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Medical Imaging Techniques in Clinical Medicine

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***Abstract*—**Medical imaging technology has experienced a dramatic change in the last few years. Medical imaging refers to the techniques and processes used to create images of the human body (or parts thereof) for various clinical purposes such as medical procedures and diagnosis or medical science including the study of normal anatomy and function. With the growth of computers and image technology, medical imaging has greatly influenced the medical field. The diagnosis of a health problem is now highly dependent on the quality and the credibility of the image analysis. This paper deals with the various aspects and types of medical imaging.

***Keywords*—**Computed Tomography, Echocardiography, Medical Imaging, Magnetic Resonance, Ultrasound Imaging.

I. Introduction

WE have all witnessed the revolutionary changes in recent years brought about by the development of Biomedical Information Technology in general and Medical Image processing in particular. Today, medical imaging forms a key part in clinical diagnosis. Previously this was in the domain of hospital radiology department but now medical imaging is being extensively used in the neurology, cardiology and cancer centres, to name a few. Depending on applications, there are various types of imaging systems. X-ray, Gamma ray, ultraviolet, and ultrasonic imaging systems are used in biomedical instrumentation. In astronomy, the ultraviolet, infrared and radio imaging systems are used. Sonic imaging is performed for geological exploration. Microwave imaging is employed for radar applications. But, the most commonly known imaging systems are visible light imaging. Such systems are employed for applications like remote sensing, microscopy, measurements, consumer electronics, entertainment electronics, etc [1].

The medical image processing encompasses a wide and varied field of applications, even in areas where human vision cannot function, e.g. infrared (IR), ultraviolet (UV), X-ray, magnetic resonance imaging (MRI), ultrasound. One of the simplest ways to develop a basic understanding of the extent of medical image processing applications is to categorize images according to their source (e.g. visual, X-ray…).The principal energy source for images in use today is the electromagnetic energy spectrum. The electromagnetic band extends from beneath the frequencies used for recent radio (at the long-wavelength end) through gamma emission (at the short-wavelength end), covering wavelengths from thousands of kilometers downwards to a fraction of the size of an atom as shown in Fig. 1. The overview of Medical image processing in different bands of Electromagnetic spectrum is discussed further.

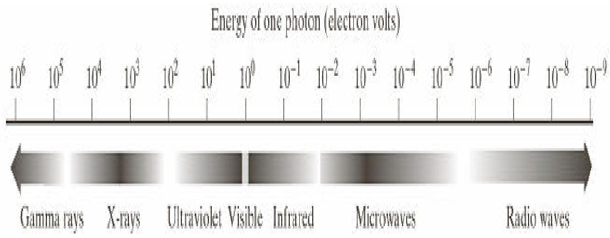

Fig. 1 The electromagnetic spectrum arranged according to energy per photon

II. Review of Literature

A. Historical Review

Medical imaging is considered as a part of biological imaging, which has been developed from 19th century onwards. A brief overview of medical imaging is as follows [2].

In 1895 Roentgen accidentally discovered X-rays. Conventional radiography has been the most widespread medical imaging technique ever science. From 1896 radio nuclides were for therapy and for metabolic tracer studies rather than imaging. Then X-ray imaging rectilinear scanner was invented. The utilization of ultrasound in medicine began during the Second World War in various centers around the earth. The work of Dr. Karl Theodore Dussik in Austria in 1942 [3] on ultrasound transmission investigating the brain provides the first presented work on medical ultrasonics. Furthermore, although other researchers in the United States, Japan, and Europe have also been cited as pioneers, the effort of Prof. Ian Donald and his colleagues [4] in Glasgow, in the mid-1950s, did much to assist the development of realistic ultrasound technology and applications. This led to the wider application of ultrasound in medical practice in consequent decades. From the mid-1960s onward, the introduction of commercially accessible systems allowed the wider circulation of the use of ultrasound. Fast technical advances in electronics and piezoelectric resources provided additional improvements from bistable to grayscale images and from still images to real-time moving images. The technological improvements at this time (mid-1960s) led to the quick raise in the applications of ultrasound. The development of Doppler ultrasound [5] has been progressing together with the imaging technology, but the

