Registration and Fusion of Medical Images based on Wavelets

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Fusion of Medical Images

Medical images - Fusion - Registration

بسم الله الرحمن الرحيم

In the name of Almighty Allah,
The most Beneficent, the most Merciful.

Department of Computer Science, International Islamic University, Islamabad.

Dated: 30-08-08

Final Approval

It is certified that we have read the thesis, titled **"Registration and Fusion of Medical Images based on Wavelets"** submitted by **Miss Maria Sabir** Reg. No. **321-FAS/MSCS/F06.** It is our judgment that this thesis is of sufficient standard to warrant its acceptance by the International Islamic University, Islamabad, for the Degree of **Master of Science.**

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Master of Science in Computer Sciences

Dedicated To

To My Mother

The most courageous lady I have ever seen in my life

Declaration

We hereby declare that this research, neither in part nor in full, has been copied from any source, except where cited; hence, acknowledged. It is further declared that this research, in its entirety, is a product of our personal efforts, under the sincere guidance of our supervisor. No portion of the work being presented herein, has been submitted to any other university, institute, or seat of learning, in support to any piece of writing for bestowment of any other degree of qualification.

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Maria Sabir
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Project in Brief

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Undertaken By:	Maria Sabir
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Abstract

In medical imaging single source images do not provide complete information for clinical diagnoses and research e.g. CT images provide best structural information on bones with less distortion, MRI provides better structural information on soft tissues, and PET provides better functional information on blood flow and flow activities. In order to integrate the complementary information from multimodality images, a process known as image fusion has come as a new and promising research field. Since the imaging data for fusion comes from different sensors and at different times, the first step is the proper alignment of images with same orientation, scaling and translation. This process of alignment is known as image registration. For the registration and fusion of medical images many techniques have been proposed yet. However in medical image processing there is always a need to produce a fused image with good enough information of the two original images.

In our work a new method is proposed for the registration of any two images in which proper boundary of an area of interest could be defined. Moreover many fusion methods have been studied and two different techniques are implemented. These are Global Energy Merging Scheme using Wavelets and PCA method to fuse low frequency components of DWT. These techniques are applied to Computed Tomography (CT), Magnetic Resonance Imaging (MRI), and Positron Emission Tomography (PET). Fusion results are compared using two quantitative measures of performance; the entropy and Root Mean Square Error. The qualitative measures of fused images are evaluated by the comments of a physician on these images.

The objective of this research is to select an optimum method for the registration and fusion of medical images and to provide enhanced medical information to medical doctors for accurate diagnosis.

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Introduction

1 Introduction

Medical imaging refers to the techniques and processes used in many areas of clinical research, diagnosis and treatment by creating the images of the human body. In order to provide quantitative and qualitative measures of the disease activities, an accurate and reliable diagnosis of the disease is required. Various medical imaging technologies are commercially available. Each technique has its own advantages and applications. Recently used medical imaging technologies include Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Ultrasound, Single Photon Emission Computed Tomography (SPECT), Computed Axial Tomography (CAT), Positron Emission Tomography (PET), Diffusion Tensor Imaging etc.

These medical imaging modalities can be divided into two major categories [1].

- Anatomical modalities, i.e., which provide a morphological/structural information of the body, include X-ray, CT, MRI, US etc.
- Functional modalities, i.e., which provide physiological/metabolic information, include SPECT, CAT, PET etc.

Based on these modalities different medical images often provide complementary information e.g. CT enhances the bone structure of the body in an image and gives less information about the soft tissues. Conversely, MR image enhances the soft tissues and gives a poor contrast to bone structure [2, 3]. In order to integrate the information of both the bones and the soft tissues in a single image, it is desired that both the X-ray computed tomography (CT) and magnetic resonance imaging (MRI) are integrated [4]. Likewise MRI image represents the anatomical structure while PET image can be used for studying the metabolic activities. Hence these two images can be combined to show physiological processes either in a specific region or through the whole body. Image fusion techniques are used to relate different modalities.

The two images belonging to different modalities are acquired through different sources and at different times. Therefore for proper integration of useful data obtained from images from different modalities is often desired. A first step in this integration process is to bring the images from different modalities into spatial alignment, a procedure referred to as image registration. After registration, a fusion step is required for the integrated display of the data involved [1]. Image fusion is an image processing technique that combines images from two or more sources to form an enhanced final image. Fused images are important in clinical research, diagnosis, and treatment like clinical surgery.

The registration solves the correspondence problem of the respective modalities and the fusion performs the integration of the image information to a single reference frame [5].

Hence our work is divided into two main phases

- **Registration**
- **Fusion**

We have studied different techniques for the registration and fusion of medical images. We have implemented three different techniques for the registration process. The first technique is proposed by Huang et.al in [6]. The second technique is discussed in MATLAB© help. These two techniques still contain registration problems regarding rotation and translation of images. We proposed a new technique for the registration of any two images in which proper boundary of foreground can be defined. This technique resolves all the problems regarding rotation and translation. We compare the results by fusing the registered images using simple averaging method for fusion and find proposed technique to be the best among three.

We then perform two different techniques for fusion on images registered by proposed method. These techniques are Global Energy Merging (GEM) Scheme using Wavelets [7], and PCA method to fuse low frequency components of DWT. The results of these techniques are compared using two different performance measures; Entropy and Root Mean Square Error (RMSE). Based on these measures we found PCA based technique to be more effective than GEM scheme.

