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13. ABSTRACT ***(Maximum 200 Words)***

In this project, we plan to use an ultrasound attenuation imaging sensor to develop a breast ultrasound computed tomography system. This first year pre-doctoral award report contains two major sections: a computer simulation of parallel-beam computed tomoraphy (CT) and a preliminary study on the C-scan ultrasound attenuation imaging prototype. The simulation studies for CT image projection and reconstruction were performed using the Shepp-Logan mathematic phantom. I found that the reconstruction image contains less artifact when the reconstruction algorithm was processed in Fourier domain using a full-sized filter. A fairly complete physical evaluation study was performed for the C-scan ultrasound attenuation imaging prototype. I found that the image resolution power of the system is about 350 microns using the Imperium microarray sensor (model I100). A more complete report of this preliminary study is presented in 2002 Era of Hope conference held in Orlando Florida (Sep. 25 - Sep. 28, 2002)

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1. INTRODUCTION

The proposed research project outlines a research/training program for the PI to develop his research in breast imaging. At the same time, this program will also allow him to become familiar with breast cancer and related research. This multidisciplinary research project established by the PI and his mentors at the Engineering School of Catholic University of America (CUA) and Georgetown University Medical Center (GUMC) will provide a unique environment for PI to explore a new research dimension in imaging the human breast under the mentors' guidance. This research is based on a projection ultrasound system that is newly invented by Dr. Marvin E. Lasser – one of the PI's technical mentors. In this research project, we would like to develop the scanning mechanism, data acquisition protocol, and reconstruction algorithms for the breast Transmission Ultrasound Computerized Tomography (TUCT). This project also possesses a strong education component including breast anatomy, breast cancer physiology, imaging physics, and engineering training.

2. RESEARCH ACTIVITIES

2.1. Task 1. Basic tomography studies and simulation work

Computer Tomography (CT) refers to the cross-sectional imaging of an object from its projection data. The mathematical basis for CT was first discovered by Radon in 1917. However, it was not until 1972 that the first CT scanner was invented, for which G.N. Hounsfield and Alan McCormack received the Nobel Prize. Since then, many advances have been made in scanner technology as well as in the algorithms used for CT reconstruction.

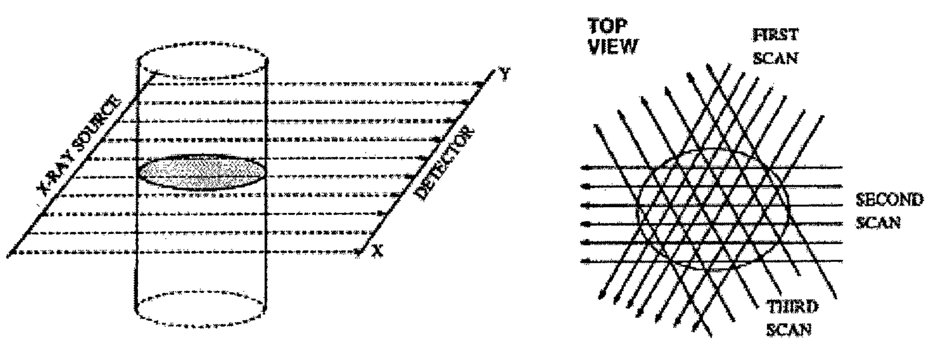


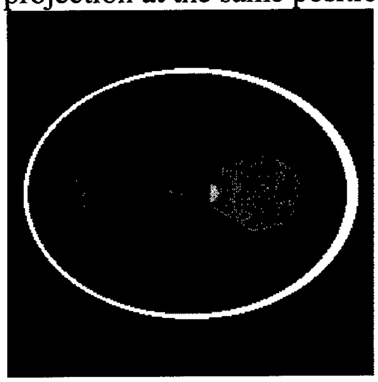
Figure 1. A simple scanning system (Generated by S-C. Ben Lo)