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fusing of the two technologies in duplex scanning and the consecutive development of color Doppler imaging provided even more possibility for investigating transmission and blood supply to organs, tumors, etc. The arrival of the microchip in the 1970s and the subsequent exponential increase in processing power facilitated the development of faster and more powerful systems incorporating digital beam forming, signal enhancement, and new ways of interpreting and displaying data, such as power Doppler [5] and 3D imaging [6]. Ultrasound has long been recognized as a powerful tool for use in the diagnosis and the evaluation of many clinical entities. Over the past decade, as higher quality and less expensive scanners are widely available, ultrasound has proliferated throughout various specialties.

In 20th century the mathematical principles behind tomographic reconstruction have been understood and positron emission tomography (PET) and X-ray computed tomography (CT) have been developed. Nuclear magnetic resonance has been using for imaging in magnetic resonance imaging (MRI).

In 21st century X-rays, MRI, ultrasound kept dominating but more interesting techniques especially imaging is getting included with microscopic as well as macroscopic biological structures (thermal imaging, electrical impedance tomography, scanned probe techniques etc).

In future the emphasis will be increased on obtaining functional and metabolic information along with structural (image) information. This can be done to some extent with radioactive tracers (e.g. PET) and magnetic resonance spectroscopy [3].

B. The Overview of Medical Image Processing

Medical imaging technology has experienced a dramatic change in the last few years. Previously, only X-ray radiographs were available, which showed the organs as shadows on a photographic film. With the advent of modern computers and digital imaging technology, new imaging modalities like Computer Tomography (CT or computer-assisted tomography), mammography and angiography are introduced in x-ray band. The Magnetic Resonance Imaging (MRI) and functional MRI (fMRI) are introduced in radio band, Positron Emission Tomography (PET) technique is developed in gamma rays, and endoscopy technique is developed in optical imaging of visible spectrum. MRI and CT have advantages over ultrasound imaging in the sense that higher resolution and clearer images are produced. Apart from electromagnetic spectrum, there are a number of other imaging modalities. Examples are acoustic imaging and synthetic imaging. Imaging using sound finds application in geological exploration, industry and medicine. Geological applications use sound in the low end of the sound spectrum (hundreds of hertz) while imaging in other areas use ultrasound (millions of hertz) [7].

C. Types of Imaging

Gamma Ray Imaging: A major use of imaging based on gamma rays is in nuclear medicine. This approach is known as Positron Emission Tomography (PET). The PET images are used to locate sites of bone pathology, such as infections or tumors.

Positron Emission Tomography: The principle of PET is same as X-ray tomography. Using an external source of X-ray energy, the patient is given a radioactive isotope that emits positrons as it decays. When a positron meets an electron, both are annihilated and two gamma rays are given off. These are detected and a tomographic image is created using the basic principles of tomography. Fig. 2 shows a sample image of a sequence that constitutes a 3-D rendition of the patient. This image shows a tumor in the brain and one in the lung, easily visible as small white masses.

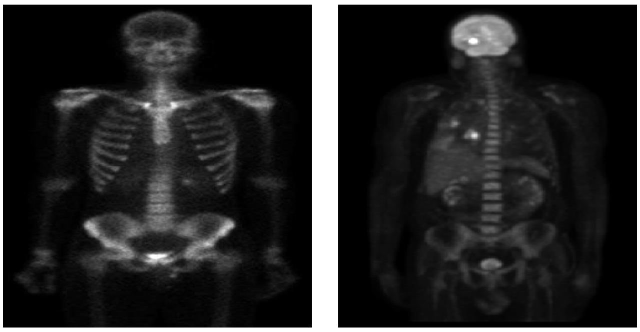


Fig. 2 An image of a partial bone scan obtained by using gamma ray imaging

D. Imaging in X-Ray

1. X-rays

X-rays use beams of ionizing radiation to expose photographic film. Placing the human body between the beam and the film leaves an image of the body on the film.

