A Study of Application of Digital Image Processing in Medical Field and Medical Image Segmentation by Edge Detection

Tanusree Saha, Kumar Vishal

Abstract - There has been significant recent development in the domain of image processing and associated imaging techniques. Medical imaging is the practice of capturing images of various body parts for diagnostic or investigative purposes. The number of imaging procedures performed each week is in the millions. This study presents the promising image processing methods currently in use in the medical field. The rapid expansion of medical imaging can be attributed to advancements in image processing methods, including image recognition, enhancement, and analysis. Utilised in the diagnosis and treatment of patients, image processing techniques have proven to be of immense benefit to surgeons and physicians. The explosion of clinical medical devices is primarily attributed to the combination of hardware and image processing techniques, both of which have made significant contributions to medical progress. In recent years, Image segmentation via edge detection has played a vital role in extracting important features of images, such as corners, lines, and curves, to recognise object boundaries, which in turn helps medical experts detect diseases in medical analysis and patient care.

Keywords: Non-Intrusive Techniques; Human Anatomy; Digital Image Processing; Diagnosis

I. INTRODUCTION

Information technology (IT) has permeated every facet of modern life, and its impact on medicine and healthcare has become increasingly apparent in recent years. The goal of medical imaging is to provide a visual representation of the anatomical structures and physiological processes occurring within a patient's body for diagnosis, treatment, and research. Through Picture Archiving and Communication Systems, Digital Imaging and Communications in Medical (DICOM), and other communication networks and protocols facilitate the efficient processing, evaluation, and dissemination of these visual representations to a global audience [4]. Biomedical images, or pictures of the human body used for medical purposes, are a vital component of the medical sciences.

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Any one-dimensional algorithm can be applied to this two-dimensional digital image by first applying it to the rows of the matrix, and then to the columns. These biomedical pictures show not only individual body parts and organs but also molecular structures. To decipher and extract useful information from these images, image processing methods are crucial. Physicians were aided in their ability to diagnose illness, locate abnormalities, and treat patients using digital imaging technology [3].

II. Image Categorization

In the field of digital imaging, there are two primary image formats. A raster image is an array of pixels, which are small squares of data that are sampled at regular intervals. There are two phases in the digitisation process: sampling and quantisation. Quantisation reduces a signal's range of possible values from an infinite number to a finite number. In contrast, sampling reduces a continuous quantity in the time and space domains to discrete amounts. The vast tonal range and inaccessibility of digital images are their defining characteristic. The resolution of digital photos remains constant because the size of the pixels used to create them is fixed. When digital images are resized, quality is lost because some of the original data is lost in the process. Digital photographs are widely used because of the high quality of their colour tones. The device used to acquire the image determines the resolution. Digital pictures can be saved in a wide variety of formats; some common ones are BMP, TIFF, PCX, and PNG [1,2].

Basic Image Processing Operations are as follows:

- Image Acquisition: This primary process involves collecting images through the use of sensors and various image modalities, represented as a matrix.
- Enhancing an image by reducing noise and making it easier to examine microscopic details of medical images like MRI, ultrasound, X-Ray, etc. and their techniques.
- Medical images taken in natural light can have their colours altered and corrected without the need for artificial lighting, thanks to this feature.
- Medical image segmentation relies heavily on edge detection as a pre-processing system for identifying internal human anatomy like lungs, organ systems, tissues, ribs, etc.
- Image Smoothing is a technique used to lessen the visual disturbances in diagnostic pictures.

- Restoring Images used to recover restorative images such as X-Ray images, ultrasound images, CT scan images, and MRI images.