Chapter 2 is "*Medical Imaging*" in which medical imaging modalities are discussed in detailed. These modalities include X-rays, Ultrasound, CT, MRI, PET and SPECT. We discuss these technologies along with their pros and cons in detail.

Chapter 3 is "*Literature Survey*". We include different research papers describing registration and Fusion techniques. After summarizing these research papers we have identified the problems in the areas of Image Registration and Fusion.

Chapter 4 is "*Research Methodology*" that we have adopted for our work. This chapter explains three different techniques for registration and two different techniques for fusion of those registered images.

Chapter 5 is "*Experimental Results*". Four different sets of medical images are tested on implemented techniques. These images belong to three different modalities i.e. CT, MRI and PET. The fused images are evaluated quantitatively by Root Mean Square Error and Entropy, while for the qualitative evaluation, the comments of a physician are included at the end of the chapter.

Chapter 6 is "*Conclusion and Future Work*" and *References* are given at the end.

Chapter 2
Medical Imaging

2 Medical Imaging

Medical imaging methods are the techniques and processes used to create images of the human body (or parts of the body) for clinical purposes or medical science (including the study of normal anatomy and function). The advancement in medical imaging presents a useful way to examine the inner structure of the human body. However, due to the different characteristics of medical imaging, a single source image cannot provide overall information for different needs. For example, CT shows the clear structure on denser tissue with less distortion, such as bone; while MRI reveals better pattern on soft tissue, such as brain [6]. Some of the modern imaging technologies are discussed below.

2.1. X-rays –The Basic Modality of Medical Imaging

X-rays were discovered by a German physicist Conrad Rontgen in 1895. X-rays are not only used in their own right as a radiological method, but are also used to produce CT images.

X-rays are part of the electromagnetic spectrum, which also contains visible light, ultra-violet light, radio waves, and infra-red radiation. Out of these electromagnetic radiations only X-rays are able to penetrate a material, that's why they are useful for imaging. They have a short wave length and thus a high frequency". [8]

X-ray images are produced by an X-ray beam. The X-rays are generated by passing a current through a vacuum tube. This induces electrons from a heated metal element (cathode) to pass across the vacuum and strike a tungsten target (anode). The anode then emits energy in the form of X-rays [8]. The X-rays passes through the patient's body and onto a X-ray sensitive-film. The different body tissues absorb this energy in different amounts, so the rays produce different shadows in the X-ray film. In this type of equipment, the data acquisition is a crucial task because information is not recorded in digital form. The advanced "Digital Radiography" is the same acquisition modality but the images are recorded digitally instead of in film form. [9]

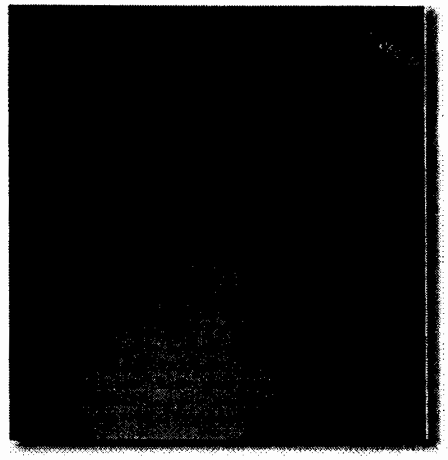


Figure 2-1: X-ray image of Chest [10]

Advantages

- X-rays are relatively cheaper than any imaging modality.
- It is most widely used and can produce excellent images of hard tissues or bones of any part of the body
- It is easy and quick to perform as experts are easily available

Disadvantages

- High radiation dose can cause damage to body tissues
- It provides poor contrast to soft-tissues and is unable to provide detailed information of small or deeper structures.
- It has a 2D projection, and can only provide still pictures.

2.2. Ultrasound

Ultrasound imaging is another imaging modality that uses high frequency sound waves of between 2.0 to 10.0 megahertz to construct cross sectional images of human body. This imaging modality is much safer than traditional X-rays as the patient is not directly exposed to radiations. It is used frequently in intensive care units where it is dangerous for the patient to move to the radiology department [11]. It is used in situations when real time movement of an object is to be studied e.g. to visualize the fetus movement in pregnant women [11]. Other important uses include vascular ultrasounds, musculoskeletal ultrasound, imaging the abdominal organs, heart, and the veins of the leg etc [11, 12]. It is also relatively cheaper and quick to perform than other techniques like X-rays, CT scan, MRI etc, but it provides less anatomical information.

"An emitter (pointer) moved by an operator on the patient's body causes the image to be taken in real-time. As each sound wave encounters tissue interfaces, a portion of the wave is reflected and a portion continues. The time required for the echo to return is proportional to the distance into the body at which it is reflected; the amplitude of a returning echo depend on the acoustical properties of the tissues and is represented in the image as brightness. The system constructs two dimensional images by displaying the echoes from pulses of multiple adjacent one-dimensional paths [9]."