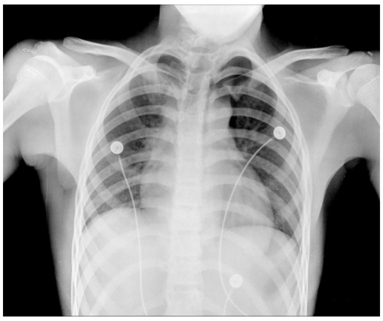


Fig. 3 Chest x-ray image

When radiation penetrates in to the tissues easily black areas are seen, for example air in the lungs on a chest x-ray. Bones appear white because they are hardest to penetrate. X-rays are a good way of looking at bones and air inside the human body but they do not show up soft tissues well Fig. 3.

2. Angiography

It is another major application in an area called contrast - enhancement radiography. This procedure is used to obtain images called angiograms of blood vessels. In this process, a catheter (a small, flexible, hollow tube) is inserted into a blood vessel or vein in the groin. The catheter is threaded into the blood vessel and guided to the area to be studied. When the catheter reaches the position under examination, an X-ray contrast medium is injected through the catheter. This enhances contrast of the blood vessels and enables the radiologist to see any irregularities or blockages. Fig. 4 shows an example of aortic angiogram. Angiography is a major area of digital image processing, where image subtraction is used to enhance further the blood vessels being studied.

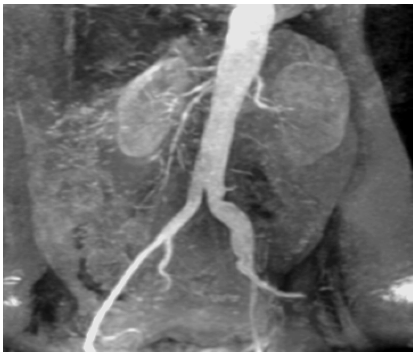
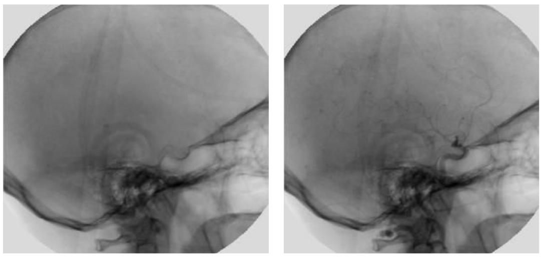


Fig. 4 Aortic angiogram

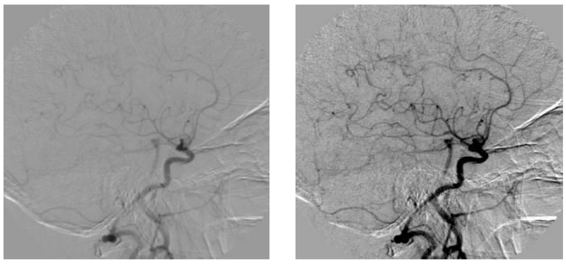
Digital Subtraction Angiography (DSA) is a dominant method for the hallucination of blood vessels in the human being. The DSA process consists of a series of X-ray projection images. These images are taken to show the path followed by a bolus, when contrast substance is injected through one or more vessels of interest. An image taken prior to injection (the mask image), and an image containing contrasted vessels (the live or contrast image) are shown in Figs. 5 (a) and (b) respectively.



(a) Mask image (b) Live image

Fig. 5 Image acquired during angiography

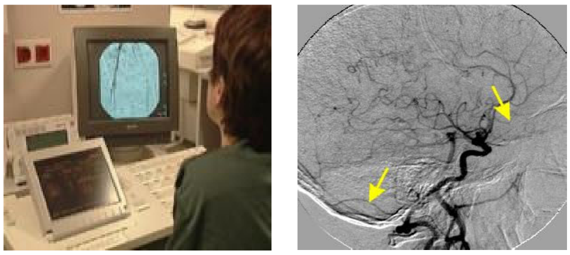
The subtraction of the mask image from the live image (Fig. 6 (a)) isolates the background structures in the image. Fig. 6 (b) shows the contrast enhancement of resultant image (Fig. 6 (a)).



