop the interface with help from the RIS/HIS and PACS vendors without compromising the confidentiality of their systems. However, the use of an intermediate computer has several disadvantages. The path the data has to travel is increased, creating additional possibilities for errors. An intermediate computer introduces another physical component that can fail. An indirect link may reduce the speed of the interface as well as the degree of integration between the two systems.

An important issue in computer interfaces is the ownership of the data while it is being transmitted from one system to another. Patient information must be kept secure and using an intermediate computer creates a potential problem. In general, an RIS, HIS or PACS is responsible for data within the physical limits of the system. When this data is transferred to another computer system it becomes the responsibility of that other system. With an intermediate computer that is part of neither of the two communicating systems, there is a short time where the data is not owned by anyone and is potentially vulnerable. This is an important consideration for vendors when developing an interface.

The results from the survey on this question reflect the tradeoffs between using a direct link or an intermediary computer. Of the RIS vendors, 89% offer direct links and 65% implement interfaces with intermediate computers. Only one of the PACS vendors uses an intermediate computer, while all have interfaces with direct links. Of the intermediate computers used, PCs were the most common (7 vendors), followed by DEC VAX's (3 vendors) and some type of gateway (2 vendors). The predominance of PCs might be due to their relatively low cost, high accessibility and ease of programming.

D.6 Type of interface.

We also asked vendors to describe the types of interfaces they support. In interfaces using terminal emulation, data does not usually pass between the systems. Users of one system open a screen or window into the other system and so review information on that other system. An automated interface is a uni-directional or bi-directional link between two distinct computer systems, over which data is automatically transferred when certain events take place on either system. In an integrated system, one product, usually an HIS, includes all the functionality of a potentially separate system, e.g. an RIS or billing system. Some PACS contain RIS but most users have found these built-in RIS insufficient to meet their needs. In such systems, data is either stored in a single database or is transferred within the system in a manner that is transparent to the user. Generally, an integrated system provides the functionality of several independent systems and is developed entirely by one vendor. The definition of an interface becomes vague in such a system and the use of communications standards becomes less important.

Vendor responses to this survey question are as follows. Of the RIS vendors, 13%, 22%, and 8% supported terminal emulation, an automated interface, and had an integrated system, respectively. Among the PACS vendors, the numbers were 57%, 96% and 35%, respectively. An automated interface represents the largest development effort of the three options described here because it implies that two disparate systems are transferring data in a well-coordinated manner. The fact that this is the prevalent type of interface makes a strong case for the need for standards.

D.7 Reasons for supporting options.

For each of the questions in the 1994 survey, we also asked vendors to indicate reasons why they chose certain options for their interfaces. The possible reasons listed on the survey form were as follows: cost-effective, robust, easy to implement, most widely used, easy to use, expandable/upgradable, and other.

We noted that the reason most cited for supporting certain options was that the option was the one most widely used. In the "other" category, vendors listed such reasons as "adherence to HL-7 standard" and "market-driven". This indicates that vendors are paying attention to standards and what other developers are doing. In designing interface options, they do seem to be interested in conforming to the standards.

E. Conclusion

The results of our study show a move towards increased support and use of standards of data communication. While many vendors still use proprietary methods, many of these same vendors now also provide the ability to interface using standard formats and protocols. In general, vendors are supporting more options in their interface solutions.

This will enable interfaces between different computer systems to be developed faster and with less redundant effort for each individual interface. Indeed, interfaces are proliferating in the RIS/HIS and PACS industries and all but one of the RIS vendors and one of the PACS vendors who responded to our survey reported existing successful interfaces of their systems to other vendors' systems.

6.0 U.S. Armed Forces Teleradiology in Korea: Initial Assessment and Evaluation Parameters and Methodologies

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Gary S. Norton, RT (R), J. Romlein

A. Significance to the Military MDIS Project and Executive Summary

Teleradiology is essential to provide medical support for U.S. Armed Forces in Korea. Investigating the impact of this technology on the daily practice of routine care as well as its effects on the medical decision making process is essential. This will bring a better understanding of its importance and the changes it can produce clinically and technically, as well as from an organizational and managerial standpoint. This report examines the different parameters to be investigated in the development of evaluation methodologies of teleradiology efforts for the U.S. Armed Forces in Korea. While the teleradiology infrastructure is in place, utilization of the system is not yet optimal. The need for teleradiology as well as telemedicine is clear, but there are still obstacles to overcome. This paper establishes the foundations for the development of a framework around which a systematic evaluation of those efforts can be accomplished.

B. Introduction

There are 17 U.S. military medical treatment facilities scattered throughout the Republic of Korea to provide health care for approximately 40,000 U.S. troops and their dependents. Only one Air Force and four Army radiologists are assigned for radiological diagnosis. In some areas, report turn-around time can be as long as two weeks. An extensive teleradiology network is planned as part of the Medical Diagnostic Imaging System (MDIS) implementation program to improve the quality of radiological service while overcoming the distance and time barriers.

The Teleradiology (TR) System is an integrated technology of computer and communication that allows electronic transmission of x-ray images from remote clinics to a designated hub where the transmitted exams are available for electronic diagnosis and consultation by central site staff radiologists. The 18th Medical Command (MEDCOM) of the U.S. military is responsible for the medical care for the U.S. Armed Forces and their dependents stationed throughout the Republic of Korea. Within the 18th MEDCOM there are 4 Army radiologists at 121 EVAC Hospital and 1 Air Force radiologist at the Osan AFB Hospital to provide radiology service for approximately 40,000 troops and their dependents stationed throughout Korea. No other U.S. military radiologists are assigned to Korea. There are 13 Army, 3 Air Force and 1 Navy medical facilities in the 18th MEDCOM.

C. System Configuration

The present telemedicine system installed in Korea allows the transmission of still radiological images as well as limited video consultation between the different sites (Figure 1). The main hub for this network is the 121 General Hospital in Seoul. There are four remote sites or spokes in this configuration (Camp Casey to the North West, Osan AFB and Kunsan AFB to the South and Camp Walker to the South East). Still radiological images are digitized at the remote sites or acquired in some cases through Computed Radiography (CR) in Osan and transmitted over

dedicated T-1 lines to 121 General Hospital in Seoul for digital optical archiving along with the reports. There is 500 Gigabyte of optical storage capability at 121.

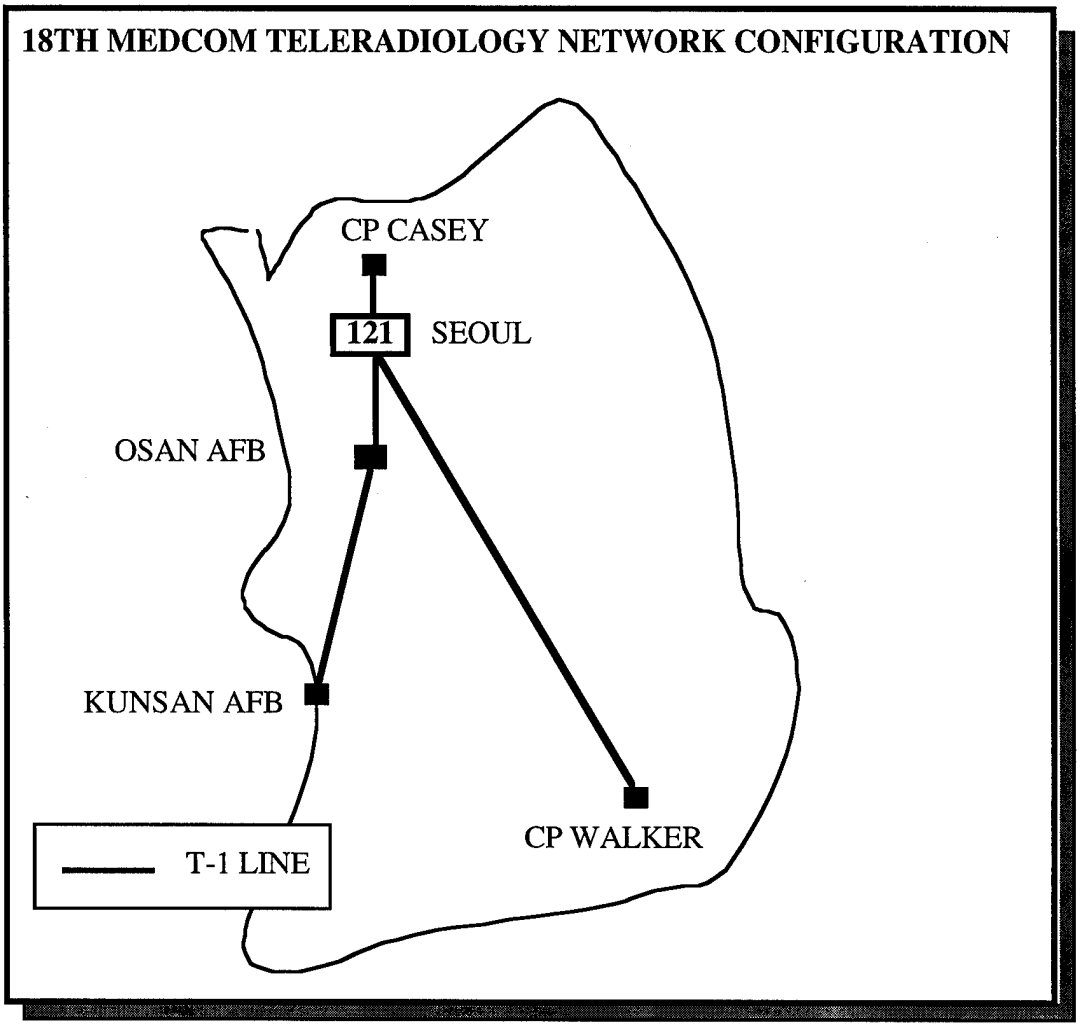

Figure 1

D. Teleradiology Subsystems

The teleradiology equipment available at each sites differs depending whether the site is an MDIS hub, large spoke or small spoke. Table 1 details the available equipment at each site.

Table 1

Equipment at the Different Sites

	121	Osan	Casey	Walker	Kunsan
VAX	1	1	1	1	1
CT modality gateway	1				
WSU	1				
microWSU		1			
CR	1	1			
FD200 (Lumisys Digitizer)			1		
FD150		1			
KELP(Kodak Ektascan Laser Printer)			1	1	1
TRS (Teleradiology Server)	3	2	1	1	1
SCIDO 2C (Clinical Workstation)		3	1	1	1
SCIDO 2A (Diagnostic Workstation)		4	1		

E. The Operational Scenario

The 121 General Hospital in Seoul operates as the main hub for the teleradiology network. It can receive images in both consultation and emergency modes from all remote sites through three teleradiology servers connected to T-1 lines. The site also has VAX WSU for temporary storage and a .5 Terabyte optical disk jukebox (ODJ) for archiving. This is where all the images are automatically stored from all sites. Images at the different spokes are stored in hard-copy format for military personnel and their dependents for the duration of their stay. After that their files are transferred to their next base. However their files are optically archived in long-term storage at 121.

Osan Air Force Base Hospital operates as a large spoke for the teleradiology system in the sense that it operates as a spoke for 121 but as a hub for Kunsan. The radiologist on-site at Osan reads images that are transmitted from Kunsan as well as some CT scans that are transmitted from 121. This large spoke also has the capability to produce hard copy x-rays or CR through a Fuji AC-1+. Osan also has high resolution monitors to display those images. The permanent storage of the images is done at 121 through the MDIS system.

Kunsan Air Force Base, Camp Casey and Camp Walker health clinics are teleradiology small spokes. These spokes differ in the workload but also in the way they are connected to the teleradiology network.. Camp Casey has the highest workload because it serves several small clinics in the area. It is directly connected to the main hub at 121. This is also the case for Camp Walker but not for Kunsan which is linked to Osan. X-rays are obtained at these sites and then digitized before transmission to the hub at 121 or Osan in the case of Kunsan. Radiological reports are then returned to the transmitting spoke for distribution.

F. Site Visit Report

Georgetown University team conducted a site visit last September. This visit was led by Matthew Freedman, MD, an internationally renown digital radiology expert.

At Osan AFB, Dr. Freedman met with Dr. Welsh, the radiologist and reviewed approximately 40 images on a soft copy workstation and identified the following problems:

1. Need for chemical control canister for processor for CR to allow greater use of CR. Currently, they do not print hard copy, only use soft copy CR images.

2. Lack of sufficient initial training in use of Loral Workstation (WS) and CR. Problems with CR and WS appear to be mainly related to lack of familiarity and lack of appropriate procedure manuals for problems solving. Current problems include the presence of inappropriate display default protocols; however, these defaults are different than those at the 121 Evacuation Hospital; those at 121 are better defaults.

3. Inability to make sufficient copies of x-ray reports for required uses, results in need to type each report twice (in order to get the three required copies.

4. Of the approximately 40 images reviewed on the WS, there were two that were unreadable, one because of noise, presumably introduced during image transmission or scanning and one because the original image was sufficiently over-exposed so that information could not be captured. The others were considered readable, though some were somewhat dark. Providing the remote site with a film densitometer and setting some standards regarding the range of lung OD would provide a guide to the technologist as to what range of OD was acceptable for teletransmitted images. Conversion to CR would be another and perhaps better option.

5. Comparing images transmitted to Osan and to 121, it is clear that the use of Kodak Insight film for chest radiographs provides a noticeable improvement in the image quality of transmitted images. Proper use of insight film is however necessary for this effect to be seen. One needs a good, properly adjusted phototimer for this advantage to be present.

6. CR images: No major problem were noted with the CR images present on the workstation. They were well positioned and appeared of high quality.

At 121 Evacuation Hospital, Dr. Freedman met with two radiologists, one of whom had been trained in CR. The following problems were identified:

1. The quality of digitized images transmitted to 121 from Camp Casey was lower than that received at Osan. They were acceptable, but not optimal. There were no really bad images, but overall, the quality was not as good as at Osan. There appeared to be (most likely) two problems resulting in this:

a. Lack of adequate demonstration of the mediastinum: this could result from the use of too low a KVP and/or the use of a film-screen system that failed to enhance the mediastinal structures. Switching to Insight film may improve the quality. The chest radiographs may also have been obtained on a lower resolution film than those sent to Osan.

b. The use of a screen film system for skeletal films that has too low a resolution and could potentially obscure small avulsion fractures of the hands, ankles and feet. An evaluation of potentially better screen film system at Camp Casey is recommended..

2. Overall image quality was acceptable, but not optimal. Improvements in the acquisition device, at a minimum improvements in screen film system used or preferably conversion to CR would improve the quality of the transmitted images. With the current system, it would not be surprising if small fractures could be missed in the hands, feet, and ankles, though no misses were seen. The lack of

penetration of the heart and mediastinum could result in retrocardiac pneumonias being missed. No problems were noted that that could be directly related to problems in image transmission or directly related to the film digitizer.

G. System Acceptance

The teleradiology system in Korea has not yet been accepted by the government. There remains a list of deficiencies that the vendor must correct before the system will be considered fully compliant with the MDIS specification and the unique needs of the Korean telemedical constellation. An acceptance testing is anticipated to determine these issues.