Advantages

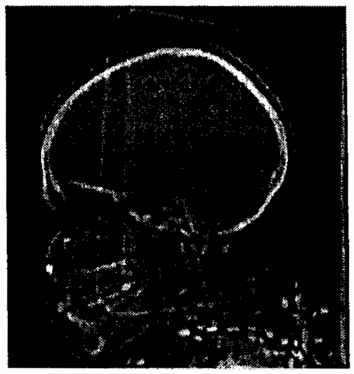
- Ultrasound is widely available, easy-to-perform and cost effective as compared to other imaging methods such as X-rays or MRI scans
- Ultrasound examinations are non-invasive (no needles or injections) technique that provide real time imaging of soft tissues of the body
- Ultrasound sound scanning is painless and has no harmful effects because it is a non-ionizing radiation. It can be done repeatedly as no risks are involved in it.
- The Ultrasound equipment is portable (can be operated from an ordinary wall socket) and store images in electronic form.

Disadvantages

- Ultrasound cannot provide images of bones so it is not possible to get information of adult skeletal system and head.
- Ultrasound provides less clear images as compared to any other technique.

2.3. CT Imaging

Computed tomography (CT), originally known as computed axial tomography (CAT or CT scan) is a medical imaging method that uses X-rays to generate images (slices) of internal body structures. The word "tomography" is derived from the Greek word "*tomos*" *means* slice and "*graphein*" means to write [10]. In Computed Tomography a digital geometry processing is used to generate a three dimensional image of the body structures from a large number of two dimensional X-ray images. During a CT scan, multiple X-rays are passed through the body, producing cross-sectional images, or "slices," on a cathode-ray tube (CRT), a device resembling a television screen [10].



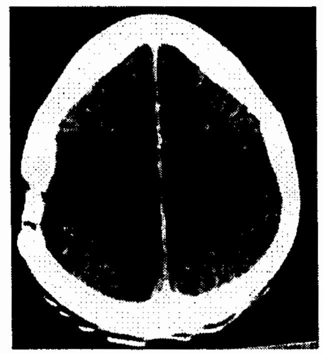


Figure 2-2: Original Slices of CT of brain

History

The first commercially available CT scanner was invented by Sir "Godfrey Newbold Hounsfield' in Hayes, United Kingdom at Thorn EMI Central Research Laboratories using X-rays. Hounsfield conceived his idea in 1967, and it was publicly announced in 1972. At the same time "Allan McLeod Cormack" of Tufts University, Massachusetts, USA independently invented a similar process, and both Hounsfield and Cormack shared the 1979 Nobel Prize in Medicine [10].

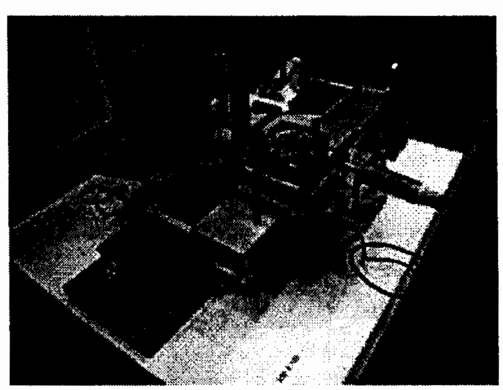


Figure 2-3: The prototype CT scanner [10]

The original 1971 prototype took 160 parallel readings through 180 angles, each 1° apart, with each scan taking a little over five minutes. The images from these scans took 2.5 hours to be processed by algebraic reconstruction techniques on a large computer [10].

Generations

Since the introduction of the first clinical system by Hounsfield, several generations of scanners have been produced, with distinguishing tube-detector configuration and scanning motion [9, 2].

Generation	Configuration	Rotation (Degree)	Detectors	Beam	Min Scan Time
First	translate-rotate	180	1~2	pencil thin	300 sec
Second	translate-rotate	180	3~52	narrow fan	20 sec
Third	Rotate-rotate	360	256~1000	wide fan	5 sec
Fourth	Rotate-fixed	360	600~4800	wide fan	1 sec
Fifth	electron beam	360	1284	wide fan electron beam	33 ms

Although numbered sequentially, the 3rd and 4th generation designs developed at approximately the same time.

CT scans are used to image bone, soft tissues, and air. Since the 1990s, CT equipment has become more affordable and available. CT scans have become the imaging exam of choice for the diagnoses of most solid tumors. Because the computerized image is sharp, focused, and three-dimensional, many structures can be better differentiated than on standard X-rays.

Applications

- Sinus studies. The CT scan can show sinusitis, sinus fractures and presence of sinus tumour in detail.
- Brain studies. Brain CT scans can detect hematomas, tumours, strokes, aneurysms, and degenerative or infected brain tissue.

- Body scans. Body CT scans can detect the presence of tumours, enlarged lymph nodes, abnormal collection of fluid, blood or fat, cancer metastasis, vertebral disc disease etc.
- Heart and aorta scans. CT scans can focus on the thoracic or abdominal aorta to distinguish between an aortic aneurysm and a tumour adjacent to the aorta. A newer type of CT scan, called electron beam CT, can be used to image calcium in bones.
- Chest scans. CT scans of the chest are useful in distinguishing tuberculosis or tumours present in the lungs.
- CT is most frequently used to diagnose diseases and disorders and is helpful for treatment planning, monitoring the tumour progression and response to treatment.

Procedure

Computed tomography (CT) uses the same basic principle as X-rays but produces images that represent slices of internal organs of the body. Also, the quality of the data obtained from a CT is much higher than that produced by a conventional X-ray [9].