(a) Original DSA Image (b) Contrast Enhanced DSA Image

Fig. 6 Images acquired during digital subtraction angiography

The subtraction technique is based on the theory that during exposure, tissues do not alter in position or density. But in practice, the movement of patient causes the subtraction images to show artifacts, which may affect proper diagnosis. The motion artifacts are reduced by registration and motion correction. The misalignment of the consecutive images in the series is determined and corrected for operations are known as registration and motion correction (Fig. 7 (a)). In clinical practice, the motion correction is partly performed by manual pixel-shifting technique. It allows for correction of translational movement only. The limitations of the manual pixel- shifting technique is shown in the Fig. 7 (b). From the figure it is found that if patient motion is more complex (in this case a revolution of the patient's head), a modification in one part of the image implies the creation of new artifacts in other parts of the image (yellow arrows in Fig. 7 (b)).



(a) The angiography machine (b) Motion correction by pixel shifting

Fig. 7 Angiography instrument and image

This explains the requirement for a fully automatic elastic registration method. Work by Erik Meijering et al. in 2001 has developed a new method for registration of digital angiographic image sequences which is both efficient and computationally very proficient [8].

3. Mammography

It is the process of using low-dose amplitude-X-rays (usually around 0.7 mSv) to study the human breast. The goal of mammography is the early detection of breast cancer. It is through detection of characteristic masses or micro calcifications. All X-rays, mammograms make use of doses of ionizing radiation to create images. Radiologists then analyze the image for any abnormal findings. It is normal to use longer wavelength X-rays than those used for radiography of bones. Mammography is believed to reduce female mortality from breast cancer [9]. Fig. 8 shows sample mammography image.

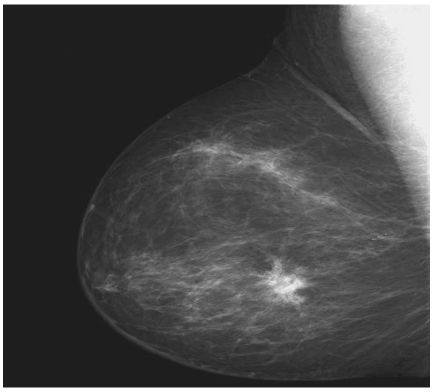
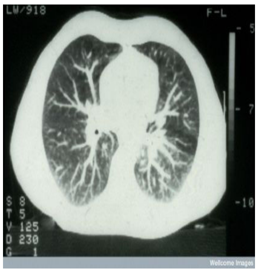


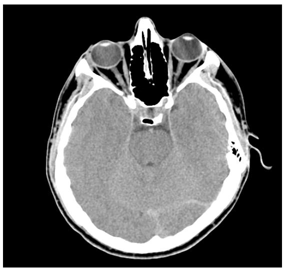
Fig. 8 Mammographic image

4. Computerized Tomography (CT) Scan

It uses multiple x-rays (ionizing radiation) to create a slice by slice image of the body. The slices (scans) are viewed as if you are looking up through the feet of the person to see the cross section. Therefore, a right sided organ such as the liver appears on the left of the image. These can be used to take an accurate biopsy. The sample CT images are shown in Fig. 9.

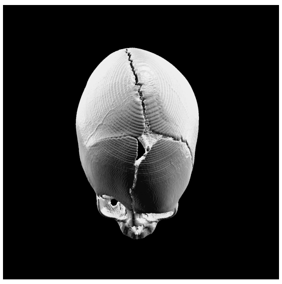


(a) Lung CT image



(b) Head CT image

(c) Skull CT image



d) Skull CT image

Fig. 9 CT images of lung, head and skull

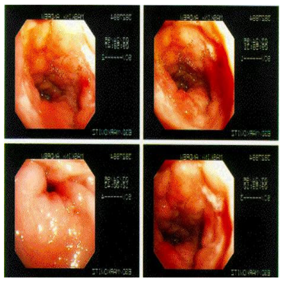
E. Imaging in Visible Spectrum

It is an imaging technique that involves inference from the deflection of light emitted from a laser or infrared source due to anatomic or chemical properties of material (e.g. cell tissue).