H. Parameters to be Studied for Teleradiology Evaluation

Our teleradiology investigation encompasses many aspects related to remote patient access to care. This study investigates different aspects and changes within the medical decision making process as they relate to organizational, managerial and administrative issues . It also investigates the clinical aspects as well the technical issues related to teleradiology. In order to determine the impact of each of teleradiology on each of those aspects, we will have to investigate the following parameters related to organizational and managerial issues, clinical, technical, service and training issues. The organizational and managerial aspects deal with infrastructure and managerial aspects. Parameters to be studied here relate to how teleradiology affects the medical decision making process through infrastructural, demographical and behavioral changes as well as the impact on turnaround time for images and reports in addition to training, service and maintenance. The clinical aspects are measured through parameters that relate to how teleradiology is integrated in the routine practice of care and how it affects patient care. The technical parameters that need to be determined are related to image acquisition, image display and output, image storage and database, image communication, network performance, system reliability and maintenance.

I. Organizational and Managerial Aspects

I.1 Infrastructure and demographics for each site
- Number of patients
- Number of in/outpatients per year
- Type of cases/case mix/patient profile
- Services available: e.g.: diagnostic radiology cases (bone, chest, etc.)
- Modality available at each site
- Beds per hospital
- Number of radiologists (Army, AF) per site
- Throughput per modality (films/day) (Unit, Location, films/day)
- Percentage of images to be transmitted at each site (Unit, Location, films/day)
- Percentage of new patients at each site
- Percentage of returning patients at each site

I.2 Turnaround time for images/reports
- Options to Teleradiology
- Couriers per spoke/hub
- Mode of transportation (bus, etc.)
- Buses a day from each location
- Problems associated with couriers
    - Frequency of rides/buses missed
    - Frequency of buses late
    - Frequency of delays

Number reports lost in the process
Number reports misplaced
Number reports late, etc.

Reliability
Turnaround time
Delay in the process
Handling of images at the spoke
Different steps that images go through
Steps in the process
Steps added for routine cases
Help from FTEs
Extra FTEs per site
Katusas per site
Batches sent per day
Emergency cases
Extra steps for emergency cases
Protocol for emergency cases
Emergency cases through TRad vs. non-TRad

I.3 Behavioral Changes
Relationship between the patient and the referring doctor/technician
Relationship between the consulting doctor and the technician or referring doctor
Relationship between staff at the hospital

Training

Instructional Material
Ease of Training
Formal Training
Initial/Refresher Training
People to be Trained
Training costs

I.5 Maintenance and Service
Maintenance
Warranty Maintenance
Maintenance costs

I.6 Clinical Aspects
Time to wait before a conference
Type of call(emergency, unplanned, planned or routine consultation)
Average time spent by consulting radiologist on cases
Accessibility of old patient images
Need for old images
Mix of images received (old vs. new)
Missing information
Reasons for evacuation
Patients evacuated per hub per week
Avoided evacuations
Not evacuated returning patients

I.7 Technical Aspects

I.7.a Image Acquisition
- Image matrix size
- Spatial resolution
- Contrast resolution / Dynamic range
- Throughput
- Modalities
- Interfaces to imaging modalities
- Operations
- Size of the image

I.7.b Image Display and Output
- Laser Printer
  - Throughput
  - Artifacts
  - Dynamic range
  - Image matrix size
  - Imager operation
  - Quality control/calibration
  - Physical size
  - Chemicals required
  - Cost for media
  - Cost for service
- Display monitors
  - Data types
  - Brightness (Luminance)
  - Gray scale display
  - Resolution
  - Dynamic range
  - Physical dimension
  - Refresh rate
  - Calibration
  - Uniformity and distortion
  - Monitor electron beam spot size
  - Frame buffer
  - Linearity
  - Half life of brightness
- Display workstation functions
  - Worklist/patient list
  - Image rearrangement and display
  - Image paging
  - Default display protocol
  - Image enhancements defaults
  - Edge enhancement
  - Window and level
  - Inverse video
  - Pointing device
  - Screen blanking
  - Zoom
  - Image roam
  - Digital magnifying glass
  - Rotation and flip
  - Mensuration

- Text and graphics annotations
- Image identification
- Delete
- Hard copy generation
- Command reversal (undo)
- Save
- Printouts
- System is working
- Screen synchronization
- Examination consultation
- Cine
- Text data display

I.7.c Image Storage and Database

- Database
  - Storage
  - Query
  - Retrieval
  - Quality assurance
- Data Storage
  - Speed
  - Data volume capacity
  - Storage media
  - Error correction
- The Logical Design – Short-term Storage and Long-term Archive
  - Definition; Short-term storage (STS)
  - Definition; Long-term archive (LTA)
- Use of the Folder Concept
  - Folder contents
  - Creation of teaching folders
  - Creation of research folders
  - Creation of management folders
- Use of Compression
- Security and Unauthorized Access
- Loss of Information
- Interface to Patient Information System
  - Nature of the interface
  - Clinical history
  - Reports
  - Information integrity
  - Use of common data elements

I.7.d Image Communication

- Communication Management
  - Dynamic bandwidth allocation
  - Transmission methods (e.g., store and forward vs. realtime)
  - Degree of integration of communication with applications
  - Record keeping and quality assurance
- Communications Link
  - Bandwidth Capability
  - Throughput Efficiency
    - Bit Error Rates
    - Transmission Delay

Communications Costs
- Setup
- Installation
- Maintenance

I.7.e Network Performance
- Data Integrity
- Data Transfer Response Time
- Minimum Bandwidth Threshold
- Redundancy/Reliability
- Crisis Management

System Reliability and Uptime

I.8.a System Reliability

I.8.b System Uptime

I.8.c Component Uptime

7.0 NATIONAL FORUM
MILITARY TELEMEDICINE: ON-LINE TODAY
RESEARCH, PRACTICE, AND OPPORTUNITIES

Department of Defense Co-Chair:
COL Anna Chacko, MC, USA, Chairman of Radiology
Brooke Army Medical Center
San Antonio, Texas

International Co-Chair:
Harold Glass, PhD, Department of Imaging Physics
Hammersmith Post Graduate Hospital
London, United Kingdom

The Association of the United States Army Collaboration:
GEN Jack Merritt, USA (Ret)
Washington, DC

Mission Statement:

The DOD has focused on the global research, development and deployment of sophisticated communication, management and imaging network systems, which will become an integral part of patient care activities. What lessons can we learn from the experience of the DOD and others? What can we expect in the future?

A national forum has been organized to develop a direction for the future by addressing these demanding questions and seeking the advice of experts in academics, industry and the medical community. Submitted papers will be considered for inclusion in poster sessions.

On January 30, 1995, the Speaker of the House of Representatives, the Honorable Newt Gingrich speaking before the American Hospital Association challenged US medicine with the following:

" I come here today to ask the American Hospital Association and all of its members to profoundly rethink your stance and your assumptions, to literally say erase the board. I don't care what your positions were as of 9 o'clock this morning, just drop all of them and rethink it . . . . if we could cut three to five years out of the transition from R.&D., to treatment, and if we could be networked to things like Internet, so that every doctor and every hospital has equal access, equal information, so that literally when you walk in, you're entering the world body of knowledge. . . . And I'll tell you, people like the U.S. Army are doing it. They're trying to design systems where a soldier who's been shot and has a particular problem, is by distance medicine being connected directly from the field hospital to the finest specialist on the planet. Now we can do that for our young men and women in uniform because we have a large system, systematically thinking through it. But then we ought to transfer that to everybody else ."

Who Should Attend:

The Forum is intended for those involved in the process of reengineering health care. This includes hospital administrators, those involved in medical informatics, and other health providers, scientists, engineers and facility planners, members of academia and industry with a special focus on practical approaches to advanced technology as it applies to medicine.

National Forum : Military Telemedicine On-Line Today
Research, Practice, and Opportunities

Program at a Glance

	Monday, March 27	Tuesday, March 28	Wednesday, March 29
0730	Registration & C. Breakfast	Registration & C. Breakfast	Registration & C. Breakfast
0830	Welcoming Remarks and Tools for Process Re-engineering	Welcoming Remarks and Cinical Perspectives within the DOD	Worldwide Telemedicine Practice
	Virtual Reality	Technology Acquisition Perspectives within the DOD	Policy Issues and Technology Assessment
1200	Lunch On Your Own	Lunch and Exhibits	Lunch and Exhibits
1330	Initiatives in Diagnostic Imaging	Plenary Session Perspectives from Government, Academia and Industry	Summation and Future Programs
	Video Tour		
	Telemedicine Specialty Applications	Plenary Session Perspectives from Government, Academia and Industry	
1700	Reception and Tour of Exhibits	Reception Tour of Exhibits and Congressional Video Links	
1930			

Note: Sunday Registration: 14:00 - 18:00

Session Coordinators:
Linda Donahue at Tel: 202-687-7955, Fax: 202-784-3479 or e-mail: tpres@isis.imac.georgetown.edu
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NATIONAL FORUM:
MILITARY TELEMEDICINE ON-LINE TODAY
RESEARCH, PRACTICE, AND OPPORTUNITIES

27-29 MARCH 1995
The McLean Hilton at Tysons Corner, McLean, Virginia

MONDAY, 27 MARCH

0830 **CONFERENCE WELCOME - BG Russ Zajtchuk, MC, USA,**
Commander, U.S. Army Medical Research and Materiel Command and
Chief Operating Officer, DOD Telemedicine Test Bed

0840 **TOOLS FOR PROCESS REENGINEERING**

Session Chair: James Zimble, MD, President, Uniformed Services University of the Health Sciences

Communication Technology
Fred Prior, PhD, Pennsylvania State University, Hershey, PA

Multimedia Technology
Yongmin Kim, PhD, The University of Washington

Computer Aided Diagnosis
Kunio Doi, PhD, The University of Chicago

Enabling Technologies for Telemedicine
Eric Tangalos, MD, Mayo Clinic

1000 **Panel Discussion**
1030 **Break**

1045 **VIRTUAL REALITY**

Session Chair: Honorable Anita Jones, PhD, Director, Research and Engineering, Office of the Secretary of Defense

Military Medicine and Virtual Reality
COL Richard Satava, MC, USA, Medical Program Office, Advanced Research Projects Agency

Medical Force Planning and Training in Simulated Environments
Norm Badler, PhD, University of Pennsylvania

Virtual Prototyping in Medical Battlefield Equipment and Devices
Ken Kaplin, PhD, Massachusetts Institute of Technology

Battlefield Casualty Care Using the Virtual Human
Scott Delp, PhD, MusculoGraphics, Inc.

1130 **Panel Discussion**

1200 **LUNCH (individually arranged, refreshments in exhibit area)**

1330 **INITIATIVES IN DIAGNOSTIC IMAGING**

Session Chair: Maj Gen George Anderson, MC, USAF, Deputy Assistant Secretary of Defense (Health Services, Operations and Readiness)

Filmless Radiology and Other Medical Imaging Services
Eliot Siegel, MD, Veterans Administration Hospital, Baltimore

MDIS Vision: Real Time Radiology
MAJ Bob Leckie, MC, USA, Walter Reed Army Medical Center

Soft Copy Diagnosis
MAJ Don Smith, MC, USA, Madigan Army Medical Center

Proactive Networks
Seong K. Mun, PhD, Georgetown University Medical Center

1430 **Panel Discussion**

1500 **Break**

1515 **VIDEO TOUR OF TELEMEDICINE EXHIBITS**

COL Anna Chacko, MC, USA, Brooke Army Medical Center

1530 **TELEMEDICINE: SPECIALTY APPLICATIONS**

Session Chair: MG John Cuddy, DC, USA, Commander, AMEDD Center and School

Surgical Simulation
MAJ Chuck Edmond, MC, USA, Madigan Army Medical Center

Digital Pathology
Lt Col Al Elsayed, MC, USAF, Armed Forces Institute of Pathology

Digital Radiography
LTC Michael Cawthon, MC, USA, Brooke Army Medical Center

Digital Mammography
Matthew Freedman, MD, Georgetown University Hospital

Teledentistry
COL Robert Vandre, DC, US Army Dental Research Detachment of the Walter Reed Army Institute of Research

1630 **Panel Discussion**

1700 **RECEPTION AND TOUR OF EXHIBITS**

TUESDAY, 28 MARCH

0830 **Welcome From GEN Jack Merritt, USA, (Ret.) Association of the United States Army President**

CLINICAL PERSPECTIVES WITHIN THE DOD

Session Chair: RADM Noel Dysart, MC, USN, Director of Medical Resources, Plans and Policy, Office of the Chief of Naval Operations

Medical Health Systems Support Perspective
Edward D. Martin, MD, Principal Deputy Assistant Secretary of Defense (Health Affairs)

Southeast Military Medical Region Perspective for Advanced Technology
BG Stephen Xenakis, MC, USA, Eisenhower Army Medical Center

Digital Free Marketplace
Jesse C. Edwards, MSCS, MSSM, Medical Advanced Technology Management Office

User Perspective, the Akamai Initiative
BG James Hastings, MC, USA, CDR, Tripler Army Medical Center

0945 **Panel Discussion**

1015 **Break**

1030 TECHNOLOGY ACQUISITION PERSPECTIVES WITHIN THE DOD

Session Chair: GEN Paul Gorman, USA (Ret.), Association of the United States Army

Global Information System Perspectives
Anthony Valletta, Deputy Assistant Secretary of Defense (Command, Control, Communications and Intelligence)

Advanced Development Rapid Prototyping for Telemedicine
COL Fred Goeringer, MS, USA, Medical Advanced Technology Management Office

Science and Technology Perspectives
Mr. George Singley, Deputy Assistant Secretary of the Army for Research and Technology (RDA)

Advanced Research Projects Agency Defense Health Care Perspectives
Donald P. Jenkins, PhD, Advanced Research Projects Agency

1130 **Panel Discussion**

1200 VIDEO TOUR OF EXHIBITS FOR PLENARY SESSION

1215 LUNCH (Full lunch in exhibit area)

1330 PLENARY SESSION - (Video link to Capitol Hill)

Perspectives from Government, Academia, and Industry

Introductory Remarks, Forum Chair
BG Russ Zajtchuk, MC, USA, Commander, U.S. Army Medical Research and Materiel Command and Chief Operating Officer, DOD Telemedicine Test Bed

Remarks By The Chief of Staff of the United States Army
GEN Gordon R. Sullivan, USA

DOD Medical Vision-Video Presentation from Capitol Hill
Honorable Stephen Joseph, MD, Assistant Secretary of Defense (Health Affairs)

Challenges for U.S. Medicine-Video Presentation from Capitol Hill
C. Everett Koop, MD, Senior Scholar, The C. Everett Koop Institute

Telemedicine Test Bed
LTG Alcide M. LaNoue, MC, USA, The Surgeon General, U.S. Army and Chief Executive Officer, DOD Telemedicine Test Bed

American Military Strategy: Challenges for Military Medicine
GEN Maxwell R. Thurman, USA (Ret.), Senior Fellow the Association of the United States Army

Advanced Technology Perspectives from Industry
Frank Lanza, Chief Operating Officer, Loral Corporation

Congressional Participation

1500 **Panel Discussion**
1530 **Break**

1545 PLENARY SESSION, CONTINUED

Perspectives from Government, Academia, and Industry—continued

Session Chair: Donald Jenkins, PhD, Advanced Research Projects Agency

The Role of Industry in Advanced Technology and Telemedicine
Catherine Burzik, President & CEO, Kodak Health Imaging Systems, Inc.
Bernie Gordon, Chief Executive Officer, Analogic
John R. Messier, Vice President and General Manager, Information Systems Division, GTE Government Systems Corporation
Michael LeBlond, Director of Communications and Collaborative Environments, Apple Computer, Inc.