Fundamentally, tomography is a reconstructed image of an object from its projections. The technique of tomography consists of passing a series of rays (in parallel, fan or cone formation) through an object, and measuring the attenuated signals of these rays by placing a bank of detectors on the receiving side in the scanning geometry. The measurement in the bank of the detector is a profile of the scan. Typically, one needs to scan the object by rotating the angle from 0 to 360 degrees to collect a complete set of profiles. There are many algorithms available for the image reconstruction of the 2D cross-sectional image from its projections. Typically, linear attenuation coefficient at each points of the object within the cross-section is the property to be studied. If this process is repeated at various heights along the object, we obtain several 2D cross-sectional images, which can then be stacked one on the top of another to get 3D volumetric data of the object. There are also several methods to collect projection data. The simplest form of projection is called "pencil-beam projection" or "parallel-beam projection" and is illustrated in Figure 1.

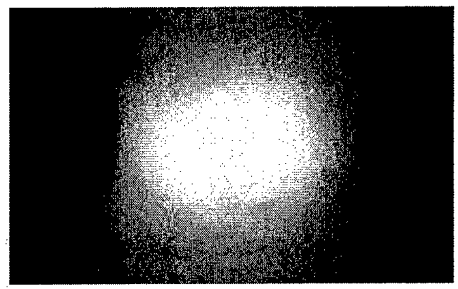
2.1.1. Computer Simulations of Projection Reconstruction in Spatial Domain and Frequency Domain

1. Parallel-beam CT reconstruction in special domain

I performed a computer simulation to generate parallel-beam projection profiles based on Shepp-Logan mathematic phantom [1] as shown in Figure 2(a). A bank of 256 detectors with an incremental angle at 1.125 degrees was used to produce a set of the profile data. I assumed that the original image as mathematic object consists of a matrix of 256 pixels by 256 pixels and each of them possesses a gray value. Based on these parameters, a profile image (256×160) shown in Figure 2(b) was generated. Each horizontal profile was a set of measure from the 256 detectors. The 160 data along each column represents the data colleted with different angles of the projection at the same position of the detector bank.



(a)



(b)

Figure 2. (a) The Shepp-Logan phantom. (b) The profile image with size of 256 ×160 pixels.

I then used filtered backprojection [2] method to reconstruct the original image base on this profile. I chose Ram-Lak filter to perform the filtering for each profile. The filtering processing on the spatial domain is achieved by using a standard *convolution method.* The algorithm of the filtering process is shown below:

$$Fp(x,\theta) = f(u) \otimes p(x,\theta) = \sum_u f(x-u) \cdot p(x,\theta)$$

where f(u) is the filter and p(x, θ) is the profile at each angle θ. Figure 3 shows the filtered profile image of Figure 2(b) with filter size 1×45. After the backprojection, the Shepp-Logan phantom image is reconstructed as shown in Figure 4. One can see that the image (Figure 4) barely shows some structures of the original image (Figure 2(a)) with an artifact showing dark area on the peripheral of the image. If I had used a smaller size for the filter kernel, the image would have a larger dark area. On the other hand, the use of larger filter kernel size would produce incomplete filtered profiles lead to strong artifacts on the reconstruction image.

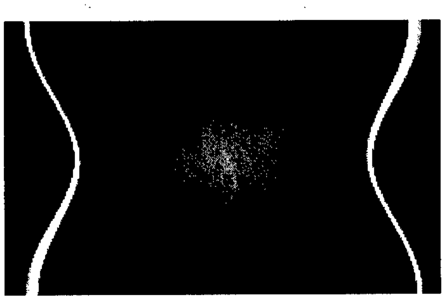


Figure 3. Filtered profiles using Shepp-Logan filter in special domain.

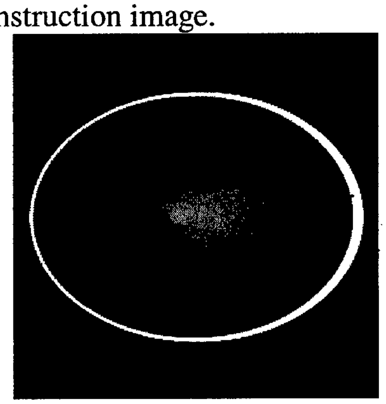


Figure 4. Reconstruction image based on Figure 3.