Unlike conventional radiography, in CT scanning a beam of X-ray is used to take the images of different sections of the body. The CT scanner consists of a doughnut-shaped box with an X-ray table through the hole in the centre. In CT scanning the patient lies on the X-ray table that moves through the machine. The machine consists of an X-ray tube and an array of specially designed "detectors". The X-ray tube produces the beam of X-rays while rotation around the patient. Depending upon the system the X-ray tube rotates for either one revolution around the patient or continuously and the detector array record the intensity of the remnant X-ray beam. The X-rays that penetrate the patient strike iodide crystals within the detectors. These crystals emit photons of light, which are detected by a photomultiplier. This converts the light into electrical pulses. The number of pulses is directly related with the number of X-rays that hot the crystals. The number of pulses then reflects the density of the specific area of the body. A computer records the electrical pulses as digital information and two- and three-dimensional images are generated. CT scan reconstruct images in a variety of body planes usually the axial or cross sectional plane. CT images reflect the physical properties of the tissues being investigated.

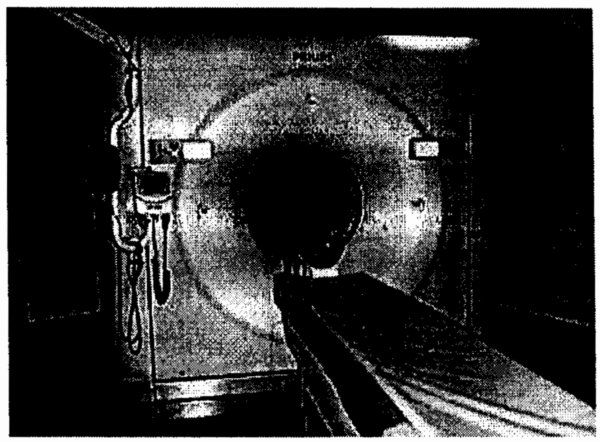


Figure 2-4: A Multislice CT Scanner [11]

Advantages

- CT is able to image bone fractures, soft tissues and blood vessels at the same time.
- Unlike conventional X-rays, CT scanning provides better contrast between bone, fat, water, and air and hence better classifies the organs.
- CT imaging is rapid and simple. It can produce images in few seconds showing the internal injuries and bleeding quickly enough to save lives in emergency cases.
- CT is less expensive and less sensitive to patient movement as compared to other techniques like MRI.
- CT is particularly useful for cancer treatment.
- CT is much safer than conventional X-rays as no radiation remains in a patient's body after scanning.
- Computers can use CT data to produce two- and three-dimensional images without superimposing the overlaying tissues.

Disadvantages

- CT scan involves body exposure to radiation so there is always a slight chance of cancer from these radiations. A thoracic CT scan may expose the patient to as much radiation as 40 chest X-rays. It is recommended that repeated CT scans must be avoided.

- The contrast agents like iodine, barium sulphate or rectal contrast used in CT exams may cause allergic problems to the patients. Hence patients should inform doctors if they have allergic problems or not prior to CT scan.
- CT scanners are expensive to purchase and hence each scan is relatively more expensive than an X-ray.
- There is a chance of missing very small and deep lesions under 1cm. Moreover CT cannot differentiate between tissues of very similar density or between areas of inconsistency within an organ.
- CT can produce images only in axial plane and not in sagitall or coronal planes

2.4. MR Imaging

MRI, also known as nuclear magnetic resonance (NMR) imaging was developed in1980s. Magnetic resonance imaging (MRI) is an advanced and specialized diagnostic imaging technique that uses radio waves, a magnetic field, and a computer for forming detailed images of internal organs and tissue. In this technique the patient lays inside a magnet and then radio waves are used to locate atoms in the tissue. Finally, images are produced by collecting and correlating deflections produced by the atoms with the help of a computer.

Magnetic resonance imaging (MRI) is the latest and multipurpose medical imaging technology. It allows the doctors to visualize highly refined images of internal body structures without surgery, Using strong magnetic fields and radio waves, this technique makes better images, with higher degree of resolution of soft tissues and internal organs, than those of other scanning technologies and help physicians to see internal body structures with greater details. MRI is particularly useful for imaging the brain and spine, as well as the soft tissues of joints and the interior structure of bones. The latest additions to MRI technology are magnetic resonance angiography (MRA) to study the blood flow and magnetic resonance spectroscopy (MRS) that identifies the chemical composition of diseased tissue and produces color images of brain function.