1700 RECEPTION IN THE EXHIBIT AREA
Congressional participation by video link to Capitol Hill

WEDNESDAY, 29 MARCH

0830 **WORLDWIDE TELEMEDICINE PRACTICE**

Session Chair: MG Ronald Blanck, MC, USA, Commander, Walter Reed Army Medical Center

Ship to Shore & other Naval Telemedicine Initiatives
CAPT Paul Tibbits, MC, USN, Executive Officer, Navy Medical Information Management Center

Telemedicine Support in Zagreb
MG Chip Roadman, MC, USAF, Deputy Surgeon General, U.S. Air Force

Seahawk Project
MG James Peake, MC, USA, Commander, Madigan Army Medical Center

Real Time Imaging Service
Hans Mosser, MD, Danube Hospital, Austria

PrimeTime and SilverStreak Telemedicine Deployments
Linda Brink, PhD, U.S. Army Medical Research and Materiel Command

0945 **Panel Discussion**

1015 **Break**

1030 **POLICY ISSUES AND TECHNOLOGY ASSESSMENT**

Session Chair: COL Joan Zajtchuk, MC, USA, Special Assistant to the Army Surgeon General

Academia/Consortia Perspective
Jay Sanders, MD, Medical College of Georgia

Technology Assessment
Mr. Silas Olsson, Swedish Planning Research Institute

Consumer/Provider/User Perspective
Jane Preston, MD, President, American Telemedicine Association

Information Systems Perspective
Col John Silva, MC, USAF, Advanced Research Projects Agency

Industry Perspective
Betsey S. Blakeslee, PhD, Coordinator, Center for Total Access, Dwight David Eisenhower Medical Center

Outcome Initiatives
Norman W. Weissman, PhD, Medical Technology and Practice Patterns Institute

1130 **Panel Discussion**

1200 **LUNCH (Full lunch in exhibit area)**

1330 SUMMATION AND FUTURE PROGRAMS

Session Chair: MG Leslie Burger, MC, USA, Director for Health Services, Operations and Logistics, Office of The Surgeon General

The Emergence of Telemedicine for Process Reengineering
Edwin Deagle, PhD, SRA Corporation

Reengineering of Medical Departments Through the Defense Performance Review
John Evans, ESC & Mike Mekshes, Mitre

Reengineering of Rural Health Networks
Dena Puskin, PhD, Federal Office of Rural Health Policy

Enabling Systems Technology
Jack Pellicci, BG, USA (Ret.), Oracle Corporation

Acquisition Innovations in Military Medical Research
Mr. Greg Doyle, Director, U.S. Army Medical Research Acquisition Activity

Future ARPA Medical Programs
Donald Jenkins, PhD, Advanced Research Projects Agency

1445 **Panel Discussion**

1515 **CONFERENCE SUMMATION:**
COL Anna Chacko, MC, USA, Brooke Army Medical Center
Seong K. Mun, PhD, Georgetown University Medical Center

1530 **ADJOURNMENT:**
BG Russ Zajtchuk, MC, USA,
Commander, U.S. Army Medical Research and Materiel Command and Chief Operating Officer DOD Telemedicine Testbed

The Chestertown Roundtable: Developing Approaches for DoD Technology Assessment and Evaluation of Telemedicine

Investigators: Walid G. Tohme, PhD, Seong K. Mun, PhD, Matthew T. Freedman, MD, MBA, Jeff R. Collmann, PhD, Wendelin S. Hayes, DO, Gilbert B. Devey

A. Significance to the Military MDIS Project and Executive Summary

The Chestertown Roundtable of July 30-August 1, 1995, brought together around fifty clinical experts, technical developers, logisticians, technology assessment scholars, and policy makers, with a mission to develop a general framework for a technology assessment study of DoD telemedicine with major impact on national issues. Clinical, technical, managerial, and organizational needs were evaluated to provide answers to critical issues posed by telemedicine practitioners. The report from the Roundtable is expected to guide telemedicine planning and implementation in current and future evaluation efforts. The lessons learned from previous telemedicine efforts were taken into consideration and traditional technology assessment methodologies were examined to identify which tools are most applicable to technology assessment of telemedicine. Since there is no established model for technology assessment of telemedicine, one of the main results of the conference was that it should be based on a living multidimensional model which highlights the specific and general characteristics of each testbed effort.

B. Introduction

Telemedicine is a topic of intense and growing interest in the health care community. The U.S. military services are leading in the development and application of telemedicine technologies around the world -- technologies that are expected to have an enormous impact on the design of future health care systems both for military and civilian environments. A key element of the military planning process for telemedicine development and deployment is the use of external scientific peer review to enhance the validity and reliability of that process. An assessment of telemedicine technologies is an important element in determining validity, and a research team at the Imaging Science and Information Systems (ISIS) of Georgetown University is assisting the US military in conducting technology assessment efforts in telemedicine.

The Chestertown Roundtable held on July 30- August 1, 1995 in Chestertown, Maryland was the first step in the development of a rigorous academic and authoritative foundation for the evaluation of military telemedicine projects. It brought together around fifty clinical experts, technical developers, logisticians, technology assessment scholars, and policy makers for an in-depth exchange of ideas as well as discussing guidelines that can be applied in the evaluation of telemedicine efforts. The mission was to develop a general framework for a technology assessment study of DoD Telemedicine with major impact on national issues.

The rationale behind such a meeting is that there are many telemedicine projects that are being implemented today in the DoD but also in civilian projects in the US and around the world. However there is not a systematic evaluation of those projects that is being undertaken and no general framework for such an evaluation exists. By bringing together fifty experts in the field, the Chestertown Roundtable's goal was to bring academic rigor to the assessment efforts in telemedicine. The experts present in Chestertown were mainly divided in two groups: On the one hand, experts who have undertaken technology assessment studies in the pharmaceutical drug

evaluation and did not necessarily have a profound knowledge of telemedicine, and on the other hand, telemedicine proponents who have undertaken telemedicine projects but do not necessarily have a deep understanding of technology assessment methodologies (Figure 1). Therefore the first two general sessions were aimed at exposing general issues in telemedicine that needed to be evaluated as well as general technology assessment issues relevant to telemedicine. The group was then divided into two breakout groups: one dealing with clinical and technical considerations while the other dealt with managerial, organizational and administrative as well as policy issues. The two breakout groups then reconvened and finally presented their conclusions in the general session.

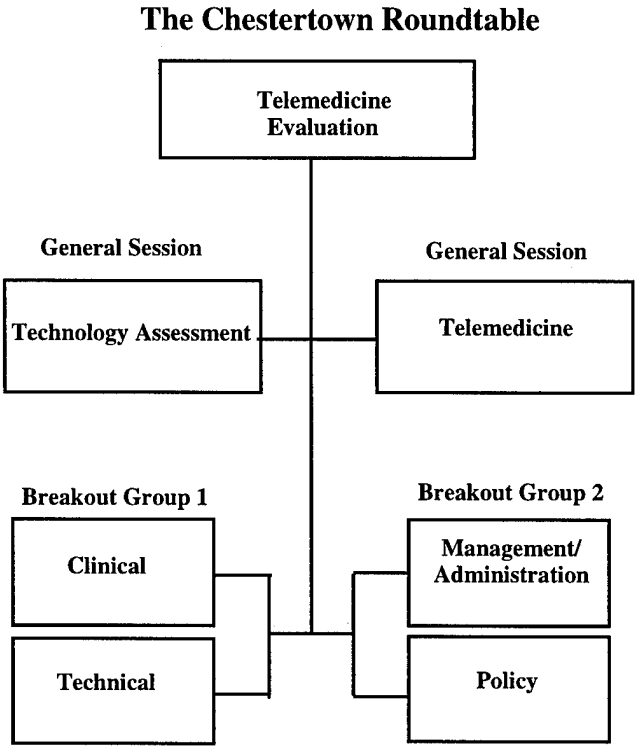

Figure 1

The participants in this meeting had diverse background due to the multidisciplinary aspect specific to technology assessment. These were divided into DoD and non DoD participants. The DoD participants were representing the Army, Air Force and Navy with MATMO (Medical Advanced Management Technology Office) headed by BG Zajtchuk and COL Goeringer. The non-DoD side had representatives of governmental agencies such as the Office of Technology Assessment, the Office of Rural Health Policy, the National Academy of Sciences, the National Library of Medicine, academic institutions and the private sector (Figure 2).

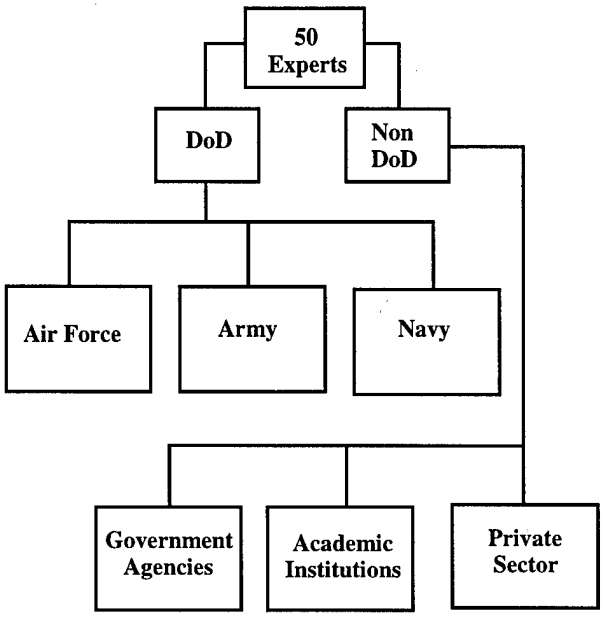

Figure 2

C. General Issues on Telemedicine

The general consensus was that telemedicine should be seen as part of the infrastructure for improving patient care and public health. It should have a continuum among peace time, disaster relief and combat casualty care environment. The Department of Defense is in a good position to lead telemedicine efforts and promote a paradigm shift in health care. The main thrust behind telemedicine is that it is a tool to improve access, quality and cost of health care from the perspective of patients, professional care providers, organizations and policy makers.

D. General Issues on Technology Assessment

The general session on technology assessment (TA) dealt first with the basic considerations of technology assessment studies. One of the main goals of technology assessment is to provide decision makers with reliable information about the value of the assessed technology. A general framework of TA must be an integral part of strategic planning of an organization.

It was agreed upon that there is no established model for TA of Telemedicine. Most participants felt that TA should be based on a living multidimensional model which highlights the specific and general characteristics of each testbed effort. This multidimensional model should include clinical, technical, management and policy issues.

Evaluation studies should be on needs assessment studies. This should be an iterative process in design, development, implementation and continuous quality improvement of care. Figure 3 shows the different stages in Telemedicine efforts leading to the continuous quality improvement of the process of care. The inputs, managerial, administrative, organizational and policy as well as the technical inputs based on the clinical need, drive the design and development stage of the process. This is followed by implementation and then technology assessment. Following

technology assessment, information related to possible improvements is fed back in a loop mode to the design stage where it can be incorporated in the next model. This process is based on the continuous quality improvement concept leading to better patient care.

Telemedicine and the Continuous Quality Improvement of the Process of Care

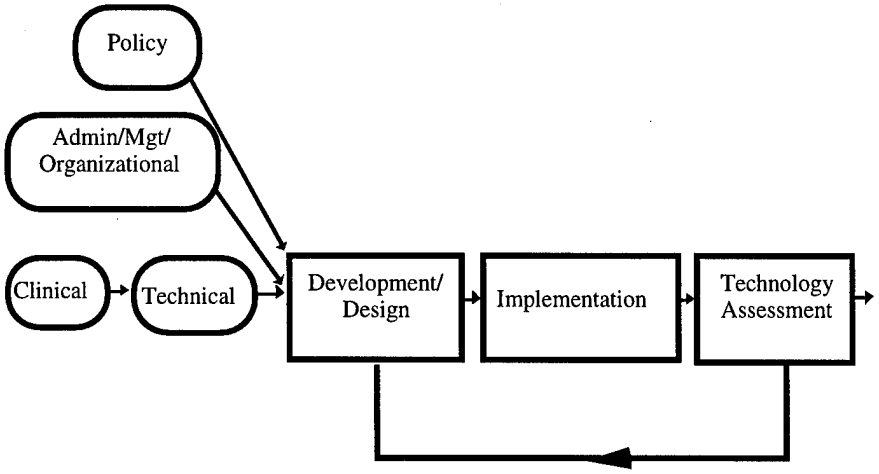

Figure 3

E. Evaluation of Clinical Aspect of Telemedicine

Approaches: The clinical aspect of telemedicine evaluation study considered whether those studies should address the question of Tmed being specialty based or process oriented. There are two ways of approaching an evaluation of telemedicine systems: one is the systems approach and the other is the piecemeal approach.

The systems approach :
- provides a complete understanding of the system
- is not likely to bias a project over another
- may become very vague

The piecemeal approach:
- builds on a portfolio of outcomes or resources
- comes up with specific requirements for specific applications (e.g.: ophthalmology project will present specific requirements for ophthalmology)
-it may be selective and present a bias towards winners

Clinical protocol for the use of telemedicine technology must be established.

Communication Paths: Evolving communication patterns among specialists, generalists and patients should be studied. There are three paths of communications in a Telemedicine environment: between specialists, specialist to generalist, specialist or generalist to patient. Changing patient flows within a health care network should be studied.

Integration of Telemedicine in the Practice of Care: Assessment studies should address the integration of Tmed capability into an organization in terms of reengineering and its timing. Do we have to make all changes at the same time, or do we consider these as serial activities. Do we fit into practice as it is or do we reengineer practice. How do we inbed telemedicine into the practice

of medicine? Should we use TMed to practice as we do now or should we reengineer heath care? Does this answer change over time?

Telemedicine must become part of routine activities of practitioner:
(1) place in path of clinician-office, while on rounds, not in separate facility
(2) Integration into medical record

F. Evaluation of Technical Aspect of Telemedicine

Telemedicine as a toolbox: Some participants supported the development of a toolbox for telemedicine: A set of standard input technologies, methods, and training material that could be developed based on experience with telemedicine projects that could then be used to simplify the implementation of new telemedicine projects. Also suggested was the concept that telemedicine was a set of services from which one could build a clinical scenario. One must define the services and tools necessary.

Technical Standards: Technical standards should be set by the professional societies. These standards should be set to promote technological innovation not stifle progress. Telemedicine systems must support interoperability, sharability, transferability and different degrees of redundancy: They should allow the sharing of information with other sites, should be interoperable on equipment of different suppliers, and whenever possible should be built with systems from the commercial sector so that costs and the risks of equipment not working would be decreased. The group discussed the importance of redundancy to avoid failure at times of critical operation. The degree of redundancy required would likely depend on the clinical scenario of the telemedicine project.

Optimization: Most current Tmed projects are based on commercially available video teleconferencing systems that are optimized for business applications not medical applications. Optimization of the technology and human factors studies should be an integral part of TA. Minimum performance requirement should be defined for specific clinical protocols.