Advantages of applying image processing techniques [10] in the medical field:

- Data stored digitally cannot be altered and always appears authentic even after being copied numerous times.
- Digital processing is an effective method for helping doctors find the most relevant images quickly.
- The image is shown instantly after it is captured.
- The enhanced/intensified images are simple to interpret for physicians.
- It quantifies changes over time.
- Image comparisons can be performed quickly

A. X-RAY IMAGING

Radiography, also known as X-ray imaging, is a medical imaging technique used to create images of internal body structures, such as bones and organs. A wide variety of medical conditions can be diagnosed with this painless, non-invasive procedure. In radiography, the patient is positioned so that an X-ray machine can produce and then pass radiation through their body. A digital sensor or photographic film records the detection of X-rays, creating an image of the body's internal structures. More dense objects appear whiter on the X-Ray image because they absorb more radiation than less dense ones, which causes the latter to appear darker. Bone fractures, lung infections, and gastrointestinal disorders are just some of the many medical conditions that can be diagnosed with radiography. Diseases like breast and lung cancer can be screened for and tracked with its help. The human chest X-ray shown in Figure 2 is pretty typical. Ever since the discovery of X-rays by the German scientist Roentgen, various components of the human body have been photographed for diagnostic purposes. Electrons are generated in the cathode through a thermal emission process and accelerated by a potential difference ranging from 50 to 150 KV within an X-ray tube. X-rays are generated through the interaction of electrons with the anode. A mere 1% of the energy is transformed into X-rays; the remainder is converted to heat. X-ray devices generate two-dimensional images, or blueprints, of the anatomical structure under investigation. An organ in motion is imaged using a fluoroscopy instrument. Photo captures are capable of being viewed, stored, and transmitted through a variety of devices. To generate images, computed radiography (CR) utilises image receptors. X-rays are emitted in the presence of a storage phosphor device that covers a screen. Mammography images are utilised to differentiate various medical conditions from breast tissue. Mammography imaging is more energy-efficient than imaging of bone structure. The range of potential differences utilised is 15 to 40 kV [5].
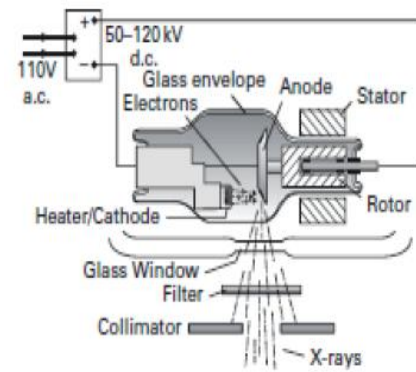

Figure 1: X-Ray Tubes

Figure 2: Chest X-Ray Image

B. MAGNETIC RESONANCE IMAGING (MRI)

MRI is a medical imaging technique which generates high-resolution pictures of the body's internal anatomy by merging a magnetic field with radio waves and a computer [8]. It is a standard diagnostic tool because patients experience no discomfort, and there is no harm during the imaging process. In magnetic resonance imaging, the patient relaxes on a table that moves into a giant cylindrical magnet. Hydrogen atoms in the body have protons that align with the magnetic field. After sending radio waves into the body, the MRI machine picks up the signal emitted by the protons. The computer then uses this signal to render accurate pictures of the body's internal anatomy. Tumours, brain and spinal cord injuries, joint and musculoskeletal disorders, and heart and vascular conditions are all diagnoses that benefit from the use of magnetic resonance imaging (MRI). It's also put to use in functional imaging, which allows doctors to examine how the brain's various regions perform their functions. MRI helps diagnose complex medical conditions because it can produce detailed images of the body's inner structures in multiple planes (sagittal, coronal, and axial) without exposing the patient to harmful levels of radiation or involving any invasive procedures. A cross-sectional MRI scan image of a human skull is shown in Figure. 4. Scanners based on MRI technology use radio waves, magnetic fields, and field gradients to create images of internal human organs for clinical diagnosis. With the data produced by MRI being small, 3, 3 kernels, Convolution Neural Networks (CNN) play an essential role in investigating brain tumours [9].
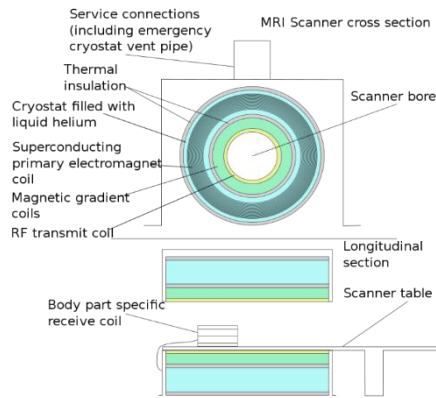
Figure 3: Diagram of Construction of a Cylindrical Superconducting MR Scanner
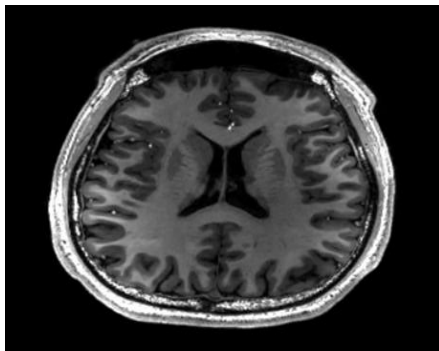