1. Visible Spectrum Imaging in Medicine

A common example of visible spectrum imaging in medicine is endoscopy. Endoscopy refers to looking in the interior of the body for medical reasons using an instrument called an endoscope. Endoscopy is a simply invasive diagnostic medical system that is used to assess the interior surfaces of an organ by inserting a tube into the body. The instrument may have a stiff or flexible tube and not only offer an image for visual inspection and photography, but also enable taking biopsies and retrieval of foreign objects. Endoscopy is the vehicle for minimally invasive surgery, and patients may receive conscious sedation so they do not have to be consciously aware of the discomfort. Complications are rare but can include perforation of the organ under inspection with the endoscope or biopsy instrument. If that occurs open surgery may be required to repair the injury. Fig. 10 (b) shows sample endoscopic images captured using an endoscope instrument shown in Fig. 10 (a).

(a) A flexible endoscope instrument



(b) Endoscopic images of a duodenal ulcer

Fig. 10 Endoscope instrument and images

F. Imaging in the Radio Band

The major applications of imaging in the radio band are in medicine and astronomy. In medicine radio waves are used in magnetic resonance imaging (MRI) and functional MRI (fMRI).

1. Magnetic Resonance Imaging (MRI) Scan

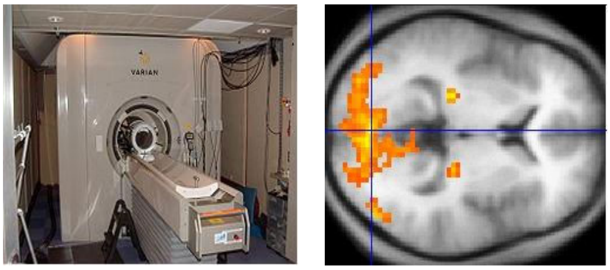
Fig. 11 MRI of the spine

MRI - images are similar to CT images except they show up the details of soft tissue better. MRI scans do not use X-rays but use a strong pulsed magnetic force to polarize cells - line up the (electrons) and measure the energy given off by the electrons when they bounce back into their normal orbits in-between pulses. The sample MRI image is shown in Fig. 11.

2. Functional MRI

The functional Magnetic Resonance Imaging (fMRI) is a type of particular MRI scan. It processes the hemodynamic (changes in blood flow and blood oxygenation in the brain) response related to neural action in the brain or spinal cord of humans or other animals. It is one of the most recently developed forms of neuroimaging. The fMRI is popular due to its low invasiveness, lack of radiation exposure, and relatively wide accessibility.

In fMRI, the hemodynamic response is carried out using Blood Oxygen Level Dependent (BOLD) process. It is the MRI contrast of blood deoxyhaemoglobin. Neurons do not have interior reserves of energy in the structure of glucose and oxygen, so their firing causes a need for additional energy to be brought in quickly. This process is called the hemodynamic response. In this procedure blood releases oxygen to neuron at a better speed than to inactive neurons, The variation in magnetic susceptibility between oxyhaemoglobin and deoxyhaemoglobin, and thus oxygenated or deoxygenated blood, leads to magnetic signal dissimilarity which can be detected by means of MRI scanner. Several repetitions of a thought, action or experience is given and numerical methods are used to establish the areas of the brain which constantly have more of this difference as a result, and therefore which areas of the brain are lively during that thought, action or experience. Fig. 12 (a) shows the instrument used in fMRI. Fig. 12 (b) shows fMRI image of human brain in gray color and colored area shows fMRI statistics of brain anatomies.