Common Technological Platform: Most telemedicine systems today employ several monitors at the same time: one for transmitting images, one for the transmitting site for video conferencing, one for the receiving site for video conferencing and others for sharing documents, etc. What telemedicine should aim towards is a common technological platform that would incorporate radiology images with video images all on the same monitor supported by a common platform. The degree of dedicated or shared technological capability and common technological platform for various Tmed applications should be studied.

G. Evaluation of Management and Administrative Aspects

Implication of Telemedicine for DoD Healthcare: TA should address the implication of telemedicine for DoD health care objectives including reduction in killed in action (KIA), maintaining a deployable force, conserving the fighting force in the theater, maintain the families of the force, maintaining the retirees and changing logistical requirements of combat and dependent health care.

Impact of Telemedicine on the Operational Environment: TA must recognize that the deployment of Tmed will impact the operational environment and that the deployed environment may have significant impact on evaluation results.

Economic Analysis: Economic analysis must be done in a general context of the direct and indirect cost drivers of fiscal incentives. Telemedicine evaluation must include the study of intended and

unintended consequences. One can draw on the established models of technology assessment in health care.

Changing Professional Relationships: Telemedicine will change relationships among the patient, the generalist, the specialist, the subspecialist, the health aid, the physician's assistant and all the other participants in the role of providing care to the patient. There are several issues to be considered as these relationships change. Each of those stakeholders has to be satisfied with the system or it will fail.

Medical Decision Making: Telemedicine is likely to change the decision making process. The impact of such a change on each player within the network should be examined. In order to do so, the patterns of the medical decision making process in telemedicine should be studied.

TA should take into consideration the impact of different telemedicine models on tasks, performance expectation, training, recruitment and deployment for staff in different services.

H. Evaluation of Policy Aspect of Telemedicine

Digital Battlefield Initiative: TA study must address the implication of Tmed within DoD for reengineering of the force structure and digital battlefield initiative.

Joint Efforts between DoD and HHS: DoD and the Health and Human Services (HHS) department should develop joint efforts to integrate and disseminate results of telemedicine evaluation in a manner consistent with the Memorandum from the Office of the Vice- President : "Proposed Agenda for Promoting Health Care Applications of the National Information Infrastructure" dated March 8, 1995.

These joint efforts could include the development of a standard lexicon, the commission of on-going critical reviews of the literature and the establishment of a common repository of information on the Internet. There is a great need to establish and maintain a general repository of information about Tmed. This is can be achieved by expanding current WWW established by MATMO.

I. Suggested Method for Technology Assessment Studies

This discussion can be divided into five parts:

I.1 Deciding on a project to evaluate
I.2 Deciding on which questions to ask and what to assess
I.3 Deciding when to measure it
I.4 Deciding on the scope of the assessment
I.5 The tools for telemedicine assessment
I.6 Cautions

I.1. Deciding on a project to evaluate:

a. Administrative aspects: Technology assessment is usually performed to influence the decision of a policy or decision maker. One should select a project that will have a result meaningful to that stakeholder.

The project must be feasible to perform and feasible to assess.

The group discussed whether one should choose a likely 'winner' to assess--whether the goal of technology assessment was to promote the continued resource allocation to the project measured or whether this approach could cause a worthwhile project that did not have easily measured criteria to become unfunded.

b. Clinical aspects: There should be clear criteria to assess success or failure. The clinical problem addressed should be of importance to the stakeholders. One will usually choose a problem related to access, cost and/or quality.

I.2 Deciding on which questions to ask and what to assess:

One can develop a list of the types of questions that one could ask. Some people put this in a multidimensional matrix as a way of deciding which items to hold constant and which to vary as well as to review the various type of statistical design methods. Such a matrix can include: types of technologies, types of health problems, impact of technology on cost, access, quality, evaluation with case method or group method, randomized trial, epidemiological, etc.

I.3 Deciding when to measure it:

Telemedicine is an evolving technology. It will likely be changing as it is being measured. If one waited until it became stable, technology assessment would loose much of its value in its role as an aid to decision makers and also in its role of recommending improvements in the technology. If one measures too early, the costs will be higher because of startup costs and training costs.

Telemedicine is likely to result in the re-engineering of how medical care and health care are delivered. The group discussed the options of measuring telemedicine when it is an incremental addition to medical care as now practiced vs. the option of measuring it after reengineering was complete, vs. following some specific period of partial reengineering.

* While telemedicine is now an amorphous jumble, technology assessment will help delineate the framework in which it will evolve. We do not need to wait too long before assessing. This is the "don't assess me yet" syndrome where it is always too early until it is too late. The problem with waiting to assess a technology is that the focal technology will change and other technologies will accumulate on top of that making it even harder to assess.

I.4 Deciding on the scope of the assessment:

The group reflected a variety of opinions on the recommended scope of the assessment. There were people who wanted to measure the whole system and measure the changes resulting from adding telemedicine to it, there were others that encouraged the measurement of pieces of the system as being more realistic in terms of resource availability. Those preferring the total systems approach were concerned about the 'Jello' effect: if you don't measure everything, the outcome you measure may be favorable, but the effect elsewhere in the system may be unfavorable.

I.5 The tools for telemedicine assessment:

Questionnaires, interviews, observation of telemedicine transactions, electronic analysis of voice patterns were each briefly discussed. Concern was expressed by several panelists regarding the possibility that the measurement itself (especially if it was a questionnaire) would interfere with the process being measured and result in the telemedicine system being used less. There seemed to be a preference, whenever possible, of building the assessment into the telemedicine system so that it was transparent or invisible to the user.

I.6. Cautions:

Several topics arose that can be considered concerns, limitations or obstacles to the implementation of telemedicine that also related to the technology assessment of telemedicine. These can be classed as

i. Legal
ii. Confidence in provider and consultant
iii. Conflicts among stakeholders

iv. Monetary
v. Standards for telemedicine
vi. Human factors

i. Legal. Current licensing laws limit the implementation of telemedicine across state lines except for the military.

How does one incorporate the telemedicine process into the medical record? An electronic medical record can include digital video or one can retain the videotape. Since videotapes can be altered, there is a need for assuring that the videotape has not been changed.

ii. Confidence in provider and consultant. If you do not know the person with whom you are communicating, you do not know their qualifications. You do not know their observational skill level, their technical skill level or their cognitive skill level and yet you are relying on them in the telemedicine consultation to be giving you valid information. This increases the risk of the interaction.

iii. Conflicts among stakeholders. The stakeholders for telemedicine include the care providers, the patients, and the payers. The stakeholders for technology assessment of telemedicine are the payers and the policy makers. Conflicts among these stakeholders, can slow or torpedo the implementation of telemedicine. Some telemedicine tests sites have had very low utilization rates. Conflicts among stakeholders may be part of the cause of this.

iv. Monetary. Currently telemedicine activities are not paid for by insurers. Thus in a telemedicine setting, the requesting physician will end up spending more time to obtain the consult and the consulting physician goes unpaid. This is not a problem for the DoD physician, but is a limitation in the civilian sector. Because civilian insurance rarely pays for transportation to the specialty site of care, that expense is borne by the patient and patients family not the insurer.

v. Standards for telemedicine. The group supported the concept that standards for telemedicine should be devised by the clinical specialty and subspecialty groups for that field of care, similar to those provided by the American College of Radiology. The concern, however, was expressed that if those standards result in the need for systems that are too expensive, certain underserved poor communities may be precluded from implementing telemedicine resulting in a lower quality of care than would result if the standards were not so strict and an intermediate quality of telemedicine were introduced.

vi. Human factors. An evaluation of human factors and human-machine interactions is considered important in the evaluation of telemedicine and is considered important in improving the quality of telemedicine. In some installed telemedicine sites, utilization has been low, and because of high fixed costs, the low utilization results in high costs per consult. The group considered that failure to recognized the impact of human factors may have contributed to the low utilization rates. Some of these human factors relate to human-machine interactions where the systems are to some degree awkward to use, are not intuitive in operation, and have cameras that may not be properly positioned.

Also considered was the implicit economic threat of having consultants competing for patients with the local practitioner vs. the increased time required of the local practitioner to participate in a telemedicine consultation, without remuneration, whereas the consultation that occurs from sending the patient to a consultant does not necessarily carry the same amount of increased time.

J. The Importance of the DoD Health Care System in the Evaluation of Telemedicine

The DoD health care system was considered by most participants as being an important system for testing new concepts in telemedicine. It has the advantage of eliminating the economic incentives and disincentives of health care providers that might interfere with its introduction, has a patient population some of which are located in medical underserved regions, in tends to bear the total cost of illness--both that caused by disease and preventive services as well as that resulting from loses of productivity that result from illness, as well as being responsible for transportation costs when patients must be treated away from their home base. The group also generally agreed, that these advantages that the DoD health care community were also inherently present in the civilian sector, but that because the costing of these factors was not generally included as a cost of health care, that the benefits that result from telemedicine would be more difficult to document in the civilian sector. Even though the gains in worker productivity and the decreased transportation costs were just as real, they tend to be borne by the patient rather than by the system.

K. Conclusion

The Chestertown Roundtable of July 30-August 1, 1995, was the first step in the development of guidelines for the evaluation of military telemedicine projects. It brought together around fifty experts, DoD and non-DoD to look into the development of a general framework for DoD telemedicine assessment . The differences among the group appeared to be mainly of degree, rather than of principles. There were disagreements as to the complexity of technology assessment that should be performed and the amount of system reengineering that should take place before the telemedicine system should be evaluated. The group did agree that telemedicine is here today and will continue to grow no matter what technology assessment may show, but that depending on the results of the technology assessment projects performed, the speed of dissemination of telemedicine could be accelerated for slowed. Most importantly, the group recognized that the properly performed technology assessment of telemedicine would provide a guide towards methods of improving the value of telemedicine within the health care system.

L. Participants

Non-DoD

Ms. Karen Bandy
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Office of Technology Assessment
United Stated Congress

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Walid G. Tohme, PhD
Research Fellow
Georgetown University Medical Center

8.2 The Fourth International Conference on Image Management and Communication (IMAC 95)

Conference Organizer: Seong K. Mun, PhD

The IMAC conference recognizes that successful implementation of computer and communication technologies to manage medical images requires close coordination of technology, management and policy. Successful clinical implementation of film independent IMAC networks in the United States, Austria, Korea and other countries, suggests that the IMAC network is no longer a technological experiment. Application of teleradiology and telepathology has been extensive throughout the world. More recently, video based telemedicine has become highly popular, especially in the United States. Establishment of digital imaging and communication infrastructure enables the development of new and innovative use of medical images, such as robotic surgery, computer aided diagnosis and intelligent data management. IMAC capability is now seen as a tool to develop a new business plan for the '90s. The success of IMAC technology has been spectacular, but a number of key issues remain in standards, technology assessment, confidentiality of data, government policy in technology, and design of new imaging services.

Following the tradition of previous IMAC International Conferences, experts in academia, management, government and industry participated in lively discussions to review past progress and formulate future direction. A combination of plenary and poster sessions facilitated ample opportunity for dialogue and debate. IMAC 95 continued the tradition of facilitating dialogue and discussion on the medical use of advanced imaging and communication technologies

IMAC 95 was jointly sponsored by the office of the Governor of Hawaii as the Eleventh Annual Governor's Symposium on High Technology. IMAC 95 is grateful for the support from the State of Hawaii.

IMAC 95

Scientific Program

Sunday, August 20, 1995

14:00 – 20:00 **REGISTRATION**

18:00 – 20:00 **Ice Breaker**

14:00 – 16:00 **Discussion on Harmonization of Standards**

14:00 – 17:00 **TUTORIAL:** (Additional Registration Required)

Tutorial Coordinator: Betty Levine, MS, Georgetown University Medical Center, Washington, D.C., USA

Eliot Siegel, MD, Baltimore VA Medical Center, Baltimore, Maryland, USA
Technology of PACS

Betty Levine, MS, Georgetown University Medical Center, Washington, D.C., USA
Information Systems and Integration

Matthew Freedman, MD, MBA,, Georgetown Univ. Med. Ctr, Washington, D.C., USA
Digital Radiography

Yongmin Kim, PhD, University of Washington, Seattle, USA
"Multimedia Workstation and Application in High-Speed Telemedicine"

Hyungsik Choi, MD, Samsung Medical Center, Seoul, Korea
"Clinical Implementation of Samsung Medical Center PACS"

Heinz Lemke, PhD, Technische Universitat Berlin, Germany
Communication Technology

Monday, August 21, 1995

7:30-15:30 **REGISTRATION**

7:30 **Continental Breakfast**

8:30 **Session 1: Eleventh Annual Governor's Symposium on High Technology: Medical Imaging and Information Systems**

Chair: Barbara Kim Stanton, Exec. Dir. and CEO of High Technology Development Corp., Honolulu, Hawaii, USA
Chair: David Yun, PhD, Department of Electrical Engineering, University of Hawaii, Honolulu, USA

Representative of the Department of Health
Hawaii, USA

Ken Cole
Director, Maui High Performance Computing Center, Hawaii, USA

Bill Santos
President, PacSPACE. Hawaii, USA

Brian Martin
Martin Information Systems, Hawaii, USA

Javed Khan
University of Hawaii, Hawaii, USA

11:00 **Session 2: IMAC Opening Session**

Chair: Seong K. Mun, PhD, Georgetown University, Washington, D.C., USA
Chair: Masayoshi Akisada, MD, Chair IMAC91, Tokyo, Japan

Honorable Governor Benjamin Cayetano of Hawaii*
Opening Address

Honorable Senator Daniel Inouye*
Key Note Address

BG Russ Zajtchuk, MD, Commander*
Army Medical Research and Materiel Command, Fort Detrick, Maryland, USA
"Role of Telemedicine in Military Medicine"

Man Chung Han, MD, PhD*
Seoul National University, Seoul, Korea
"Imaging Service in Network Environment"

COL John Silva, MD
ARPA, Washington, D.C., USA
"Integrated Approach to Medical Information Network"

* Invited and To Be Confirmed.