Figure 4: MRI of the Human Brain

C. COMPUTER TOMOGRAPHY

Medical imaging using X-rays and a computer is known as computer tomography (CT), and it is used to produce detailed images of the body's inner structures. Varieties of medical conditions can be diagnosed with this painless, non-invasive procedure. Through the CT scan procedure, the patient lies on a table that moves into a doughnut-shaped machine. The patient is positioned in the centre, and the machine rotates around them, sending X-rays through their body. The information is fed into a computer, which produces high-resolution internal images of the human body. Tumours, injuries, infections, and vascular disease are some of the many medical conditions that can be diagnosed with a CT scan. Diseases like lung cancer and heart disease can be detected and tracked with its help. Figure 4 depicts A CT scan of a human brain showing multiple brain slices [14].
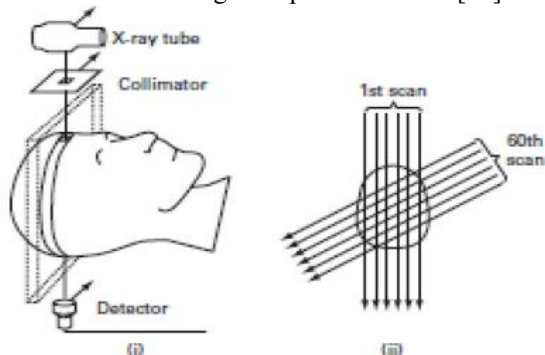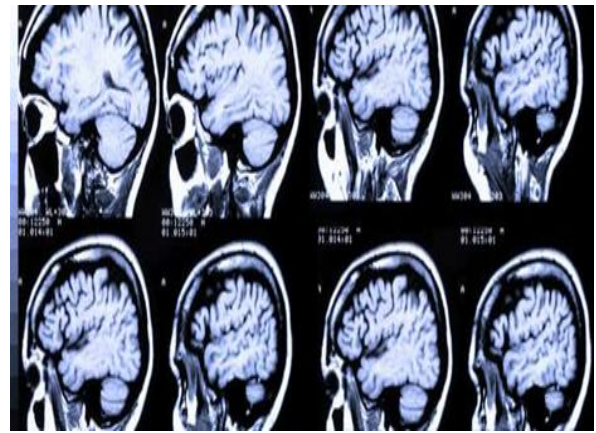

Figure 5: CT Scanner

Figure 6: A CT Scan of a Human Brain in Multiple Slices

D. NUCLEAR MEDICINE

This imaging modality utilises radioisotopes to produce images of the functions of various structures, including the kidney, heart, and liver. Pharmaceutical materials are labelled with radioisotopes to enable targeted delivery to specific organs.

