Enabling Technology for Telemedicine and Telehealth

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Abstract- **Telemedicine is a growing field and has to face various challenges like its integration to the medical practice and to the health care system, its economic implication and its social impact. This paper will focus on the technological aspects of Telemedicine that will be first reviewed. Three main dimensions will be shown to structure the technological space of Telemedicine: Network, Information Processing and Knowledge Engineering. These three components will be briefly discussed. In a second part we will develop three specific issues addressing challenging image and knowledge engineering problems.**

I. Introduction

Telemedicine can be defined as a means provided by advanced technologies of allowing distant medical resources to meet unfulfilled demands in healthcare services [1]. Beyond the technical dimension, this growing field has to face various challenges like its integration to the medical practice and to the health care system, its economic implication and its social impact. This paper will focus on the technological aspects of Telemedicine that will be first reviewed. Three main dimensions will be shown to structure the technological space of Telemedicine: Network, Information Processing and Knowledge Engineering. These three components will be briefly discussed. In a second part we will develop three specific issues addressing challenging image and knowledge engineering problems.

We will conclude with some current trends related to the development of telemedicine applications.

II. Telemedicine Engineering Dimensions

A. Information Exchange in the Medical Practice

Regarding engineering dimension, it is commonly accepted that telemedicine refers to the technology that allow several health care professionals to communicate in order to improve health care delivery to a given patient, within the framework of a diagnostic or therapeutic approach. According to this definition, technology allows the classical medical behavior for new extensions, including functionalities that cope with spatial and temporal discontinuity. However, we can adopt a more general conceptual scope, if, following Ingernef [2], we notice that "Telemedicine means organizing and integrating information technology in such a way that resources outside the local organization can be used systematically in the activities health service". In such a broader context, two ways of communication should be distinguished [2]. First, communication between humans by means of new techniques where human readability of the transferred data is the main target. Second, communication between interconnected software applications where machine processability of the transferred data becomes more and more important.

Data exchange and transmission in medical practice implies interaction between users (health care professionals and patients), and data bases (medical information sources and medical knowledge sources). These interactions strongly depend on spatial and temporal constraints, and each type of constraint has a specific impact on the interactions. Regarding the spatial level, two situations only have to be addressed, whether the user exploits the information on the very same site where both information and user are, or user and information stand on different locations. At the temporal level, two cases can happen whether the same time or different times are used during information exchange.

Therefore, four types of interactions have to be addressed:

1. Same location: typically, users and data bases are within the same room
2. Different locations: either one of the users or a databases is not located in the same room as the main user.
3. Same time: users communicate at the same time, or access information at the same time that it is recorded.
4. Different times. Typical examples of such situations are users exchanging information through e-mail, or user accessing a stored database including the patient record.

The combination of the four situations above leads to four scenarios of information exchange:

A. Same location and same time
B. Different locations and same time
C. Same location and different times
D. Different locations and different times

The telemedicine field usually restricted to case B, and occasionally D, can be seen as belonging to a more general framework including all possible situations of information exchanges in medicine.

The former set of constraints implies two structuring notions: on the one hand, synchronism/asynchronism of information exchange and communications, and on the other hand, localization/distribution of stored information. Cases A and B represent synchronous situations and cases C and D are asynchronous. Situations A and C correspond to a localized or centralized information organization, cases B and D belonging to the opposite situation. It is rather straightforward to break down the usual telemedicine applications using the former categories. Remote consultation, telepathology, teleradiology, telestaff, telemonitoring, telesurgery and even teleformation (to be more general), can describe almost extensively the telemedical field. Based on the former analysis, it is now easy to focus on some engineering dimensions of Telemedicine.

1) Since information has to be exchanged, computer and telecommunication networks play an important role. Thus, some characteristics of quality of service will directly impact on the telemedical application. Error rates and security are definitely the most important parameters for any telemedicine application, whereas bandwidth, time of delay and jitter will only affect synchronous applications, like for any multimedia network.