10:30 **Coffee Break**

12:30 **Lunch**

14:00 **Session 3: Harmonization of Information Standards**

Chair: Fred Prior, PhD, Penn State University, College of Medicine, Hershey, Pennsylvania, USA
Chair: Heinz U. Lemke, PhD, Technische Universitat, Berlin, Germany

Nagaaki Ohyama, PhD, MEDIS-DC and Tokyo Institute of Technology, Yokohama, Japan

Steven Horii, MD, ACR/NEMA and the University of Pennsylvania, Philadelphia, USA
"The DICOM Efforts"

Kouichi Kita, MEDIS-DC, Tokyo, Japan

David Best, ACR/NEMA and Kodak Corp., Rochester, New York, USA

Masuyoshi Yachida, PhD, MEDIS-DC and RICOH Info. and Comm. R&D Ctr., Japan

15:30 **Break**

16:00 **Session 4: Hospital-Wide PACS System**

Chair: Nagaaki Ohyama, PhD, MEDIS-DC and Tokyo Institute of Technology, Yokohama, Japan
Chair: Meryll M. Frost, Jr., PhD, University of Florida, Gainesville, USA

Eliot Siegel, MD, Baltimore VA Hospital, Baltimore, Maryland, USA
"PACS in a 'Digital Hospital': Experience with Filmless Operation at the Baltimore VA Medical Center"

Tetsuo Okabe, PhD, Tokyo Hitachi Hospital, Japan
"Four Years' Experience of Hospital-Wide PAC System"

Duk-Woo Ro, PhD, Samsung Medical Center, Seoul, Korea
"PACS at Samsung Medical Center: Thirty Something"

Dan Shock, MA, RT(R), West Virginia University, Morgantown, West Virginia, USA
"Phased Approach to DICOM Compliant Medical Imaging System for a Health Care Network"

Matthew Freedman, MD, MBA, Georgetown University Medical Center, Washington, D.C., USA
"Redesigning the Patterns of Radiological Practice for the 21st Century: Digital Imaging. Digital Networks, Digital Medical Records"

Jens Ricke, MD, Virchow-Klinikum, Humboldt University, Berlin, Germany
"Computer Conferencing Support in Radiology–How Economic Viability Will Make it the Radiologist´s Workspace of the Next Decade"

18:00 **Poster Session (Monday Evening Only)**

The RFI (Request for Information) as a Tool to Identify an Optimal Departmental and Institutional PACS
Pradeep Mutalik, PhD, Vladimir Neklesa MD and Henry Swett MD
Yale University, School of Medicine, New Haven, Connecticut, USA

Large-Scale Laser Film Digitization and CD-ROM-Based Image Archival: Experience with a High-Resolution Workstation for Multicenter Osteoporosis Drug Trials
Janos Redei, PhD, X. Ouyang, PhD; K. Engelke, PhD; C.-C. Glüer, PhD; H.K. Genant, MD
University of California, San Francisco, California, USA

Comparison of Rural Remote Site Production of Digital Images Employing a Film Digitizer or a Computed Radiography (CR) System
Dan Shock , MA, RT(R), Mathis Frick, MD, Kenneth Douglas, PhD
West Virginia University, Morgantown, West Virginia, USA

Image Presentation Options for a Distributed PACS Environment
F. Habbal, PhD and E.B. Cargill, PhD
Polaroid Corporation, Waltham, Massachusetts, USA

Approaches to the Ethical Administration of Computerized Medical Records
Jeff Collmann, PhD, Georgetown University Medical Center, Washington, D.C., USA

Heavy-Ion Medical Accelerator in Chiba
Kiyomitsu Kawauchi, PhD,(1), Hidenobu Sakamoto, Ph.D. (2),
Kenjiro Ikeuchi (2), Hidetoshi Konishi (2)
(1)National Institute of Radiological Sciences, (2)Mitsubishi Electric Corporation, Japan

Developments and Directions of Technology Assessment in Telemedicine
Walid Tohme, PhD (1), and Silas Olsson (2)
(1) Georgetown University Medical Center, Washington, D.C., USA
(2) SPRI, Stockholm, Sweden

Designing a Telemedicine Platform for Three Different Medical Applications
Walid Tohme, PhD, Wendelin Hayes, DO, Seong K. Mun, PhD,
Darmadi Komo, Marion Meissner
Georgetown University Medical Center, Washington, D.C., USA

RIS Interface for Mammography Results and Patient Reporting
James L. Halverson, MD, Deb Dolezal, RT(R), Mary Lechner, MD,
Eugene Elvecrog, MD, Michael T. Nelson, MD
Park Nicollet Medical Center, Minneapolis, Minnesota, USA

Data Conversion between IS&C Format and DICOM Format Images in a Personal Computer Environment
Yutaka Ando, PhD, Osamu Kawaguchi, Masayuki Kitamura, Katsuhiko
Ogasawara, Atsushi Kubo, Yoichi Arai *
Dept. of Radiology, Keio University, Japan
*IS&C-PT, RICOH Company, Japan

Image Management and Communication at Primary Health Care Center in Sweden: Experience and Results
Göran Karner 1) , Mjölby Primary Healthcare Center, Mjölby, Sweden
Silas Olsson 2), Spri, Stockholm, Sweden

An Adaptive Multi-Disciplinary Telemedicine System
William Chimiak, PhD, Robert Rainer and Jay Cook
Bowman Gray School of Medicine, Winston-Salem, North Carolina, USA

High Performance, Multi-Level RAID Image Servers
Dennis Wilson, PhD, Robert Glicksman, Ken Shastri and Mitchell Goldburgh
Loral Medical Systems, San Jose, California, USA

PACS and Medical Media in a 'Filmless' Hospital
Eliot Siegel, MD, Baltimore VA Medical Center, Baltimore, Maryland, USA

Niche-PACS: Entree to a Hospital-Wide IMAC System
Dave Zelitt, MD, Rick Holmes, Charles Willis, PhD,
University of Texas, Houston Health Science Center, USA

Digital Mammography: Current Status
Matthew Freedman, MD, MBA, Dot Steller, RT (R)(M), Jacqueline Hogge, MD, Raj Katial, RT (R)(M), Rebecca A. Zuurbier, MD, Hamid Jafroudi, PhD, Seong Ki Mun, PhD
Georgetown University Medical Center, Washington, D.C., USA

Dual Telepathology Workstation Design and Results
Steven A. Lange, PhD and Arvie A. Lake, Jr.
Boeckleler Instruments, Inc., Tucson, AZ, USA

Image Archive Evolution at the University of Florida
Meryll M. Frost, Jr., Janice C. Honeyman, Edward V. Staab
University of Florida, Shands Teaching Hospital, Gainesville, Florida, USA

The Use of Soft Copy to Enhance the Interpretation of Hard Copy Digital Images
Major Amy E. Benson and COL Anna K. Chacko
Brooke Army Medical Center, Fort Sam Houston, Texas, USA

A Scalable Teleradiology System
Bruce K.T. Ho, PhD, Hooshang Kangarloo, Richard J. Steckel
University of California at Los Angeles, USA

Teleradiology over the Internet
Darmadi Komo, Paul Keezer, Seong K. Mun
Georgetown University Medical Center, Washington, D.C., USA

Creation of a Collaborative Radiology Database
Mohan R. Ramaswamy, MD, Lloyd Yin, BS; David Patterson, MD;
HK Huang, DSc; Ronald L. Arenson, MD; Eric vanSonnenberg, MD
University of Texas Medical Branch, Galveston , USA

A Business Approach to PACS Implementation: Cost Projections and Data Networking
Mary Shaw, RT(R) and Quentin Anderson, MD
Hennepin County Medical Center, Minneapolis, Minnesota, USA

Tuesday, August 22, 1995

7:30-15:30 **REGISTRATION**

7:30 **Continental Breakfast**

8:00 **Session 1: Tripler Army Medical Center**

Chair: TBD
Chair: TBD

Mark Hansen, COL, MC, TAMC, Honolulu, Hawaii, USA
"Radiology and the Digital Environment in the Pacific"

Brian Goldsmith, MD, TAMC, Honolulu, Hawaii, USA
"The Remote Radiation Therapy Treatment Planning Project"

Jay Cook, LTC, MC, TAMC, Honolulu, Hawaii, USA
"Telemedicine in the Pacific"

9:30 **Coffee Break**

10:00 **Session 2: Virtual Library**

Chair: Naomi Broering, MLS, MA, Georgetown University Medical Center, Washington, D.C., USA
Chair: TBD

Thomas G. Basler, University of South Carolina, Charleston, South Carolina, USA
"The Virtual Library and the Curriculum"

Naomi Broering, MLS, MA, Georgetown University Medical Center, Washington, D.C., USA
"Digital Image Library Collection of Educational Programs"

Scott T. Plutchak, St. Louis University, St. Louis, Missouri, USA
"Electronic Publishing and the Virtual Library"

Roger Guard, University of Cincinnati, Ohio
"The Ohio Valley Community Health Information Network (OVCHIN)"

11:30 **Lunch**

13:00 **Session 3: Digital Pathology and Telepathology**

Chair: LTC Al Elsayed, MD, Armed Forced Institute of Pathology, Washington, DC, USA
Chair: Steven Lange, Boeckleler Instruments, USA

Yukio Shimosato, National Cancer Center, Tokyo, Japan

J. O'D. McGee, Oxford University, United Kingdom

Tor Jacob Eide, University of Oslo, Norway

Charles Pemble, AFIP, USA

LTC Al Elsayed, MD, AFIP, Washington, DC, USA

17:00 **Banquet at Polynesian Cultural Center** (Bus leaves hotel at 17:00)

Wednesday, August 23, 1995

7:30-15:30 **REGISTRATION**

7:30 **Continental Breakfast**

8:00 **Session 1: IMAC Systems**

Chair: Yongmin Kim, Ph.D., The University of Washington, Seattle, USA
Chair: F. Habbal, Polaroid Corporation, Waltham, Massachusetts, USA

Richard L. Morin, PhD, Mayo Clinic Jacksonville, Florida, USA
"The Electronic Radiology Practice at Mayo Clinic Jacksonville"

Michael A. Cawthon, DO, LTC(P), MC, US Army, Brooke Army Medical Center, Fort Sam Houston, Texas,
"Soft Copy Interpretation Implementation Strategies"

Robert A. Glicksman, Loral Medical Imaging Systems, San Jose, California, USA
"Image Management in a Multi-Hospital Environment"

T. Shiga, PhD, Hokkaido University School of Medicine, Sapporo, Japan
"Application of PACS to Stereotactic Radiosurgery (SRS)"

J.A. Rafael, PhD, University of Aveiro/INESC, Aveiro, Portugal
"A Distributed Multimodality IMAC Architecture"

9:30 **Coffee Break**

10:00 **Session 2: Evaluation of IMAC**

Chair: Jean-Francois Moreau, MD, Hopital Necker, Paris, France
Chair: Bruce K.T. Ho, PhD, University of California, Los Angeles, California, USA

Kiyonari Inamura, PhD, Osaka University, Osaka, Japan
"Electronic Filing of Medical Images - Its Costs, Reimbursement and Standardization"

W.M. Boushka, Brooke Army Medical Center, Fort Sam Houston, Texas, USA
"Time Requirements of Hard- versus Soft-Copy Interpretation of SICU Computed Radiographic Images"

Gerhard Haufe, PhD, Siemens AG, Erlangen, Germany
"Film is Silver, Can IMAC-Systems be Gold?"

Bernard Crowe, MPH, Health Informatics Society of Australia, Canberra, Australia
"Evaluation of Teleradiology at a Children's Hospital"

11:30 **Lunch**

Chair: Melvyn Greberman, MD, Food and Drug Administration, Rockville, Maryland, USA
Chair: TBD

Augusto Silva, PhD, INESC/DET University of Aveiro, Portugal
"Telecineangiography: A Case Study with Client-Server Environments and ATM Backbones"

Kenneth H. Cho, MD, Walter Reed Army Medical Center, Washington, D.C., USA
"The Internet and Radiology- The Walter Reed Experience with the World Wide Web"

Lutz Kleinholz, PhD, Virchow-Klinikum, Berlin, Germany
"Multimedia Medical Conferencing with PC and ISDN: Results of the Komet Project"

Jean-Francois Moreau, MD, Hopital Necker, Paris, France
"Teleteaching for Medical Education: Why and How to Do It"

14:30 **Coffee Break**

15:00 **Session 4: Assessment of Telemedicine**

Chair: Silas Olsson, SPRI, Stockholm, Sweden
Chair: Bernard Chang, MD, The Johns Hopkins Medical Institution, Baltimore, USA

Silas Olsson, SPRI, Stockholm, Sweden
"Evaluation of Telepathology in Sweden"

Octavio Barbero, PhD, Unitat de Diagnostic per la Imatge d'Alta Technologia, Sabadell, Spain
"Development and Implementation of Two Teleradiology and Teleconsulting Applications in Catalunya: RAIM and CARE"

Jean-Pierre Thierry, PhD, CNEH, Paris, France
"The Current Status of Telemedicine in France"

Steve Mills, PhD, The University of Virginia, Charlottesville, Virginia, USA
"Process Models as Templates for Healthcare Standardization and Management"

Kathleen O'Malley Coumans, SAIC, San Diego, California, USA
Development of a Model for the Analysis of Cost-Effectiveness for Telemedicine Services

Thursday, August 24, 1995

7:30-15:30 **REGISTRATION**

7:30 **Continental Breakfast**

8:00 **Session 1: Digital Imaging**

Chair: TBD
Chair: Duk-Woo Ro, PhD, Samsung Medical Center, Seoul, Korea

Michael T. Nelson, MD, Park Nicollet Medical Center, Minneapolis, Minnesota, USA
"A Clinician's View of Digital Mammography"

Stephen M. Pomerantz, MD, Baltimore VA Medical Center, Baltimore, Maryland, USA
"PACS in the Operating Room: Experience at the Baltimore VA Medical Center"

Mohan Ramaswamy, MD, University of Texas Medical Branch, Galveston , Texas, USA
"Implementation of Computed Radiography in a Trauma Center"

Kenichiro Kajiwara, MD, Kurume University Hospital, Kurume, Japan
"HDTV as the High Resolutional Color Display Terminal for Digital Images"

9:30 **Coffee Break**

10:00 **Session 2: Intelligent Systems**

Chair: Kiyonari Inamura, PhD, The University of Osaka, Osaka, Japan
Chair: TBD

Vladimir P. Neklesa, MD, Yale University School of Medicine, New Haven, Connecticut, USA
"A Prototype System for Feature-Directed Automatic Searching of Image Databases"

Javed Khan, PhD, University of Hawaii, Honolulu, Hawaii, USA
"Content-Based Search in Medical Image Archive"

Spiros Dembeyiotis, National Technical University of Athens, Greece
"An Image Processing and Management System for Radiology'"

Andrew Laine, PhD, University of Florida, Gainesville, Florida, USA
"Wavelet Processing Techniques and Multiscale Representations for Computer Aided Diagnosis of Digital Mammography"

11:30 **Lunch**

12:30 **Session 3: Information Systems**

Chair:
Chair: Bill Chimiak, Ph.D., Bowman Gray School of Medicine, Winston-Salem, North Carolina, USA

Yasser Alsafadi, PhD, University of Arizona, Tucson, Arizona, USA
"Digital Video Server for Ultrasound Services"

William Chimiak, PhD, Bowman Gray School of Medicine, Winston-Salem, North Carolina, USA
"A Flexible Telepathology System"

Lutz Kleinholz, PhD, Virchow-Klinikum, Berlin, Germany
"Multimedia Medical Conferencing with PC and ISDN: Results of the Komet Project"

Scott Foshee, Booz, Allen & Hamilton, Inc., McLean, Virginia, USA
"Mixed Image Format Environments: Comparisons, Tradeoffs, and Issues"

14:00 **Coffee Break**

14:30 **Session 4: New Approaches for IMAC**

Chair: TBD
Chair: Charles Willis, PhD, University of Texas, Houston Health Sciences Center, Houston, Texas, USA

Robert Leckie, MDIS Project Team, Fort Detrick, Maryland, USA
"A PACS and Telemedicine Configuration for Walter Reed Army Medical Center and the National Capital Region"

Mark DeSimone, General Electric Corporation, Milwaukee, Wisconsin, USA

F. Kruggel, PhD, Max-Planck-Institute for Cognitive Research, Leipzig, Germany
"A Collaborative Image Database Out of the Box"

Fred Prior, PhD, Penn State University, College of Medicine, Hershey, Pennsylvania, USA
"Database Access Methods for Medical Imaging: DICOM, SQL and HTML"

Antonio Sousa Pereira, PhD, Universidade de Aveiro/INESC, Aveiro, Portugal
"A Teleradiology Experiment in Portugal using an ISDN Based System."