The photons generated by the patient are detected and converted into signals by the detectors. These signals are turned into digital images that may be interpreted. Nuclear medicine scanning modes include planar, tomographic, and positron emission tomography (PET), among others. Planar emission generates two-dimensional pictures. Both tomographic and positron emission images generate 3D images. Figure 7 depicts the process of Nuclear Medicine imaging [13].
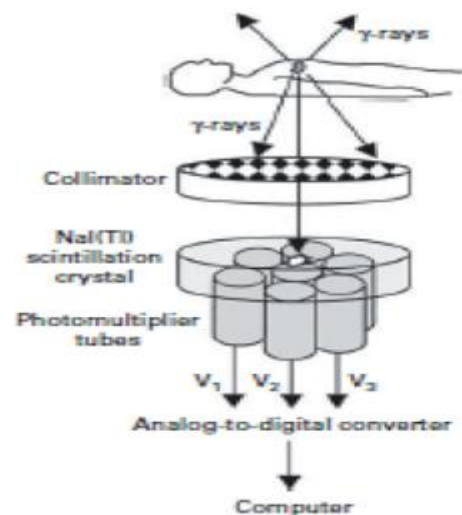

Figure 7: Nuclear Medicine Imaging

E. MEDICAL ULTRASONOGRAPHY

Medical ultrasound [7], also known as diagnostic sonography, generates images of the internal structures of the body using high-frequency sound pulses. A diverse range of medical conditions can be identified through the utilisation of this non-invasive and painless method.

To perform an ultrasound, a transducer, which is a compact, hand-held instrument, is applied to the skin over the area of interest. The transducer generates echoes by emitting high-frequency sound waves, which subsequently reflect off the internal structures of the body. The transducer captures these echoes to create visual representations of the body's internal structures, which are displayed on a screen. Ultrasound capabilities extend to the diagnosis of malignancy, liver and kidney disease, and complications that may arise during pregnancy. Additionally, it serves as an instrument for guiding needle aspirations and biopsies in the medical field. In Figure 9, ultrasound images of a maturing foetus are displayed. An automated technique that joins and separates the foetal image by employing morphological operators, which are a category of nonlinear image processing filters.
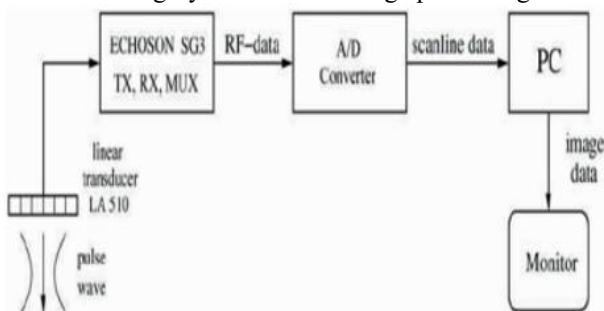

Figure 8: Ultrasound Imaging

Figure 9: Ultrasound Imaging of a Developing Fetus

F. Electrocardiography (ECG)

The electrocardiogram (ECG) [6] is a diagnostic tool used to assess cardiac function. It is a painless and non-invasive method used for diagnosing various heart conditions. During an electrocardiogram, small electrodes are adhered to the skin of the arms, chest, and legs. Electrical signals generated by the heartbeat are recorded by a device connected to the electrodes. The recording shows the heart's rhythm and can help find electrical problems in the heart. Arrhythmias, heart attacks, and heart failure are just some of the heart conditions that the electrocardiogram (ECG) is used to diagnose. It can also be used to detect changes in the heart's electrical activity and evaluate the efficacy of treatments for these conditions. Using digital signal processing, Multi-Resolution study and filtering techniques are employed to remove accidental troubles caused by ECG nodes efficiently, and the Wavelet Transform is utilised to achieve a practical filtering effect. Figure 10: An Electrocardiogram (ECG) of a Human Heart.
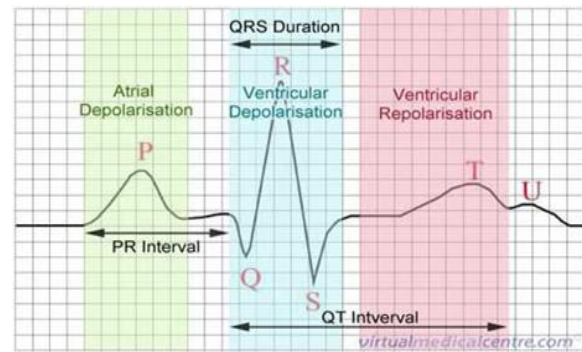