2.Parallel-beam CT reconstruction in frequency domain

By applying Fourier Transform method to the profile and the filter, we can translate them to frequency domain. The filtering method in frequency domain is shown below:

$$Fp(x,\theta) = \Im^{-1}\left(F(v) \times P(v,\theta)\right)$$

where F(v) and P(v, θ) are Fourier transforms of f(u) and p(x,θ). In the Fourier domain, we can use the full size filter kernel and apply Fourier Transform to perform the filtering process by multiplying each Fourier transformed profile with the Fourier transformed filter and then take Inverse Fourier Transform to obtain the filtered profiles as shown in Figure 5. The corresponding reconstructed image is shown on Figure 6 that possessing greater balanced image contrast.

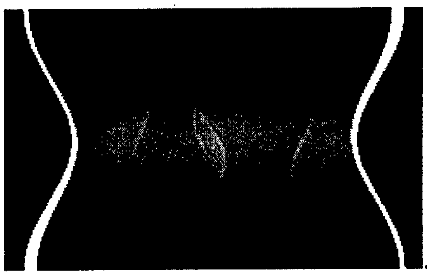


Figure 5. Profile image filtered in frequency domain.

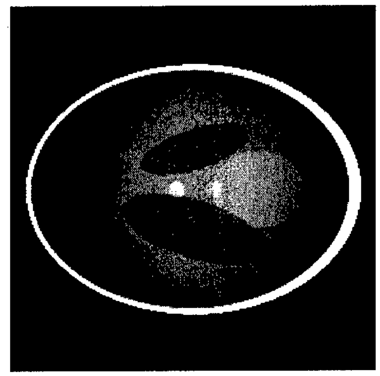


Figure 6. Reconstructed image using FFT method.

2.2. Task 2. Development of the laboratory transmission ultrasound CT (TUCT) system

In the past 10 months (project started from late 11/01), I used a PC, electronic parts, and phantoms and worked on the laboratory system to perform a series of basic imaging study using projection attenuation ultrasound device installed in the ISIS Center and Imperium Inc. [3]. (Note: I worked with Dr. Ben Lo at the ISIS center Georgetown University as my main research lab)

To generate real-time images, ultrasound is introduced into the target under study with a large unfocused ultrasound plane wave. The resultant pressure wave strikes the target and is attenuated and scattered. An acoustic lens collects the energy and focuses it onto the ultrasound sensitive array. The array is made up of two components, a silicon detector/readout array and a piezoelectric material that is deposited onto the array through semiconductor processing (see Figure 7). The array is 1 cm on a side consisting of 128×128 pixel elements (16,384) with 85μm pixel spacing. The energy that strikes the piezoelectric material is converted to an analog voltage that is digitized and processed by low cost commercial video electronics.

Note that there is an ultrasound-receiving (piezoelectric) layer deposited onto the chip. A picture of the microarray is shown in Figure 8. The array is responsive over a wide range of ultrasound frequencies, although most imaging is done between 1MHz and 10MHz. The use of a lens provides a simple, inexpensive alternative to complex beam forming often employed in ultrasound imaging. The user simply focuses by adjusting the lens while looking at the image on a monitor. Figures 9 and 10 show the overall system configuration and the laboratory setting in a water tank, respectively.

The system operates by pulsing a commercial off-the-shelf ultrasonic spike pulser in 5 MHz frequencies. This excites the large area unfocused ultrasound transducer (only used as a source) and sends an ultrasound plane wave through the water. This plane wave enters the target, scatters, exits the target and strikes the acoustic lens which collects the scattered energy and focuses it onto the array. This operation repeats 30 times/second to generate real-time image. Standard video electronics and image processing are used to format the image for presentation to the user and perform real time image processing; either on a PC monitor or LCD. Figure 12 schematically shows this architecture for the inspection of an object. Figure 11 illustrates the components of the C-scan ultrasound image prototype. Figure 12 shows some pictures obtained from this system.