16:00 **Closing Statement**

Seong K. Mun, PhD, Georgetown University Medical Center, Washington, D.C., USA

8.3 Developments of Telemedicine Applications: A Methodological Review

Investigators: Walid G. Tohme, PhD and Silas Olsson*

*Swedish Institute for Health Development (Spri), Stockholm, Sweden

A. Significance to the Military MDIS Project and Executive Summary

There are several telemedicine projects being developed today. Many of them are in the military and DoD environments but there are also many others in civilian applications. In order to keep track of those disparate efforts, we have developed a methodological review of more than 125 different telemedicine related efforts documented in the literature. The goal is to provide a quick reference and classification review of the most relevant efforts undertaken in the field.

In this work, we have reviewed over 125 papers about telemedicine, published and listed in medical databases (mainly in Medline). There is a difference in the approaches in technology assessment, undertaken by the studies performed during the past few years. Before this date, assessments focused on technical feasibility like network performance, image quality, etc.. Today papers can be found showing results regarding medical performance and medical implications, patient satisfaction, and economical consequences. Other efforts include cost-effectiveness, organizational infrastructure, ethical consequences, data security and confidentiality, and healthcare policy implications.

B. Introduction

Telemedicine, or medicine at a distance, is being tested in various medical fields including radiology, pathology, dermatology, psychiatry, etc. Telemedicine projects have been flourishing lately to a great extent. After some initial trials in the late 1950s [1-3], other telemedicine efforts were established in the 1970s. However, few of them survived due to lack of continued support once the initial funding was over [4]. Few evaluation efforts were undertaken then to justify the need for telemedicine [5,8].

Since the early 1990s, fueled by the tremendous technological leaps accomplished in telecommunications technologies, many new telemedicine projects are being undertaken. With them, technology assessment efforts are also being undertaken in one form or another.

When telemedicine projects were first initiated in the 1950s and then in the 1970s, few evaluation efforts were undertaken. Most telemedicine papers or reports were descriptive. Costs of the technologies were not described but the technology itself and the way to achieve it was well documented [5-9]. However the technical efficacy of the systems was not fully established.

Recently many studies and reports have been interested in the evaluation of telemedicine in order to justify other dimensions than the basic technical configuration and system design. Today telemedicine systems have to respond to a specific clinical need and cannot be technology driven. The stage of technological wizardry has passed and it is now very important to establish the need for telemedicine along all dimensions of technology assessment. Those include economic

analyses, studies of organizational impact, ethical consequences, data security and confidentiality and health care policy and legal implications.

In this paper, we reviewed over 125 papers related to telemedicine projects and efforts to evaluate them.

C. Methodology

We have divided the studies into a matrix with several dimensions based on the different aspects taken into consideration by the studies we examined [Figure 1].

The studies were divided along three main axes: studies that relate to projects in the pre-implementation phase, studies that look at the status, potential and review the current literature and finally projects that are in the post-implementation and clinical trials phases. The first group was further stratified into three categories: feasibility, technical and clinical issues. The second into four categories: studies of educational and teaching potential, literature and general reviews, policy and patient confidentiality issues as well as security and ethical questions raised by telemedicine and finally standards questions and telemedicine definitions. The third group was stratified into six categories: Technical issues, clinical trials, economical analyses including cost-benefit, cost-effectiveness and cost-minimization analyses, user and patient satisfaction studies, studies looking into organizational and structural issues and finally studies considering general aspects of telemedicine. The studies were also categorized with respect to which clinical application they considered [Figure 2].

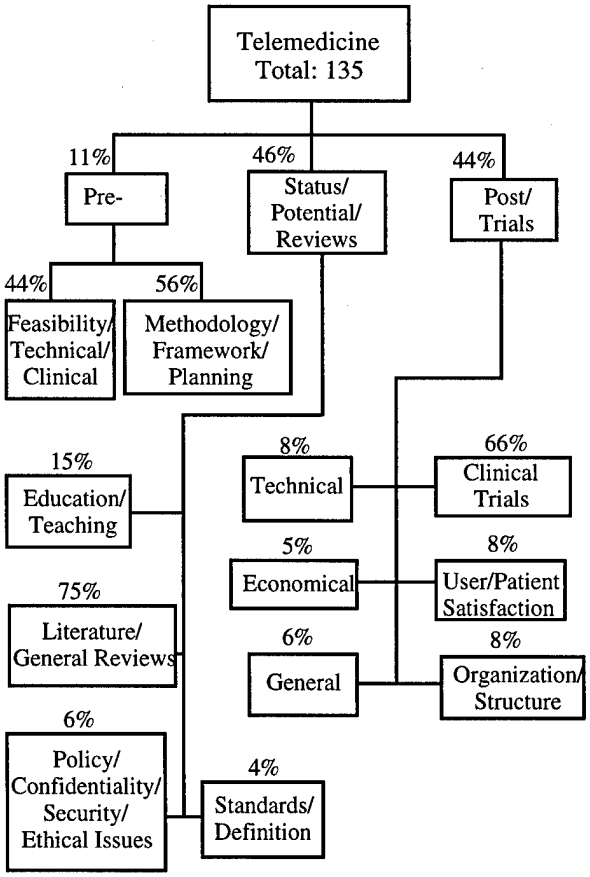

Figure 1

D. Results

Our results show that post-implementation constitutes less than half of the papers considered (44%). While the technical requirements for teleradiology seem to have been established (to a lesser degree with telemammography), requirements for telepathology applications are not yet developed. The applications in terms of technology range from simple telephone consultation [10-15] to robotic telepresence surgery [16-22]. Almost all papers seem to be very enthusiastic about the prospects of telemedicine. However the vast majority of clinical projects are based on a small number of patients. User education and ease of use of the system as well as whether the telemedicine technology needs to be embedded in the routine practice of care seem to be crucial to improve clinical results.

The studies considered 20 different clinical applications with slightly more than 20% of those relating to projects in radiology while less than 20% covered pathology related applications.

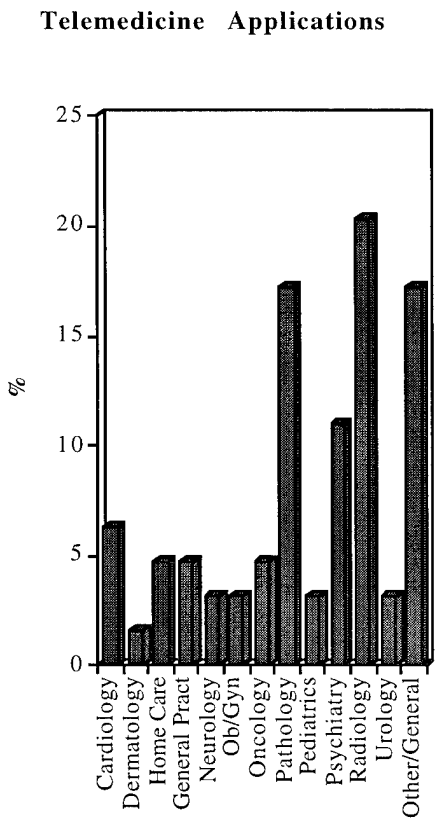

Figure 2

E. Conclusion and Discussion

In this study, we have reviewed over 125 papers related to telemedicine projects. Our methodology categorized the papers into a multidimensional matrix with different categories where each study would fit. This review clearly shows that health care delivery based on telemedicine is still in its infancy. However, some applications are significantly more diffused such as teleradiology, telepathology and telepsychiatry although technical requirements for telepathology are not finalized. While the range of technologies covered is very wide, they all share the same enthusiasm about the potential of telemedicine. No doubt, telemedicine will be seen, when further developed, as a very powerful tool to improve access to healthcare, raise the quality and efficiency and control the cost of health care delivery.

Only very few telemedicine applications are used in daily clinical routine and fully integrated in the health care delivery organization. Most of the applications are still to be viewed as trials and depend upon special funding and/or enthusiasts. To speed up their development and diffusion, it is important to see telemedicine also from a managerial point of view. This is to say that telemedicine, to be fully explored, should be integrated into the overall strategic managerial planning, locally, regionally, state and nationwide. Superimposing telemedicine on top of the existing organizational infrastructure will not necessarily bring down the cost of healthcare. The major challenges facing telemedicine will be to develop or change the organization and structure of the health care system as well as the way it is delivered.

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8.4 Establishment of Technical and Performance Requirements for Telemedicine Systems

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A. Telemedicine

Telemedicine can be broadly defined as the use of imaging information and communication technology to deliver health care services from one location to another. Telemedicine systems will have wide range of performance capabilities, system complexities and costs depending on clinical applications.

A.1 Building Blocks for Telemedicine.

For telemedicine, there are three basic building blocks. All three must be integrated seamlessly for a successful operation:

Communication Infrastructure
Telemedicine Infrastructure
Telemedicine Applications and Clinical Protocol

Communication infrastructure can be either short or long distance communication or both.

Telemedicine infrastructure refers to technologies and individual devices required for telemedicine such as imaging systems, display products, data storage systems, software and firmware.

Telemedicine applications mean clinically relevant use of technology and patient care protocol to deliver health care from one location to another.

A.2 Basic Functions of Telemedicine System.

The primary function of the telemedicine (T-MED) system is to communicate and manage high quality multimedia (still images, video images, sound, graphics and text) medical data for the purpose of the use in diagnosis, and consultation by clinicians and other health care providers. The system also supports medical education, resource management, service and maintenance. The T-MED system is a network of computer based medical devices that

(a) accepts multimedia medical data,
(b) communicates medical information to and from the patient care information system,
(c) archives and manages multimedia medical data,
(d) displays images and data at workstations for interpretation and consultation and,
(e) communicates interactively multimedia medical data to and from other clinical sites.

A.3 Telemedicine Evaluation Studies.

Evaluation studies can be grouped into several categories of questions.

Does telemedicine improve the access to health care?

Does telemedicine improve the quality of health care?
Does telemedicine reduce the over all health care cost?

Evaluation questions listed above require the use of telemedicine systems of optimal quality and operational capability. This document outlines the necessary parameters to define performance and technical requirements of the future systems for various telemedicine applications.

A.4 Composite Health Care System.

The T-MED System should be integrated with the DOD standards and Composite Health Care System (CHCS) where appropriate to facilitate efficient network operations and data management. Where CHCS is not installed, the T-MED system should provide for stand alone data entry, use of demographic data, order entry/order processing, and results reporting capability.

A.5 Rapid Prototyping.

Optimal technology for telemedicine has not been established except in the case of teleradiology which was defined primarily by the MDIS project. Following the rapid prototyping model for research in advance technology, technical specifications and performance requirements will be defined through a continuous and evolutionary manner in collaboration with project participants.

A.6 Telemedicine Subsystems.

Technical requirements will be defined by describing the following telemedicine subsystems :

a. The Multimedia Medical Data Acquisition Subsystem
b. The Multimedia Output and Interactive Display Subsystem
c. The Multimedia Database and Storage Subsystem
d. The Communication Network Subsystem

Furthermore, the performance requirements will be defined by describing the following features

a. Systems Integration
b. Network Performance
c. Telemedicine Studio and Installation
d. Training and Maintenance

A.7 Technical Requirements for Clinical Applications.

Varying technical requirements are expected to support different clinical applications. For example, telepathology, teledermatology, teleradiology, telepsychiatry and others will have different requirements. While there will be large area of common requirements for many applications, each specialty applications will have unique requirements. One way to group various applications in terms of technical requirements might be as follows:

- Moving video intense applications (endoscopy, neurology, etc.)
- Still video intense applications (pathology, dermatology, etc.)
- Digital image intense applications (radiology)
- Audio intense applications (cardiology, echocardiography, etc.)

A.8 General Approaches to Establish Technical Requirements.

The following approaches will be used to establish the technical and performance requirements:

Questionnaire forms filled out by the participants
Consensus panel of experienced users (DoD and other experts)
Site visits and interviews
Laboratory test

ROC studies
Literature survey

This document lists the parameters necessary to establish technical and performance requirements for telemedicine systems. Over the project period, these parameters will be further refined.

A.9 Academic Team Members.

The scientists from the following academic institutions will work with the Georgetown University team, by providing additional expertise:

- The University of Washington, Seattle, WA
- Pennsylvania State University, Hershey, PA
- The University of Pennsylvania, Philadelphia, PA

B. Multimedia Medical Data Acquisition Subsystem

B.1 Motion Video Acquisition.

Motion video includes video input from clinical applications such as endoscopy, and other general applications using composite NTSC video and Y/C outputs. The parameters to be defined for motion video are:

B.1.1 Color fidelity
B.1.2 Frame rate (fps)
B.1.3 Video standards supported
B.1.4 Lines of resolution: horizontal/vertical
B.1.5 Signal to noise ratio (dB)
B.1.6 Focal length range (ratio)
B.1.7 Sensitivity (lux)
B.1.8 Type of video signal
B.1.9 User interface for remote control
B.1.10 Number of video inputs
B.1.11 Video compression
B.1.12 Camera tilt/pan and motion
B.1.13 Field of view

B.2 Still Video Acquisition.

Still video includes all clinical applications that use snapshot capability to freeze frame motion video such as pathology, dermatology, ophthalmology and graphics data. The parameters to evaluate are:

B.2.1 Image output formats
B.2.2 Image resolution (matrix size)
B.2.3 Field of view
B.2.4 Magnification range
B.2.5 Still video compression
B.2.6 Color fidelity
B.2.7 Digitization speed
B.2.8 Signal to noise ratio
B.2.9 Focal length
B.2.10 Sensitivity
B.2.11 Data transfer rate
B.2.12 Camera motion
B.2.13 Operations

B.3 Audio Acquisition.

Audio acquisition involves voice inputs thorough a microphone for regular speech as well as remote stethoscope application to monitor patient cardiac status. The parameters to evaluate are:

B.3.1 Type of microphone
B.3.2 Type of audio standards supported
B.3.3 Full duplex audio
B.3.4 Noise suppression
B.3.5 Remote audio system component requirements
B.3.6 Remote stethoscope frequency spectrum
B.3.7 Audio compression
B.3.8 Volume control

B.4 Direct Digital Image Data Acquisition.

This type of data acquisition includes Magnetic Resonance Imaging (MRI), Computed Tomography (CT) and radiology images obtained either through direct digital capture such as in Computed Radiography (CR) or through digitization techniques. The parameters are:

B.4.1 Image matrix size
B.4.2 Spatial resolution
B.4.3 Contrast resolution / Dynamic range
B.4.4 Throughput
B.4.5 Modalities
B.4.6 Interfaces to imaging modalities
B.4.7 Operations
B.4.8 Size of the image

C. Multimedia Output and Interactive Display Subsystem

Image display and output consists of hard and soft copy versions of medical images. Hard copy outputs include paper, film, and other media produced from an video or digital image acquisition devices. Soft copy outputs are defined as still and motion video images produced on CRT display workstations.