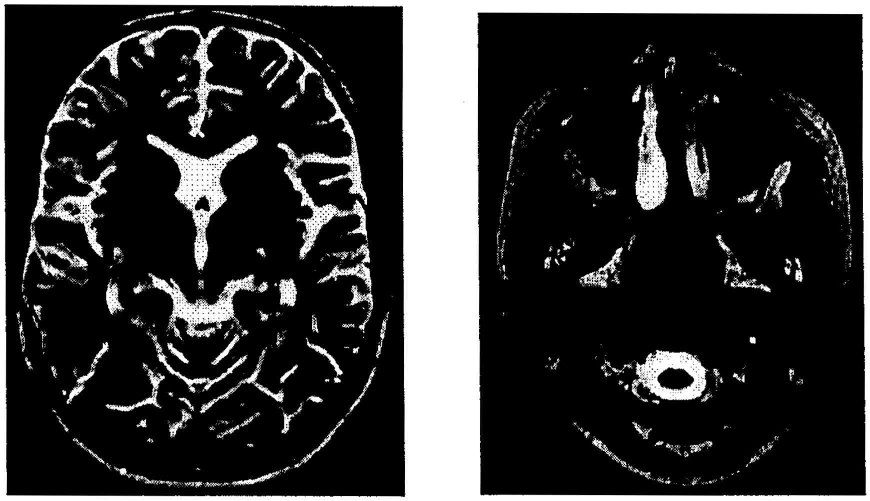


Figure 2-5: Original Slices of MRI of brain

History

The development of magnetic resonance imaging (MRI) began with discoveries in nuclear magnetic resonance (NMR) in the early 1900s and demonstration of magnetic properties of an atom's nucleus by Wolfgang Pauli in 1924.The first basic NMR device was developed by I. I. Rabi in 1938. This device depicts the magnetic properties of certain substances; however, the device could analyze only gaseous materials, and provide indirect measurements of these materials. These limitations were overcome in 1945, when two groups of scientists, led by Felix Bloch of Stanford University and Edward Purcell of Harvard University, independently developed improved NMR devices. After further technological improvements, Magnetic Resonance Imaging (MRI) was first used for medical purposes in 1976. The functional MRI was developed in 1993.

Applications

- Brain and head. It is one of the few imaging tools that can see through bone (the skull) and deliver high quality pictures of the brain's delicate soft tissue structures. MRI can be used to detect brain tumour, stroke, or infection (such as meningitis). And other brain diseases such as Alzheimer's or Huntington's diseases, or multiple sclerosis. It can also provide pictures of the sinuses and other areas of the head beneath the face.

- Spine. MRI is particularly useful for identifying and evaluating degenerated or herniated inter-vertebral discs. It can also be used to determine the condition of nerve tissue within the spinal cord.
- Joints. MRI can provide clear images of the bone, cartilage, ligaments, and tendons that comprise a joint. So it can be used to diagnose joint damage due to sports, advancing age, or arthritis. It can also be used to diagnose torn rotator cuff, and hidden tumour or infection in a joint, and can be used to diagnose the nature of developmental joint abnormalities in children.
- Skeleton. The properties of MRI that allow it to see though the skull also allow it to view the interior of bones. It can be used to detect bone cancer, inspect the marrow for leukaemia and other diseases, assess bone loss (osteoporosis), and examine complex fractures.
- The rest of the body. MRI provides more detailed images of chest, abdominal, and general body than CT and ultrasound in certain circumstances, or when repeated scanning is necessary. It is particularly used for spotting and distinguishing diseased tissues (tumours and other lesions) early in their development because of its contrast sensitivity to distinguish fine variations in tissues deep within the body.

Procedure

Magnetic Resonance Imaging (MRI) scanners rely on the principle of Nuclear Magnetic Resonance (NMR) to produce highly detailed images of the human body. The patient lies down on a narrow table and radio-wave transmitters are positioned on the body. Depending on the area to be imaged, the transmitters are positioned in different locations [10].

- For the head and neck, a helmet-like covering is worn on the head.
- For the spine, chest, and abdomen, the patient lies on the transmitters.
- For the knee, shoulder, or other joint, the transmitters are applied directly to the joint.

The table then moves inside a huge powerful magnet that generates an intense magnetic field. This magnetic field polarized and exited the hydrogen nuclei (single proton) in water molecules in human tissue. Hydrogen is the simplest element known, the most abundant in cellular tissue, and one that can be magnetized. All hydrogen nuclei act like tiny magnets and align themselves with a north and south orientation within a strong magnetic field. Once a patient's hydrogen atoms have been aligned in the magnet, a radiofrequency (RF) pulse is transmitted by a radiographer using a transmitting device. The RF pulse alters the natural alignment of hydrogen atoms. The transmitting RF pulse is switched off and the hydrogen atoms begin to return to their natural state. In doing so they emit an RF radiation i.e. NMR signal which is detected by a receiving device or RF antenna. From this received signal, MRI equipment is used to record the duration, intensity of the signal, and the differences in the orientation of nuclei. The signal pattern, produced in diseased tissue, differs from those of healthy tissue of the same type, and thus helps physicians to identify tumors and other lesions. In some cases, chemical agents such as gadolinium can be injected to improve the contrast between healthy and diseased tissue. From this viewpoint, the computer performs advanced image reconstruction calculations and produces an image that can be viewed, hard and/or soft copied and interpreted for any diagnosis.

Healthy and diseased tissues produce different signal patterns and thus allow physicians to identify diseases and disorders.

A single MRI exposure produces a two-dimensional image corresponding to one slice through the entire target area. The table then moves a fraction of an inch and the next image is made. The whole process takes 30 to 90 minutes approx. During this time, the patient must remain still as movement can add noise to the image produced. The patient may be asked to hold his/her breath as each exposure is made. A series of these image slices are closely spaced (usually less than half an inch) and a three-dimensional view of the area can be visualized [10].