2) Different sorts of data related to the patient, including text, biological data, signals, 2D or 3D images, and video can be used for a diagnostic or a therapy. This multimedia

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information has to be processed. Image and video sequences play a specific role because of the quantity and of the quality of information they contain. For on-line or synchronous transmission, as well as for fast storage and retrieval, the compression of these data is often necessary and has to face very demanding constraints. On the medical side, the information has to be transmitted or retrieved without any loss, or at least without any diagnostic alteration.

3) Knowledge has to be accessible. When dealing with referenced data bases including multimedia information, like images and video, a challenging area is related to the various ways of efficiently organizing and retrieving an element of the database using the content of the images. For instance in the case of a diagnostic process, the medical expert uses a predetermined terminology describing the various situations he is likely to face. Such a terminology corresponds to an information at a level higher than the image analysis results. On the one hand the physician uses a structured information related to the pathologies, which complies with some coded or standardized procedures, and the other hand the image analysis tools operate in another space based on image features, like the classical color, shape and texture. Between these two description spaces, it is necessary to develop mechanisms of reasoning, accounting for the consistency of medical information and its mapping in the observation world. Similar considerations can be derived from other knowledge-based tasks like data mining. Knowledge engineering can be therefore presented as the third technical pillar of medical information processing and telemedicine.

B. Medical Knowledge Engineering

Medical knowledge-based systems are designed to support health care practitioners in decisions concerning diagnosis and therapy. These systems rely on two basic concepts: *knowledge representation* and *reasoning* about the knowledge in order to perform the intended tasks. Knowledge representation is the formal analytic study of knowledge source systems. This includes the development of competence theories for basic mental capacities, and the study of epistemological issues as they relate to theories of human cognition. Sometimes the structure of the knowledge is very obvious. In other cases, mainly in medical applications, the knowledge is so deeply embedded in the problem solving methodology that it can not be identified as an entity. Once the knowledge has been formally represented, the medical knowledge-based system must be provided with reasoning methods for applying the knowledge. Two knowledge levels can be considered: the *real world level* and the *information processing level*. An intermediate knowledge transformation level allows the association between these two spaces. Information imperfection sources are mainly related to this knowledge transformation level.

1) Real world knowledge level

This knowledge level concerns *the visited organ* as well as its spatial context (called the *real world scene*). It is important to point out that this level makes a complete abstraction of acquisition systems and corresponds to the basic medical knowledge that all the physicians are assumed to have.

Several knowledge sources are associated to this level:

1) The anatomical knowledge source including the structural information of different organs as well as the spatial relationships between these organs.
2) The physiological knowledge source.
3) The medical knowledge source describing the pathologic as well as the non pathologic organs. This knowledge source is strongly related and mainly expressed by the means of the two first knowledge sources.
4) The *prior* knowledge source including the medical history of the examined patient.

Knowledge representation of these different sources is also concerned with the human cognitive knowledge representation process. Therefore, modeling these knowledge sources remains an open problem. For instance, the anatomical knowledge source is summarized in anatomical atlases coupled with expert linguistic variables giving textual description of different organs. Also, different scientific fields (chemistry, physics, biology...) are used in the description of these knowledge sources.

2) Knowledge transformation level

The knowledge transformation level consists in realizing the *projection* of the different real world knowledge sources into new representation forms where mathematical models can be exploited in order to visualize, process and interpret the *real* world information. This processing level is of extreme interest since it constitutes the filter between real world (*i.e.* organs, real world scene and expert's knowledge sources) and the *observable* world. Two main topics are considered at this level,

(i) ***Data acquisition***

A medical data acquisition system exploits a given physical process in order to extract one or several characteristic parameters of the analyzed scene from the real world. This simply means that the resulting image obtained represents partial facets and not all the reality of the analyzed scene.

(ii) ***Knowledge source transformation.***

This relates to the knowledge source transformation from the real world into the computer representation world. For instance, when a physician examines a patient, he mentally exploits some anatomical source of knowledge. The question is then how can we transform this knowledge source, using some knowledge representation approach, in order to have an integrated knowledge-based system?