Figure 10: An Electrocardiogram (ECG) of a Human Heart

III. Fundamentals of Digital Image Processing

i.   Image enhancement.
ii.   Image Segmentation.

Image enhancement is a technique to increase the clarity and quality of images. With the support of computer software and different tools, this technique combines objective and subjective improvements. The image enhancement technique incorporates local and point operations. The regional input pixel values determine how the local processes work. Two different kinds of enhancement techniques that are widely used, namely, the Spatial and transform domain approaches [12]. The physical approaches operate at the pixel level or spatial domain, whereas the transform method operates on the Fourier domain and then the spatial domain. Image segmentation is a process of dividing an image into its constituent components. The primary goal is to simplify the image for analysis and elucidation. Using Edge detection, Image segmentation is done for improving the image perceptibility and quality by using computer-aided software [11]. In digital image processing, A sharp change in the brightness of an image is referred to as an edge. Methods that approximate gradients and derivatives are utilized in edge detection to identify these regions. Some common Edge Detection [15] techniques are:

Robert's Kernel: The method by which the distinctions between two adjacent pixels are ascertained is referred to as forward differences. This method helps locate boundaries in images with high levels of noise. For calculation, a first-order fractional derivative and cross-gradient operator are applied. The equations are given as follows:

$$\frac{df}{dx} = f(i + 1, j + 1) - f(i, j) \qquad \text{.......Equation 1.}$$

$$\frac{df}{dx} = f(i + 1, j) - f(i, j + 1) \qquad \text{.....Equation 2.}$$

Two 2*2 matrices are being used to apply the fractional derivative. Roberts's masks are as follows:

$$Gx = \begin{bmatrix} -1 & 0 \\ 0 & 1 \end{bmatrix} \text{ and } Gy = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}$$

Prewitt kernel: This edge detection technique is implemented based on the idea of central differences. It is improved compared to Roberts's operator. The matrix has an arrangement of pixels [i, j] as:

$$\begin{bmatrix} a0 & a1 & a2 \\ a7 & i,j & a3 \\ a6 & a5 & a4 \end{bmatrix}$$

Compute the fractional derivative of the Prewitt operator as:

$$Gx = (a2 + pa3 + a4) - (a0 + ca7 + a6) \quad ....\text{Equation } 3$$

where p is a constant representing the pixels close to the centre of the image. Gx and Gy are the calculations at [i, j]. When p equals 1, the Prewitt kernel is calculated as:

$$Gx = \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix} \text{ and } Gy = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix}$$

Sobel kernel: This method relies on the central difference, which, on average, tends to gravitate towards the central pixels. The formulation for this method is a 3 x 3 matrix applied to the first derivative of the Gaussian kernel. This method is computed as follows:

$$Gx = (c2 + 2c3 + c4) - (c0 + 2c7 + c6)$$

and

$$Gy = (c6 + 2c5 + c4) - (c0 + 2c1 + c2)$$

The Sobel masks are the following:

$$Gx = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix} \text{ and } Gy = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$$