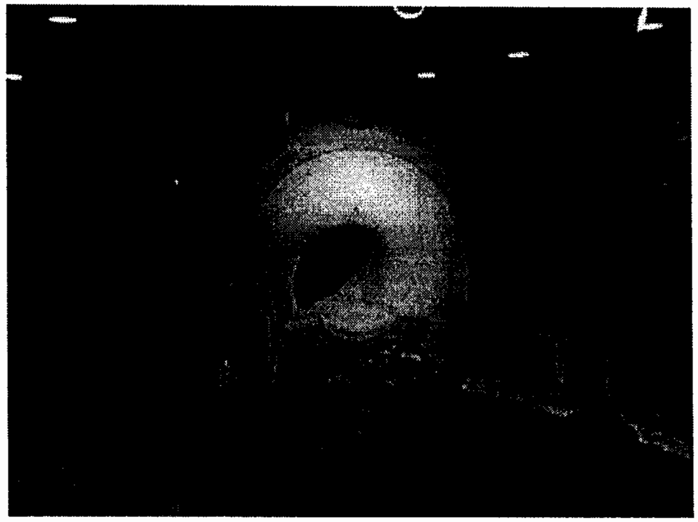


Figure 2-6: Modern 3 Tesla clinical MRI scanner [10]

Advantages

- MRI systems do not involve radiation exposure, so there are no risks involved in this procedure.
- Unlike CT, MRI can produce images in any plane including axial, sagitall and coronal.
- MRI is able to image deep within the body and offers increased-contrast resolution providing highly detailed information about soft tissues. Hence it is useful for diagnosing the tumours, infections and strokes in their earliest stages.
- MRI can be used for angiography as functional MRI can show the working of brain and heart by imaging the flow of blood.
- Since no contrast agents are used in this technique hence it involves no side effects or allergy problems like CT.

Disadvantages

- MRI is relatively expensive and rare than CT and conventional X-ray technologies.
- It is a time consuming procedure. Typical MRI exam can take 20 to 90 minutes for a complete scan.
- MRI procedure is complex to perform. An experienced radiologist and a highly trained operator is required to perform the test.

- MRI is much sensitive to the patient movement. A slight movement of the organ being scanned can lessen the quality of the image.
- MRI machine produces unpleasant loud noise during the scan which may cause in some cases temporary or permanent hearing loss. Therefore patients are advised to use earplugs or stereo headphones during the test.
- MRI is unable to image calcium and hence provide poor contrast to bones.
- MRI may cause danger for the patients suffering from claustrophobia. Moreover the patients with pacemakers or having any metal implant cannot be safely scanned with MRI.

2.5. Positron Emission Tomography (PET)

Positron emission tomography (PET) is a nuclear medicine medical imaging technique that uses short lived radio-labeled compounds to produces three-dimensional images of the body's biological function through the detection of gamma rays that are emitted when introduced radionuclide's decay and release positrons [10] .The concept of emission and transmission tomography was introduced by David Kuhl and Roy Edwards in the late 1950's

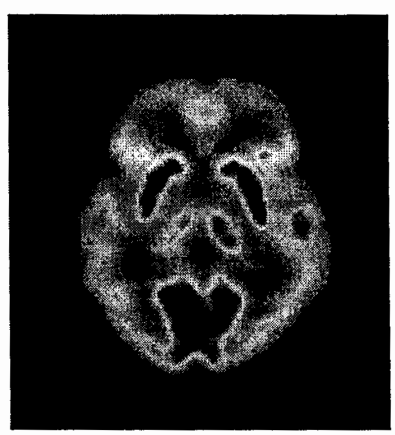


Figure 2-7: PET scan of the human brain [13]

Applications

- PET is used to investigate the metabolism of normal organs and various neurological diseases and disorders, including stroke, epilepsy, Alzheimer's disease, Parkinson's disease, and Huntington's disease.
- PET is also used to image various psychiatric disorders, such as schizophrenia, depression, obsessive-compulsive disorder, attention-deficit/hyperactivity disorder, and Tourette syndrome,
- PET is a cancer diagnostic tool and detects metastatic tumours that may not be visualized by other imaging techniques.
- PET is used to assess response to chemotherapy.
- PET differentiates malignant from benign cell growths, and in assessing the spread of malignant tumours.
- PET is used to detect recurrent brain tumours and cancers of the lung, colon, breast, lymph nodes, skin, and other organs.

Procedure

To conduct the scan, small amount of a radioactive substance such as glucose, labeled with a radioactive atom is injected into the patient. After some time (typically an hour) the metabolically active molecule becomes concentrated in the tissue to be studied. The patient is then placed in the imaging scanner. As the radioactive atoms in the compound decay, they emit positively charged particles called positrons. As positrons collides with an electron (negatively charged), a pair of photons (gamma rays) are emitted. These photons move in opposite directions and are recorded as signals by the detectors of the PET scanner surrounding the body. A computer uses this information to generate 3-D cross-sectional images which shows that how the organ is metabolizing the injected substance.