(a) fMRI instrument (b) fMRI of human brain

Fig. 12 fMRI instrument and fMRI image

G. Other Imaging Modalities

In other imaging modalities, the technique similar to the echolocation used by bats, whales and dolphins, as well as SONAR used by submarines is employed in ultrasound imaging.

1. Ultrasound Scans

These scans use high frequency sound waves which are emitted from a probe. The echoes that bounce back from structures in the body are shown on a screen. The structures can be much more clearly seen when moving the probe over the body and watching the image on the screen (Fig. 13). The main problem in these scans is the presence of speckle noise which reduces the diagnosis ability. The Sample ultrasound images are shown in Fig. 14.

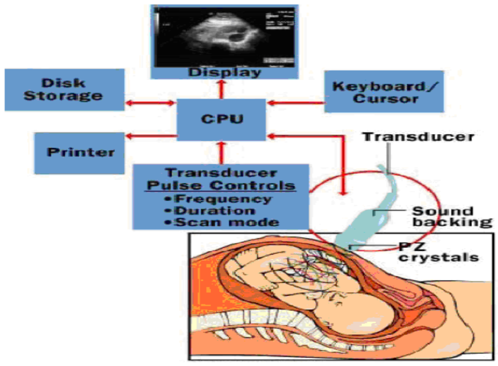


Fig. 13 The parts of an ultrasound machine

(a) Ultrasound scan of polycystic ovary (b) Ultrasound scan of liver (c) Ultrasound scan of kidney

Fig. 14 Ultrasound scan different organs of a human

2. Echocardiography

M-mode of ultrasound is used in cardiology, and it is actually an A-scan (Amplitude) plotted against time. The result is the display of consecutive lines plotted against time. Using this mode, detailed information may be obtained about various cardiac dimensions and also the accurate timing of vascular motion. Fig. 15 shows the sample echo image.

Fig. 15 Echo image

Moving blood generates a Doppler frequency shift in the reflected sound from insonated red blood cells, and this frequency shift can be used to calculate the velocity of the moving blood using the Doppler equation [10]. The invention of gated Doppler ultrasound in the late 1950s allowed velocity sampling at different depths and positions, and its subsequent combination with B-mode real-time ultrasonic imaging led to the development of duplex ultrasound. Stenosis in any vessel is characterized by an increase in systolic and diastolic velocities. Several types of Doppler systems are used in medical diagnosis: continuous wave (CW) Doppler, pulsed wave (PW) Doppler, duplex ultrasound, and color flow duplex. In CW Doppler, the machine uses two piezoelectric elements serving as transmitters and receivers. They continuously transmit ultrasound beams. Because of the continuous way that ultrasound is being transmitted, no specific information about depth can be obtained. PW Doppler is used to detect blood flow at a specific depth. Sequences of pulses are transmitted to the human body, which are gated for a short period of time to receive the echoes. By selecting the time interval between the transmitted and received pulses, it is possible to examine vessels at a specific depth.

In color-coded ultrasound, every pixel is tested for Doppler shift. Using this technique, the movement of the red blood cells is finally depicted through color. The final image results by superimposing the color-coded image on the B-mode image.

Power Doppler is the depiction of flow based on the integrated power of the Doppler spectrum rather than on the mean Doppler frequency. This modality results in an angle, which is independent of the resulting enhanced sensitivity in flow detection as compared to the color-coded Doppler, and, therefore, the detection of low flow is better viewed.

III. Conclusion

Imaging techniques in medicine has seen truly exciting advances in recent years. Newly invented imaging methods can now reflect internal anatomy and dynamic body functions. The image processing in various bands of electronic spectrum are used in various fields like medical, industrial, military and research for various purposes. Although computing speed certainly has reached the point where iterative methods are clinically feasible for 2D problems, the focus is now on 3D images where the size of an image is 11-15 times larger than in 2D (after exploiting symmetries). Thus there is continuing need for new ideas in image reconstruction algorithm development. This paper can be treated as the tutorial or an overall review to the subject matter**.**

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