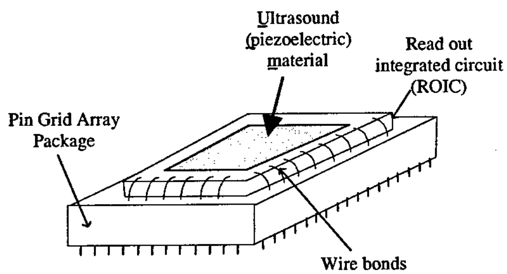


Figure 7. Schematic of array

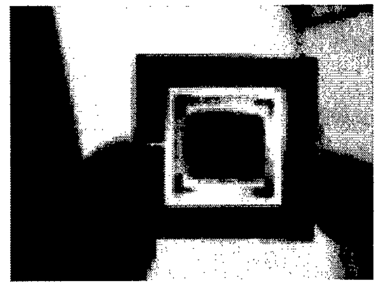


Figure 8. The 128 × 128 assembled array

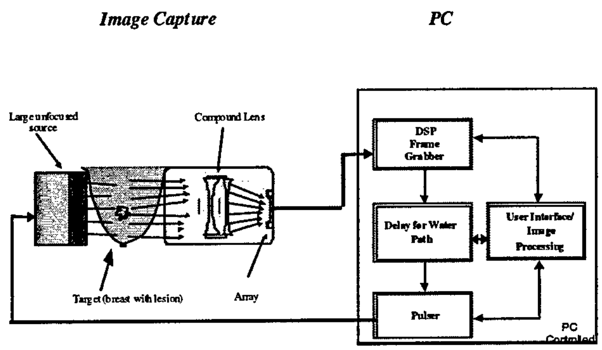


Figure 9. The prototype system configuration

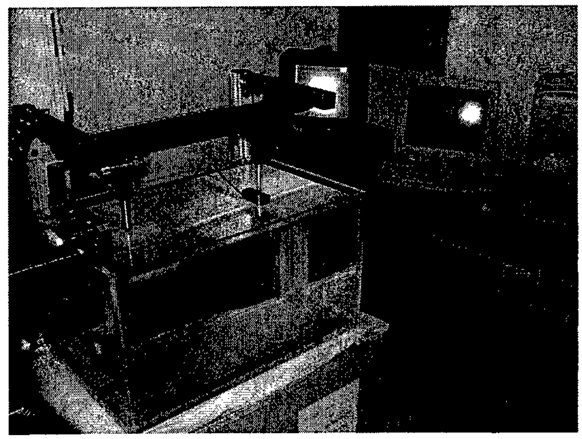


Figure 10. An ultrasound device setting in our laboratory

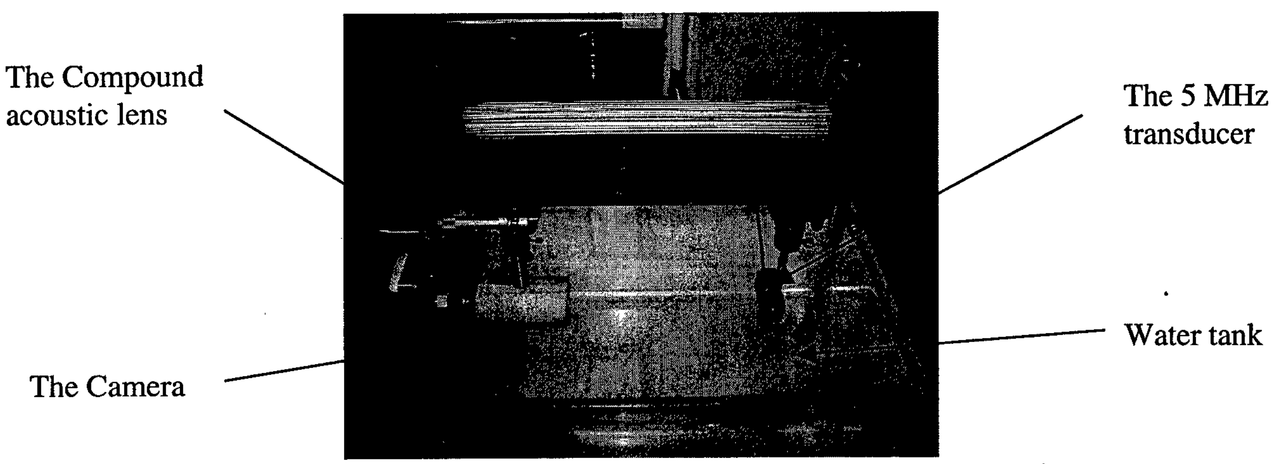


Figure 11. System components of the prototype transmission ultrasound system.

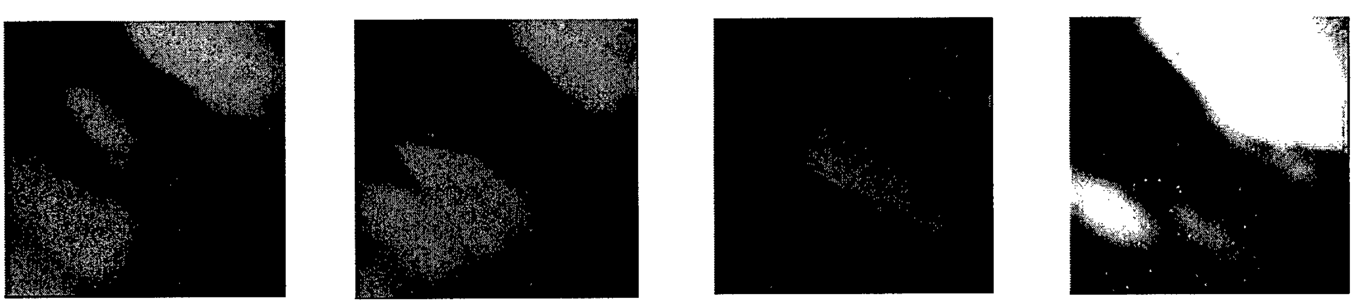


Figure 12. Ultrasound attenuation images taken from a human fingers.

KEY RESEARCH ACCOMPLISHMENTS:

- Task 1. Initial tomography training and understanding breast cancer.

  Completed the X-ray computerized tomography simulation study in parallel beam case. The PI plans to study fan-beam reconstruction and incomplete data reconstruction that is the case of the ultrasound imaging system.

- Task 2. Test of the laboratory TUCT system: altered electronic component, designed phantoms and evaluated the laboratory system.

  Successfully getting prototype transmission ultrasound images in our laboratory and also taking series of ultrasound attenuation images from the system.

REPORTABLE OUTCOMES:

- Simulation study in computed tomography.
- Summer internship in Imperium Inc: Develop methods to detect and remove inactive pixels in the test images (Summer, 2002.)
- Poster presentation in the U.S. Army Medical Research and Materiel Command's (USAMRMC) Era of Hope 2002 DoD Breast Cancer Research Program Meeting to be held in Orlando, Florida, September 25~28, 2002.

CONCLUSIONS

Base on the transmission ultrasound device we successfully generate the real time image. This system has several major components: The 5MHz transducer, the compound acoustic lens, the camera with a piezoelectric sensing microarray, a water tank and a control computer. There are some inactive pixels on the microarray and we are trying to solve this problem by using a point detect filter. A fairly complete physical evaluation study was performed and the results were reported and presented as a poster in the 2002 Era of Hope conference held in Orlando Florida (September 25- September 28, 2002) Since this ultrasound system has the ability to create real time image, we will establish a scanning mechanism and to develop an ultrasound computerized tomography image system in the next year. In addition, we will develop the ultrasound scattering reduction method and also design a wave-base filter to improve performances of the current system.

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