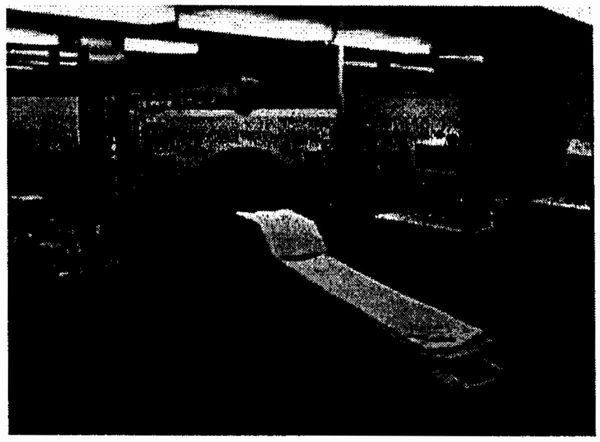


Figure 2-8: Image of a typical positron emission tomography (PET) facility [10]

Advantages

- PET imaging is unique in that it shows not only the structures but also the organ functionality precisely. Hence PET imaging may detect the changes in the biochemical processes that may suggest the diseases in earliest stages.
- Because of its increased sensitivity PET can provide useful information that helps the physician to diagnose or to determine appropriate treatment, if any.
- Radiation exposure is extremely low as short lived radiations are used in the process. Thus the radiation risk is very low.

Disadvantages

- It is very expensive and not easily available. Moreover its maintenance costs are very high.
- Although very rare but risks of ionizing radiations are there. Slight pain may be felt due to injection of the radiotracer
- Diabetic patients or patients with abnormal blood sugar or blood insulin levels may have false test results.
- It requires highly specialized radiologist to perform scans and also the availability of radioactive substance on time

2.6. Single-photon-emission computed tomography

Single photon emission computed tomography (SPECT) is a nuclear medicine tomographic imaging technique using gamma rays to provide 2-D images (also called projections), as cross-sectional slices through the patient. A computer is then used to apply a tomographic reconstruction algorithm to the multiple projections to get 3-D view of the organ similar to MRI, CT, and PET.

Procedure

To acquire SPECT images, the gamma camera is rotated around the patient. Projections are acquired at defined points during the rotation, typically every 3-6 degrees. In most cases, a full 360 degree rotation is used to obtain an optimal reconstruction. The time taken to obtain each projection is also variable, but 15 – 20 seconds is typical. This gives a total scan time of 15-20 minutes.

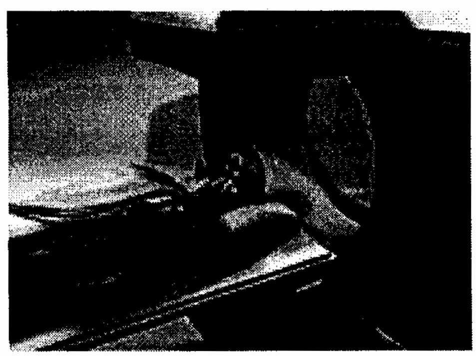


Figure 2-9: SPECT imaging machine [10]

Application

- SPECT can be used for any gamma imaging study, where a true 3D representation can be helpful e.g. tumour imaging, infection (leukocyte) imaging, thyroid imaging or bone imaging.
- It can be used to provide information about localized function in internal organs e.g. functional cardiac or brain imaging.

Advantages

- It is less expensive and widely available process with immediate results.
- SPECT produces 3-D images providing organ functionality
- No ionizing radiations are used
- It is clinically validated technique to study the brain functionality.

Disadvantages

- Poor spatial resolution and relatively long scanning time than PET.
- Because of its decreased sensitivity it does not provide detailed anatomical information.
- It uses radiations and injections and may cause Claustrophobia.
- It is sensitive to patient movement and can distort the image with slight movement.

Chapter 3
Literature Survey

3 Literature Survey

We have divided our work in two phases. The first phase involves registration of two medical images belonging to different modalities. These modalities include CT, MRI and PET. The other phase consists of fusion of these registered images. We have studied many research papers regarding our work. Few of them are described below.

3.1. Medical Image Registration and Fusion with 3D CT and MR data of Head [6]

In this paper Huang et.al proposed a procedure for 3D image reconstruction which consists of the following five steps [6]

1. CT and MR images preprocessing
2. Calibration and registration of volume data
3. 3D image reconstruction
4. Fusion and
5. 3D visualization to reveal the 2D planes or 3D surface.

The procedure for image registration described by Huang et.al [6] is as follows

a) The resolutions adjustment of the two images is done. Since the slice thickness of MRI is larger than the CT, the data of MRI were interpolated first to achieve the same slice thickness of CT.

b) Within the two third sections of both data sets, the slices containing the contour with the maximum areas were searched for the target slice. Sobel detector is used initially to detect the contours which are then refined manually.

c) Difference measurements in scale, rotation and translation are computed. For this purpose two sets of feature points, {a, b} in CT image corresponding to {c, d} in MRI, are selected manually. From these two points, two vectors $\vec{V}ab$ and $\vec{V}cd$ are derived. The angle θ between these two vectors is derived as eq. (3.1).

$$\theta = \cos^{-1}\frac{(\vec{V}ab.\vec{V}cd)}{(|\vec{V}ab||\vec{V}cd|)} \qquad \text{eq. (3.1)}$$

d) The parameters of scale, rotation and translation derived above are used to find the new index of two images as eq. (3.2) for image registration.

$$\begin{bmatrix} X' \\ Y' \end{bmatrix} = \begin{bmatrix} m \\ n \end{bmatrix} + s\begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}\begin{bmatrix} X \\ Y \end{bmatrix} \qquad \text{eq. (3.2)}$$

Where m, n denote the translation in X and Y direction; s represents the scale and θ specifies the rotation angle.