C.1 Paper Printer

C.1.1 Throughput
C.1.2 Color fidelity
C.1.3 Artifacts
C.1.4 Dynamic range
C.1.5 Image matrix size
C.1.6 Imager operation
C.1.7 Quality control/calibration
C.1.8 Physical size
C.1.9 Stability
C.1.10 Cost for media
C.1.11 Cost for service

C.2 Film Printer

C.2.1 Throughput
C.2.2 Color fidelity
C.2.3 Artifacts
C.2.4 Dynamic range
C.2.5 Image matrix size
C.2.6 Imager operation
C.2.7 Quality control/calibration
C.2.8 Physical size
C.2.9 Chemicals required
C.2.10 Cost for media
C.2.11 Cost for service

C.3 35 mm Slide Production

C.3.1 Ease of use
C.3.2 Throughput

C.4 Multimedia Interactive Display (MID) Subsystem

C.4.1 Display monitors
C.4.2 Multimedia interactive display workstation functions

C.5 Audio Output (Speakers and Earphones)

C.5.1 Frequency response
C.5.2 Amplification
C.5.3 Power capacity (Watts)
C.5.4 Sensitivity (dB)
C.5.5 Physical dimensions

D. Multimedia Data Base and Storage Subsystem

D.1 Data Types

D.1.1 MPEG
D.1.2 Quick Time Movie
D.1.3 AVI
D.1.4 Audio
D.1.5 Images

D.1.6 Text
D.1.7 Graphics

D.2 Database

D.2.1 Storage
D.2.2 Query
D.2.3 Retrieval
D.2.4 Quality assurance

D.3 Data Storage

D.3.1 Speed
D.3.2 Data volume capacity
D.3.3 Storage media
D.3.4 Error correction

D.4 The Logical Design – Short-term Storage and Long-term Archive

D.4.1 Definition; Short-term storage (STS)
D.4.2 Definition; Long-term archive (LTA)

D.5 Use of the Folder Concept

D.5.1 Folder contents
D.5.2 Creation of teaching folders
D.5.3 Creation of research folders
D.5.4 Creation of management folders

D.6 Use of Compression

D.6.1 Still picture
D.6.2 Motion video
D.6.3 Digital images
D.6.4 Audio
D.6.5 Text

D.7 Security and Unauthorized Access

D.8 Loss of Information

D.9 Interface to Patient Information System

D.9.1 Nature of the interface
D.9.2 Clinical history
D.9.3 Reports
D.9.4 Information integrity
D.9.5 Use of common data elements

E. Communications Subsystems

E.1 Coder/Decoder

E.1.1 Frame rate (fps)
E.1.2 Line rates (Kbps)
E.1.3 Communication standards
E.1.4 Video compression/Decompression standards
E.1.5 Number of ports requirements
E.1.6 Type of ports: RS232, RS449
E.1.7 Audio frequency response
E.1.8 Video frequency response
E.1.9 File transfer capability

E.2 Communication Management

E.2.1 Dynamic bandwidth allocation
E.2.2 In Band (allocation of data channels)
E.2.3 Transmission methods (e.g.: store and forward vs. realtime)
E.2.4 Degree of integration of communication with applications
E.2.5 Record keeping and quality assurance

E.3 Communications Link

E.3.1 Bandwidth Capability
E.3.2 Multipoint capability
E.3.3 Throughput Efficiency

E.4 Communications Options

E.4.1 Type of service (e.g.: switched vs. dedicated)

F. Telemedicine System Operations: System Integration

F.1 Operational Scenario

F.1.1 Interactive
F.1.2 Non-Interactive

F.2 System Integration

F.2.1 The multimedia medical data acquisition subsystem
F.2.2 The multimedia output and interactive display subsystem
F.2.3 The multimedia database and storage subsystem
F.2.4 The communications network subsystem

G. Network Performance

G.1 Data Synchronization
G.2 Data Integrity
G.3 Data Transfer Response Time
G.4 Minimum Bandwidth Threshold
G.5 Redundancy/Reliability
G.6 Crisis Management

H. Telemedicine Studio and Installation

H.1 Relative Locations of Subsystems

H.1.1 Input devices
H.1.2 Camera locations
H.1.3 Number of cameras
H.1.4 Display devices
H.1.5 Recording devices
H.1.6 Controls

H.2 Cabling

H.2.1 Devices
H.2.2 Communication

H.3 Furnishings

H.3.1 Patient support
H.3.2 Staff support
H.3.3 Device support

H.4 Environment

H.4.1 Noise
H.4.2 Lighting
H.4.3 Temperature

H.5 Peripherals

H.5.1 Tripods
H.5.2 Camera mounts
H.5.3 Tables

I. Training

I.1 Instructional Material
I.2 Ease of Training
I.2 Formal Training
I.3 Initial/Refresher Training
I.4 People to be Trained

J. System Reliability and Maintenance

J.1 System Reliability
J.2 Maintenance
J.3 Warranty Maintenance

8.5 Reflecting on the Ethical Administration of Computerized Medical Records

Investigator: Jeff Collmann, PhD, Seong K. Mun, PhD and Matthew T. Freedman, MD, MBA

A. Significance to the Military MDIS Project and Executive Summary

This project examines the ethical issues raised by computerized image management and communication systems, the ethical principals that should guide development of policies, procedures and practices for electronic systems, such as MDIS, and who should be involved in developing a hospital's approach to these issues.

The ready access of computerized records creates special hazards of which hospitals must beware. Hospitals must maintain confidentiality of patient's records while making records available to authorized users as efficiently as possible. The general conditions of contemporary health care undermine protecting the confidentiality of patient record. Patients may not provide health care institutions with information about themselves under conditions of informed consent.

Patients must be informed about the existence of computerized medical records, the rules and practices that govern their dissemination and given the opportunity to give or withhold consent for their use. Departmental and hospital policies on confidentiality should be reviewed to determine if revisions are necessary to manage computer-based records. Well developed discussions of the ethical principles and administrative policies on confidentiality and informed consent and of the risks posed by computer-based patient records systems should be included in initial and continuing staff system training. Administration should develop ways to monitor staff compliance with confidentiality policies and should assess diligence in maintaining patient record confidentiality as part of staff annual performance evaluations.

Because of the installation of MDIS and other similar systems, these issues are particularly significant for the management of the medical records of military personnel.

B. Introduction

What ethical issues should concern radiology practitioners and administrators as they begin planning computerized image management and communication systems? What ethical principals should guide them as they develop policies, procedures and practices for ethically managing picture archiving and communication systems (PACS)? Who should be involved in developing a hospital's approach to these issues? If we reflect on these questions in the course of developing our PACS systems, we will not be guilty of the contemporary sin of rushing headlong into technological innovation without developing a moral framework for its interpretation and management. The broad deployment of the MDIS radiological image management system, the development of the composite health care medical records system (CHCS), and the effort to make CHCS image capable have created a major testbed environment for the examination and development of polices and procedures governing confidentiality and security of computerized medical records.

Can we avoid this discussion? In its recently published study of the contemporary patient record, the Institute of Medicine identified five conditions that favor and virtually make inevitable the computerized medical record:

1. the uses of and legitimate demands for patient data are growing in clinical care, financial and organizational administration, clinical research and medical practice guideline development;

2. more powerful, affordable technologies to support computer-based patient records are becoming increasingly available;

3. computers are increasingly being accepted as tools for enhancing efficiency in all facets of everyday life;

4. the aging and mobility of the US population create pressures for easily transferable patient record systems that can manage large amounts of data, and;

5. the automation of patient records is crucial to successfully reforming the health care system.

The very success of this process and its perceived inevitability nonetheless have provoked broad professional and public concern about its effect on patient privacy and the confidentiality of their records. Radiology professionals have a duty actively to, participate in this debate between, enhanced access to patient information and the protection of patients' constitutional and moral rights to keep their affairs to themselves.

C. What are the Key Issues?

A legal obligation exists to protect patients' privacy stemming from common and constitutional law. This obligation is difficult to honor when working with stigmatizing conditions such as HIV/AIDS, mental illness, and substance abuse. The ready access of computerized records creates special hazards of which hospitals must beware. The sensitivity of HIV/AIDS has encouraged many states to create special statutes with rigorous requirements. Cohen notes

Under common law, the tort of giving "publicity to a matter concerning the private life of another" usually requires that the embarrassing private fact be publicized to more than one person. However, HIV/AIDS confidentiality statutes often state that hospitals will be liable for any publication of HIV/AIDS information to an unauthorized party. These statutes will set new standards of "publicity", making a health care institution liable for privacy torts even if the confidential information was publicized to only one person.

Cohen notes that if a disclosure of confidential medical information is done recklessly or willfully, punitive damages might also be appropriate. Some statutes make it possible to sue hospitals for negligence if a medical record containing HIV/AIDS information is accidentally disclosed to an unauthorized person. The requirements of these HIV/AIDS statutes set standards for the protection of all patients' privacy rights analogous to the effect of Universal Precautions on patient care.

The general conditions of contemporary health care, particularly in the type of tertiary care institutions likely to implement full-scale PACS systems, make difficult protecting the confidentiality of patient records. These conditions include:

1. many types of people (physicians, nurses, receptionists, billing clerks, clinical researchers, administrators, insurance company functionaries and others) have legitimate access to patient medical records;

2. many legitimate uses (direct patient care, quality assurance, medical training, clinical research, billing, regulatory review and others) now exist to which patient data is put;

3. patient data is routinely transmitted outside the boundaries of the health care setting in which it was originally produced (hospital corridors, clinical and teaching conferences, scientific presentations, health insurance companies, central data collection companies, commercial clients of central data collection companies), and;

4. third parties with non-health care related interests (for example, risk rating in employment, life insurance, and credit) have access to patient medical information.

When patients provide health care workers with information about themselves, they routinely expect that the information will remain confidential and that their informed consent will be sought when it is necessary to give information to a third party. Most hospitals require patients to sign various types of authorization and consent forms upon presentation for care, including general consent for care forms, special procedure informed consent forms, clinical research consent forms and third party payor assignment forms. Questions still remain, however, about how much patients really know about the use and distribution of the information they surrender. One might suspect that many patients are unaware of the number, types or purposes of people who will legitimately review their records. How many patients know how their information is stored? Even when patients sign third party payor assignment forms, do they really understand who outside the hospital may eventually have access to their information with patient identifiers? For example, how many patients appreciate that health insurance companies send patient information to central data banks who may resell it to yet another party? Please note: these questions raise serious issues about the legitimate uses of patient information to say nothing about the opportunities for illegitimate and abusive violations of patient confidentiality. The possibility exists that when patients provide health care institutions with information about themselves, they are not really doing so under conditions of informed consent.

D. What is to be Done?

Traditional methods of protecting confidential information primarily relied upon the moral constraints of the doctor-patient relationship, namely the doctor's integrity and subscription to the canon of medical ethics as embodied in codes such as the Hippocratic Oath. To the extent that computerized patient information systems, including PACS systems, perform as they are being designed to perform, their ease, wide distribution and speed of communication undermine traditional approaches to protecting the patient record. What should radiology professionals do to safeguard their patient records when installing a PACS system? Unlike the traditional approach, the answer to this question comes from many disciplines.

The field of information science must design sophisticated systems of computer security that stratify access, create audit trails on data changes and system use, safeguard patient data from corruption, and protect the databases from outside invasion. These are not trivial problems or restricted to medical records. Hospitals that now use computerized hospital or radiology information systems are familiar with the general concept of stratifying access to the patient record using passwords. They are also familiar with the limitations of existing approaches, including sharing of passwords and updating authorized user lists. A password or badge identification

system is one piece of a comprehensive approach to protecting patient confidentiality, not the whole approach itself. Audit trails on user entry and manipulation of the data, data base and system are an added security. The problems of safeguarding data from viruses, false keystrokes and other corrupting influences and of protecting databases from outside invasion require great information science expertise. The point is that radiology professionals must both work with information science experts in their own hospitals to create institutional safeguards and include the adequacy of security measures as a criterion for evaluating PACS systems.

New policies and procedures on maintaining computerized patient records must be developed that obligate all members of the health care staff, not just care givers. Richard Caputo has suggested a framework for developing such policies specifically designed with computerized social service client (including patient) records in mind. Caputo's approach is grounded in the observation that all patients are citizens and have certain rights as citizens, including the right of privacy. This is useful because it allows a policy on patient record confidentiality to be based on people's general social standing, not just their status as patients, and to be applied to all hospital employees, not just doctors, nurses or other health care professionals. Caputo outlines five injunctions that should ground a hospital's approach to computerized medical records:

1. Patients should be informed of the existence of a computerized patient record system;

2. Patients should be informed about the use of information, its dissemination, to whom and in what form;

3. Informed patient consent should be required before inclusion in the system, except as otherwise legally required;

4. Patients should be permitted to inspect information about themselves, to correct errors and to add new information;

5. Patients should be permitted to expunge all or parts of their records, except as otherwise legally required.

Caputo's injunctions establishes a high standard for computerized patient information management and imposes some new administrative burdens. Injunctions one, two, and three require changes in patient registration procedures. Before patients begin to complete a patient data or encounter form at a reception desk, a staff member should consult with them about the computerized medical record system, or in radiology, about the PACS system. Given the complexity of PACS, hospital information systems (HIS), and radiology information systems (RIS), and of the use and dissemination of patient information, a routinely trained receptionist is probably not suitable, particularly for patients who have serious questions. Health care workers commonly delegate obtaining informed consent for procedures to as low a level in the hierarchy as possible; but, this practice is no more appropriate in the case of patient records than in risky medical procedures. Who performs this task will vary from hospital to hospital depending on local circumstances. Because patients should be able to get as much information as they require, staff trained in records management procedures, skilled in explaining them and sensitive to the importance of patient confidentiality should become part of the patient registration team. Patients who desire to review their record and make changes should be aided by a person trained in these issues.

Patient registration forms should include language and signature space for granting and withholding permission to include a patient's records in the computer system. Patients should also

have the opportunity to complete written authorizations that subject to certain clearly defined circumstances limit the range of persons who have access to their records, the types of information that may be released, redisclosure(that is, a third party giving patient information to a previously uninvolved party such as a central data bank), and new uses of data not explained as part of the original registration. If restricting dissemination of information affects the services the hospital can provide, the patient must be informed of these consequences. For example, a patient should be told that it may not be possible for her to assign third party payer benefits to the hospital and refuse permission for information about her care to be sent to the insurance company. A patient should be informed that he has the right to inspect his medical record, correct errors and add new information subject to legal restrictions.

Installing a computer based image management and communication system is an organizational as well as a technological event. Its ethical management must be woven into an institution's routine administrative life. Departmental and hospital policies on confidentiality should be reviewed to determine if revisions are necessary to manage computer-based records. Well developed discussions of the ethical principles and administrative policies on confidentiality and informed consent and of the risks posed by computer-based patient records systems should be included in initial and continuing staff system training. Administration should develop ways to monitor staff compliance with confidentiality policies and should assess diligence in maintaining patient record confidentiality as part of staff annual performance evaluations.