IV. EXPERIMENTAL RESULTS OF EDGE DETECTION TECHNIQUES

In this section, a comparison of the efficacy of several edge detection methods, including Roberts, Sobel, Prewitt, and Laplacian Canny Edge Detector, is presented. The edge detection methods were implemented utilising Co-Lab and evaluated on a chest x-ray image of a human. The purpose of these procedures is to generate a pristine edge map by extracting the principal edge characteristics of the image. Figures 11, 12, 13, and 14 present both the original image and the image generated through the implementation of various edge detection techniques, respectively.
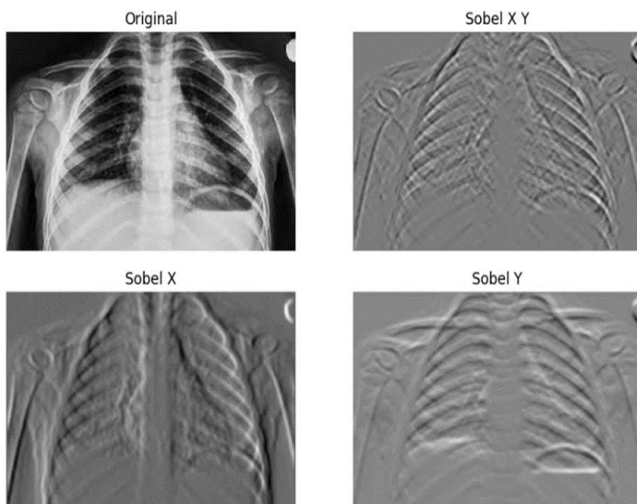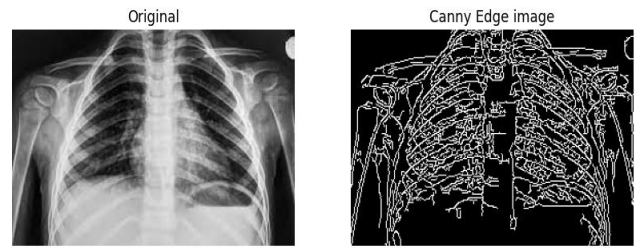

Figure 11: Sobel Edge Detection
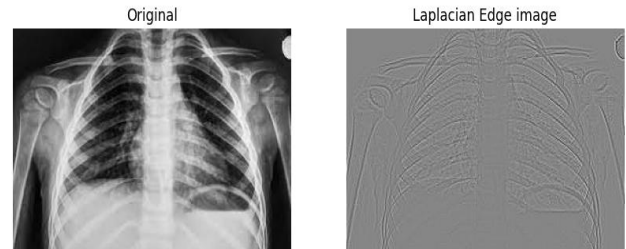

Figure 12: Canny Edge Detection

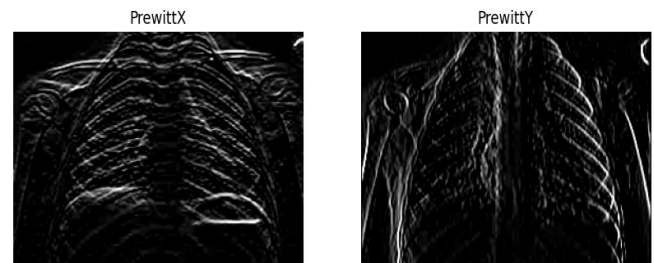**Figure 13: Laplacian Edge Detection**

Figure 14: Prewitt Edge Detection

Sobel and Prewitt Laplacian results deviated, and Canny produces an almost identical edge map. It can be observed from the figure that the Canny result is superior by far to the other results.

V. CONCLUSION

Multimodal image processing methods are gradually replacing the more traditional single-modality approaches. The computational techniques integrate imaging with other forms of data. The advent of digital image processing has greatly facilitated many facets of our lives, including work and study. As digital image processing advances into the field of algorithmic research with the help of neural networks, fuzzy logic, and artificial intelligence, associated image processing expertise will be carried out to fulfil the purpose. The expansion of AI and Deep Learning has led to the gradual development of image enhancement algorithms based on deep convolutional neural networks. The method is fast and accurate enough to meet the requirements of digital image processing.

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