This same question can be raised for the other real world knowledge sources. The answer is that there is no universal solution. For instance, a physician analyzing a tumor in order to determine whether it is malignant or not, may use a physiological point of view. Such real world physiological knowledge is mapped into the image representation space, and can be translated for instance in terms of geometrical properties of the shape of a malignant tumor.

3) Reasoning level

It is important to consider the reasoning process conducted by physicians in order to design knowledge-based systems of real interest in medical practice. The question now is how to integrate in a single framework all these sources of knowledge in order to obtain a suitable knowledge-based system of real interest for physicians. Another important issue concerns the knowledge representation such that these different sources can be combined through an efficient information fusion process? Similarly to the knowledge transformation level, there is no universal approach able to address these issues. The different information imperfections play the most important role in order to choose one of the theoretically available approaches.

The domain of artificial intelligence constitutes an important issue in terms of offering several technical approaches for medical knowledge representation and reasoning means. To illustrate the diversity of situations, several typical cases can be presented:

- If the knowledge elements to be processed suffer from random uncertainties, then, the use of *the probability theory*, modeling different uncertainties through probability density functions (the presence or the absence of a tumor in an analyzed image for instance), as well as the framework of the Bayesian conditional probability for reasoning offers a suitable framework for information processing.
- If the knowledge elements to be processed suffer from ambiguity type of uncertainty (i.e. the partial membership / non-membership to an ambiguous concept), then the use of the *fuzzy set theory* offers a suitable framework for knowledge representation.
- If the structure of the knowledge elements to be processed is of a certain complexity, then the use of the *Case-Based Reasoning* (CBR) approach is of great interest. In fact, the knowledge elements considered in this approach are the old encountered cases (pathologic cases in a medical diagnosis application). The reasoning aspect of this approach is reduced to a case similarity measure leading to the determination of similar cases as the target case.
- If the knowledge elements to be considered by the system are given by means of binary logic propositions (*i.e.* with two true or false values) and logic *If* (.) *Then* (.) implication rules, then, the use of *Expert Systems* (ES) approaches offers an adequate knowledge processing framework.

The most challenging research topic in the area of knowledge representation and reasoning actually concerns the *information fusion*. In fact, as already mentioned, different theories offer interesting means in order to represent knowledge elements issued from different sources. Nevertheless, the question now is how to merge together different knowledge elements is a homogeneous framework? This question does not concern the knowledge representation approach solely. It also concerns the reasoning approach to be used. For instance, how can we integrate in the same reasoning framework a medical image with *prior* anatomical knowledge? This question opens a huge challenging research avenue for future developments.

III. Image and Knowledge Engineering Issues in Telemedicine

A. Multimedia medical image management

Management and processing of diagnostic information obtained from multimedia data, is essential to provide a practical and well-accepted solution. Nowadays, despite the rapid development of multimedia technologies, the question has not been addressed in detail by medical information processing. Notwithstanding its original applications spectrum around commercial and recreational applications, the MPEG-4 (Moving Picture Experts Group) standard offers a broad variety of tools and resources, which can also be applied to handle medical information, like multimedia data acquired for diagnostic purposes [3]. MPEG-4 characterizes different media as independent objects, coded in elementary streams. Separated streams are used for objects and their descriptions. Optional textual information about the objects and identification of their intellectual property can be additionally supplied. The grouping of these objects by means of scene and object description information is called composition. Apart from formatted text documents, objects are natural video and sound, synthetic video and sound, and compound objects. In addition to a flexible content representation and user interactivity with the different objects, the standard proposes adaptable data storage and transportation. Different profiles are created for different application environments with subsets of the standard specifications: visual, audio, graphics, scene graph, and one object profiles. Detailed descriptions of the standard can be found in [4] and [5].

B. Multimedia Medical Knowledge Bases Constitution and Management

The objective is here to build a reference data bases of images and video sequences, to organize a content-based indexing system for computer-assisted retrieval of specific images. From a technical point of view, the main interest of indexing is to insure compression, storing and retrieval of images with minimal volume of storage, storage and retrieval time, and loss of information from compressed data. From a medical point of view, images, text, and biological results are documents of the same importance which are concerned with three main objectives: health care to a specified patient, clinical and epidemiological research, and teaching.