E. Who Should be Involved in the Discussion?

As John Fletcher notes, "Ethics is everybody's business, especially in regard to confidentiality". Hospitals should establish forums where specialists in information science, records management, and radiology sit down with patients, patient advocates, staff users and hospital administrators to recommend policy and evaluate practice on these systems. In hospitals with well functioning ethics committees, computerized patient record management systems should be added to their routine agenda. As issues emerge, knowledge of their existence and of how the institution is managing them should be widely disseminated. The implication of this analysis is that computerized patient record management (including radiology image management and communication systems) should be subject to the same kind of scrutiny as other clinical medical ethical issues. If hospitals include these processes in their planning for RIS, PACS, and HIS systems, they should have time to develop institutional expertise on these questions before and as systems are installed rather than only as ethical dilemmas develop during their use.

9.0 Summary

A significant portion of this year's research and development effort was devoted to enhance the radiological capabilities of the MDIS network in the areas of intelligent network through the use of computer aided diagnosis and pattern recognition and automatic reorientation of chest images at workstations. There is a need to continuously improve the quality of images in the MDIS network. This is achieved through the use of innovative data compression, quality control of CR based digital radiography including the reader and plate handling system. A new prototype high resolution film scanner with 21 micron capability was evaluated in terms of image quality. The reading throughput on a workstation is an important factor in the clinical acceptance of MDIS. In order to improve the visualization techniques of MRI studies that can involve hundreds of images, a neural network has been applied to view 3D image data of MRI of the breast. Results of this research will be incorporated into development of an intelligent workstation.

Teleradiology is a significant part of MDIS for the peace time as well as the deployment environment. For clinics with small work loads, there is a critical need for a teleradiology system that can use "no-cost" communication capability. A set of software tools has been developed to conduct teleradiology sessions on the Internet. This capability will be tested with a couple of DOD sites and if successful, the capability will be offered to the DOD for a general use.

To maintain MDIS's position on the cutting edge of technology and to protect the investment, MDIS must integrate new technologies. A new approach to interface computed radiography to MDIS is discussed. A new digital radiography system will be made available from AGFA Corporation. We have developed an MDIS digital interface for this AGFA product. Standard interfaces are making systems integration much simpler now, but there are still many blind spots in system integration in spite of great progress in interface standards. Some of these blind spots are analyzed. To test the idea of an intelligent MDIS network a new prototype system experimental network with higher performance is under development in collaboration with Cray. We plan to continue testing the idea of intelligent network to improve the throughput. We hope to have the operating prototype this coming year.

Implementation of the MDIS network accented the importance of training for users of the workstation and computed radiography. We have developed a three-day, hands-on CR training program that can be taught at Georgetown as well as any DOD site with a CR system. We plan to offer CR training to a number of DOD sites this coming year.

Telemedicine is an important extension of teleradiology, which is an integral part of the military MDIS. A teleradiology experiment was conducted using T-1 ACTS between Washington, D.C. and Tripler Army Medical Center. There is a need for a system that can support high resolution teleradiology and multimedia telemedicine. Georgetown has developed such a system in collaboration with KLT Communications by integrating a high resolution film scanner and Osiris radiology software with Shared-View VTC. The system is under operational evaluation between Martinsberg, WV and Georgetown. This new system will be tested at several additional sites. If successful it will be tested with selected DOD programs.

MDIS is a powerful technological and clinical infrastructure with an inherent capability to support more than just radiology service. To expand the capability of MDIS, Georgetown has been experimenting with digital pathology and telepathology in collaboration with the AFIP and Nikon Corporation. A prototype system has been designed and an operational protocol has been established during the first year. The use of neural network in pathology has been explored. A prototype telepathology network will be established 1 inking Japan, England, AFIP, Wright

Patterson AF Hospital and Georgetown this coming year. If successful, the network will be expanded to other DOD sites.

As part of the image capable hospital workstation project, we have reviewed industry trends in the use of various standards. Image capable HIS workstations will be a major effort this coming year. We intend to work with the PACMEDNET project that deals with CHCS.

There are a number of MDIS networks at a number of DoD sites, but no formal evaluation has been conducted. An evaluation plan has been under development for post MDIS installation study. The first study will focus on Korea teleradiology. Formal evaluation will start in Korea as soon as Loral has passed acceptance testing in Korea.

Telemedicine is a complex issue for the DOD from the technological, clinical, as well as management perspectives. A major national conference was organized by Georgetown in collaboration with the DOD and AUSA. The meeting was attended by 1,200 people representing military, government, industry, and academia. It was a highly successful meeting to establish the vision of the military medical leadership and set the goals of telemedicine for the military. A second National Forum on telemedicine is planned for April, 1996 with an international and global theme.

The evaluation study of telemedicine is an important step in re-engineering military medicine. There is no past experience in evaluating such technology in medicine. To develop a general framework of telemedicine evaluation studies, a roundtable discussion was organized of 50 experts including practitioners, assessment experts, scientists, engineers, policy makers and managers. A follow-up workshop is planned this coming year to review the progress.

To highlight the medical research activities of Tripler Army Medical Center, the Fourth International Conference on Image Management and Communication (IMAC) was organized in Hawaii in collaboration with the Governor's Symposium on High Technology. The Governor of Hawaii, The Honorable Benjamin Cayetano, delivered the keynote speech.

The evaluation study of telemedicine has a number of major components, including clinical, management, and technical. The Georgetown team has focused on the technical aspect during the first part of this project. Evaluation parameters have been established and study protocol is under development. Data collection will start as soon as a telemedicine network is operational at any one of the DOD sites.

The electronic network presents a great challenge in confidentiality and ethics of privacy. A sociology professor with anthropology training at Georgetown is developing a guideline on these issues. Our efforts will be coordinated with national and military policies.

This research project is designed to support and benefit the MDIS project, telemedicine and other medical research projects of the Department of Defense. The benefits to the military are maximized by close collaborations with a number of DOD project sites and offices. Georgetown now has on-going research collaborations with several offices within the US Army Medical Research and Material Development Command, Advanced Research Program Agency, Armed Forced Institute of Pathology and Brooke Army Medical Center, Bethesda Navy National Medical Center and Walter Reed Army Medical Center. As Tripler Army Medical Center established research efforts in telemedicine and MDIS, Georgetown will be prepared to provide research assistance.

Appendix A

Acronyms

2.1.1 CADx for Lung Nodule Detection for an Intelligent MDIS Network

ANN	Artificial Neural Network
BP	Back-Propagation
CADx	Computer Aided Diagnosis
CNN	Convolution Neural Network
COG	Center of Gravity
GUMC	Georgetown University Medical Center
MDIS	Medical Diagnostic Imaging Support
MOM	Mean of Maximum
NDI	Normalized Disease Index
ROC	Receiver Operating Characteristics
SNA	Suspected Nodule Area
SSE	Sum-of-Squared Error
TPF	

2.1.2 Wavelet-Based Convolution Neural Network for Disease Pattern Recognition

BP	Back-Propagation
CNN	Convolution Neural Network
CNN/WK	Convolution Neural Network using a Wavelet Kernel
DWT	Discrete Wavelet Transform
MDIS	Medical Diagnostic Imaging Support
NDDI	Normalized Disease Detection Index
ROC	Receiver Operating Characteristics

2.1.3 Automatic Detection of Lung Orientation in Digital Chest Radiographs

CAD	Computer Aided Diagnosis
CR	Computed Radiography
PACS	Picture Archive and Communication System
ROI	Region of Interest

2.2.1 A Contour Coding and Full-Frame Compression of Discrete Wavelet and Cosine Transform

CR	Compression Ratio
CT	Computed Tomography
DSA	Digital Subtraction Angiography
FFDCT	Full-Frame Discrete Cosine Transform
FFDWT	Full-Frame Discrete Wavelet Transform
LSB	Least Significant Bit
MDIS	Medical Diagnostic Imaging Support
MR	Magnetic Resonance
MSB	Most Significant Bit
MSE	Mean-Square-Error
MTF	

2.2.3 Performance Characteristics of High Resolution Film Scanners

CCD	Charge Coupled Device
GUMC	Georgetown University Medical Center
HWFM	Half-Width Full Maximum
ISIS	Imaging Science and Information Systems
LUT	Look Up Table
MDIS	Medical Diagnostic Imaging Support
MTF	Modular Transfer Function
OD	Optical Density
PACS	Picture Archive and Communication Systems
USAF	United States Armed Forces

2.2.4 Quality Control on Storage Phosphor Digital Radiography Systems

AAPM	American Association of Physicists in Medicine
CR	Computed Radiography
DMS	Data Management System
HR	High Resolution
IDT	Identification Terminal
IM	Image Monitor
IP	Imaging Plate
LP	Laser Printer
OD	Optical Density
PACS	Picture Archive and Communication System
PM	Preventive Maintenance
QA	Quality Assurance
QC	Quality Control
SDD	Source to Detector Distance
SF	Screen Film
ST	Standard Resolution

2.3.1 Single Image Hardcopy Display of Musculoskeletal Digital Radiographs

DP	Dorsal Plantar
DRC	Dynamic Range Compression
DRE	Dynamic Range Compression Effect
OD	Optical Density

2.3.2 A Neural Network Based Computer Vision System Applied to 3D MRI: A Model for MR Image Navigation

BMRI	Breast Magnetic Resonance Imaging
CNN	Convolution Neural Network
FISP	Fast Imaging with Steady State Free Precession
GRE	Gradient Echo
MDIS	Medical Diagnostic Imaging Support

2.4 Teleradiology over the Internet

CT	Computed Tomography
FFP	File Format Protocol

FTP	File Transfer Protocol
HTML	HyperText Markup Language
ISIS	Imaging Science and Information Systems
MDIS	Medical Diagnostic Imaging Support
MRI	Magnetic Resonance Imaging
MTF	Medical Treatment Facilities
PACS	Picture Archiving and Communication System
RGS	Resource Gateway Server
WAIS	Wide Area Information Server

2.5.1 Fuji CR Link to MDIS Network

CR	Computed Radiography
CRAW	Computed Radiograph Acquisition Workstation
ET	Exam Terminal
IDT	Identification Terminal
MDIS	Medical Diagnostic Imaging Support
ODF	Optical Disk Filing System
PACS	Picture Archiving and Communication System
RIS	Radiology Information System

2.5.2 Agfa ADC - MDIS Interface

ACR-NEMA	American College of Radiology - National Electronics Manufacturers Association
ADC	Agfa Diagnostic Center
CR	Computed Radiography
EPROM	Erasable Programmable Read-Only Memory
GUMC	Georgetown University Medical Center
ISIS	Imaging Science and Information Systems
MDIS	Medical Diagnostic Imaging Support
MIU	Modality Interface Unit
RIS	Radiology Information System
TCP/IP	Transmission Control Protocol/Internet Protocol

2.5.3 Open Issues in Interface Standards

ACR-NEMA	American College of Radiology - National Electronics Manufacturers Association
CR	Computed Radiography
HIS	Hospital Information System
MDIS	Medical Diagnostic Imaging Support
NFS	Network File System
PACS	Picture Archiving and Communication System
RIS	Radiology Information System
SQL	Structured Query Language

2.5.4 Prototype Next Generation Intelligent MDIS Network

CADx	Computer Aided Diagnosis
CR	Computed Radiography
CT	Computed Tomography
GUMC	Georgetown University Medical Center

HIPPI	High Performance Parallel Interface
HPC	High Performance Computing
MDIS	Medical Diagnostic Imaging Support
MRI	Magnetic Resonance Imaging
ROI	Region of Interest

2.6 A Training Workshop in Computed Radiography

CR	Computed Radiography
ISIS	Imaging Science and Information Systems
MS	Musculoskeletal
QA/QC	Quality Assurance/Quality Control

3.1 Experiment with the NASA Advanced Communications Technology Satellite

ACTS	Advanced Communications Technology Satellite
BER	Bit Error Rate
CSU	Channel Service Units
CSU/DSU	Channel Service Unit/Data Service Unit
CT	Computed Tomography
ESF	Extended Super Frame
FTP	File Transfer Protocol
GUMC	Georgetown University Medical Center
MR	Magnetic Resonance
MSM	Microwave Switch Matrix
MSP	Modular Switching Peripheral
TAMC	Tripler Army Medical Center
VSAT	Very Small Aperture Terminal

3.3 Designing a Common Telemedicine Platform for Three Different Medical Applications

BRI	Basic Rate ISDN
DoD	Department of Defense
GUMC	Georgetown University Medical Center
ISDN	Integrated Services Digital Network
ISIS	Imaging Science and Information Systems
NTSC	National Television Standards Committee

4.1 Telepathology over the Internet

AFIP	Armed Forces Institute of Pathology
DoD	Department of Defense
FTP	File Transfer Protocol
GSOP-TP	Global Standard Operating Procedure for Telepathology
TCP/IP	Transmission Control Protol/Internet Protocol
UDP/IP	User Diagram Protocol/Internet Protocol

4.2 Segmentation and Analysis on Pathology Images by an Adaptive-Sized Hybrid Neural Network

ASH-NN	Adaptive-Sized Hybrid Neural Network
CADx	Computer Aided Diagnostic
IGF-II	Insulin-Like Growth Factor II
MDIS	Medical Diagnostic Imaging Support

5.1 RIS/HIS and PACS Interface: Trends in Compliance to Standards

ACR-NEMA	American College of Radiology - National Electrical Manufacturers Association
ASCII	American Standrd Code for Information Interchange
DICOM	Digital Imaging Communications Standard
HIS	Hospital Information System
HL-7	Health Level 7
IEEE	Institute for Electrical and Electronic Engineers
ISIS	Imaging Science and Information Systems
MDIS	Medical Diagnostic Imaging Support
PACS	Picture Archiving and Communication System
RIS	Radiology Information System
TCP/IP	Transmission Control Protocol/Internet Protocol

6.0 US Armed Forces Teleradiology in Korea: Initial Assessment and Evaluation Parameters and Methodologies

CR	Computed Radiography
CT	Computed Tomography
KELP	Kodak Extascan Laser Printer
KVP	Peak Kilovoltage
LTA	Long-Term Archive
MDIS	Medical Diagnostic Imaging Support
MEDCOM	Medical Command
OD	Optical Density
ODJ	Optical-Digital Jukebox
SCIDO	Soft Copy Image Display - Optimized
STS	Short-Term Storage
TR	Teleradiology
TRS	Teleradiology Server
WS	Workstation
WSU	Working Storage Unit

8.1 The Chestertown Roundtable: Developing Approaches for DoD Technology Assessment and Evaluation of Telemdicine

DoD	Department of Defense
HHS	Health and Human Services
ISIS	Imaging Science and Information Systems
KIA	Killed in Action
MATMO	Medical Advanced Technology Management Office
MDIS	Medical Diagnostic Imaging Support
TA	Technology Assessment
WWW	World Wide Web

8.4 Establishment of Technical and Performance Requirements for Telemedicine Systems

CHCS	Composite Health Care System
CR	Computed Radiography
CRT	Catho Ray Tube

CT	Computed Tomography
DoD	Department of Defense
LTA	Long-Term Archive
MDIS	Medical Diagnostic Imaging Support
MID	Multimedia Interactive Display
MRI	Magnetic Resonance Imaging
NTSC	National Television Standards Committee
ROC	Receiver Operating Characteristic
STS	Short-Term Storage
T-MED	Telemedicine

8.5 Reflecting on the Ethical Administration of Computerized Medical Records

CHCS	Composite Health Care System
HIS	Hospital Information System
IMAC	Image Managemnt and Communication
MDIS	Medical Diagnostic Imaging Support
PACS	Picture Archiving and Communication System
RIS	Radiology Information System