Indexing and healthcare

The medical diagnosis approach is based on the collection of clinical, biological, functional and morphological signs or symptoms with reference to knowledge of diseases and pathological status. The absence of a sign can be as important as its presence. The indexing must describe not only information on patient, investigation and chronology of medical events but also the image or document contents with sufficient data to reach rapidly the target information among the numerous documents of the patient file.

Each physician concerned with the patient care needs to reach all pertinent documents whatever place or time: multidisciplinary approaches are common in the follow up of chronic and severe diseases; the development of complex medical technology and the costs impose to realize some acts in hospitals far from the patient home and the follow-up must be jointly realized by a physician teams. Images and their interpretations must be stored together and from a practical point of view, image indexing and interpretation must be realized at the same time by the imaging expert (*e.g.*

endoscopist), and the method for indexing must be similar to the usual way to describe the lesions.

Indexing and medical research

Another objective of storing medical information is to constitute data bases, that can be used in a medical research context. In therapeutic trials, evolution of lesions can be measured directly on consecutive images. Evaluation of new diagnosis process, concordance analysis between imaging experts are other examples of the interest of images in clinical research. With this objective, the link to the patient file itself is not so important, but the selection of the target document assumes a content-based indexing, and other types of documents related to the image can also be necessary.

Indexing and teaching

The third significant objective of storing multimedia medical information is to supply reference data bases for teaching: thematic iconography, computer-assisted teaching or computer-assisted diagnosis. The imaging expert can be confronted with difficulty in interpretation of unusual observations. The immediate access to comparable clinical situations could help him in his diagnostic approach: diagnostic proposals for assumptions, advice on the complementary examinations to realize, advice on therapeutic attitude.

Indexing of documents by their medical symbolic content is not sufficient, and more primitive information must be extracted from the image. However, the link between the medical approach level and the image process level must be preserved.

C. Case-Based Reasoning in Diagnostic Imaging and Medical Data Mining

The philosophy of Case-Based Reasoning (CBR) [6] relies on a simple postulate: the experience gained in solving problems (cases) can, by analogy, permit to solve the similar ones (new cases). From a cognitive point of view, such reasoning in a way intends to simulate human behavior.

In diagnostic imaging, CBR approach can lead to very efficient tool [7]. For instance, an upper digestive endoscopic examination allows "to visit" the esophagus, the stomach, the duodenum and produces video optical color imagery. Pertinent endoscopic scenes (images or sequences) will feed the case base. An endoscopic description of several digestive pathologies [8] constitutes the knowledge base. Owing to these bases, a CBR will allow a physician to describe an endoscopic scene under consideration as well as the patient context and, either to return analogous scenes with diagnoses and reports, or to amend and even to learn

The endoscopic case base is made up of picked scenes with associated diagnostic reports. This base is indexed using a certain number of descriptors, some concerning the scene positioning and the general diagnosis, others describing the observed objects (lesions) together with their diagnoses, and some others finally informing about the patient.

The endoscopic diagnoses description [9] details the image-translation of a set of digestive pathologies, where each diagnosis is defined by one or several associated objects, assigned by indices of possibility. In the same way, each object and "its" patient context are depicted from the whole of the descriptors' choices, according to their necessity and possibility degrees.

II. Conclusion

Telemedicine is a growing field and has to face various challenges like its integration to the medical practice and to the health care system. Many open technical problems still have to find efficient solutions accepted by the healthcare practitioners. In this paper, three main dimensions have been shown to structure the technological space of Telemedicine : Network, Information Processing and Knowledge Engineering. As examples, we have then addressed three specific topics, medical image compression and multimedia environments, multimedia medical knowledge bases constitution and management, and case-based reasoning in diagnostic imaging and medical data mining. The most important trend today seems to be the growing involvement of the patient himself in the telemedical process. New e-health services allow the patient to access health delivery through Internet, like on line medical information through health portals including teleconsultation services, and e-commerce services for drug delivery, health insurances, etc. This evolution raises new technological issues that need efficient solutions, which will keep busy researchers and engineers of the information and knowledge engineering field.

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