The registered slices are then used for 3D image reconstruction which is through Shell rendering [14] and Surface rendering [15]. Shell rendering is used to visualize the registered volume data and Surface rendering is used to reconstruct the target contours including the face and brain.

After image calibration and registration Fusion of images is done by superimposing the two sets of volume data from CT and MRI and displaying in different colors.

Advantages

- An algorithm for selection of reference slices, from CT and MRI datasets, is proposed.
- The combination of the volume data of CT and MRI can provide physicians integrated information of bone and soft tissue.
- 3D construction by Shell rendering is fast and consumes less memory

Disadvantages

- Image quality by Shell rendering is coarse.
- Selection of feature points from reference slices is manual.
- Extra edges appear in contour surface have to be removed manually.

3.2. Fusion for Registration of Medical Images; a Study [16]

This paper proposed a new fusion algorithm based on discrete multiwavelet transform (DMWT). In this paper Kapoor et.al compare their results with the results from FCM algorithm used for the similar purpose. They perform their tests on CT, MRI and SPECT images. For MRI-SPECT a pixel level multisensory image fusion is performed and for CT-MRI feature level multisensory image fusion is done. The images are decomposed using GHM multiwavelets to 2nd level. The pixels of the sub images consist of corresponding multiwavelet decomposition coefficients. The low-low sub bands block shows the image approximate characteristic, so the feature point for fusion is the cluster formed by the extrema density points using the nearest neighborhood approach. The coefficients of composite sub bands are formed by selecting coefficients belonging to the feature-cluster-block between two source images. The selected cluster-contour coefficients are used to represent the salient features in the sub bands of the source image. Finally, the fused image is constructed by successively performing reconstruction and the post filtering on the combined coefficients.

For image registration an information-theoretic measure, cross entropy, also known as relative entropy and Kullback-Leilber distance are used.

Advantages

- Multiwavelet has advantages of combining symmetry, orthogonal, and short support, which cannot be achieved by scalar two-channel wavelet systems
- The DMWT method is not only better than FCM approach but also better than any other Wavelet technique, like Daubechies wavelet.

Disadvantages

- For correct alignment of images on pixel by pixel basis no proper procedure is defined rather it is assumed that the images are perfectly registered
- It would be better if the authors use some performance evaluation criteria to support their proposed algorithm

3.3. A Novel Wavelet Medical Image Fusion Method [7]

This paper proposes a novel global energy merging (GEM) scheme that is a region-based analysis approach. GEM is based on discrete wavelet transform (DWT).

The procedure used for the fusion of images is described by Zhang et.al as follows.

1. Multi-resolution wavelet decomposition on each source image is performed.
2. The energy of the each 3*3 pixels matrix region is calculated.
3. Using wavelet decomposition coefficient and the energy, the match measure is calculated. The match measure is a metric reflecting the resemblance between the input images.
4. The three high frequency coefficients of the fused image are produced by comparing match measure of several source images.
5. The low frequency coefficient lies on the choice of the three high frequency coefficient.
6. Finally, by applying the inverse wavelet transform the final fused image is obtained.

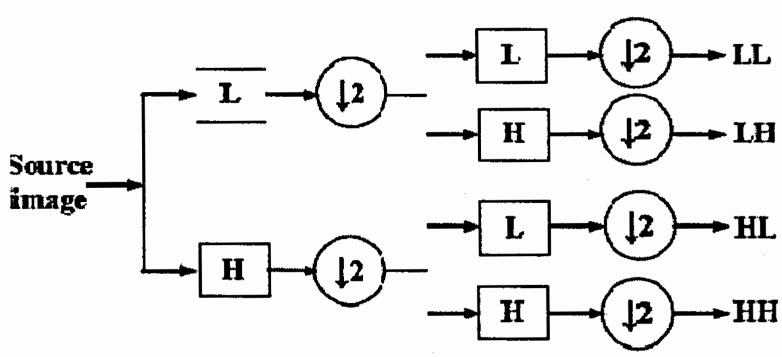


Figure 3-1: A Structure of the DWT [7]

Advantages

- The composite images can preserve more relevant information about the edges.
- The Root Mean Square Error (RMSE) values show that the proposed wavelet image fusion method has better performance than REM (Region Energy Merging), Maximum and Variance based methods.

- Since each frequent band coefficient comes from the same image, the consistency of coefficients is achieved.

Disadvantages

- DWT results square effect at the edges of the final fused image.
- Further processing has to be done to improve the contrast of final image.

3.4. A Multiresolution Image Fusion Based on Principle Component Analysis [17]

This paper presents a multi-resolution image fusion method using principle component analysis (PCA). The registered images are decomposed using wavelet transform. Different fusion rules are used for low frequency wavelet coefficient and high frequency ones. The final fused image is obtained by taking the inverse wavelet transform for the fused wavelet coefficients. The fused image provides both the global structure and significant features in the same imagery [17]. This wavelet based image fusion scheme by Huaixin Chen is summarized as

1. Registered images are taken as the combining source images, with their corresponding pixels aligned.
2. The discrete wavelet transform of each of the two registered images is computed.
3. The wavelet coefficients maps are fused using the fusion decision map rule in the wavelet transform domain.
4. The wavelet coefficients are fused using different combining rule for low frequency band and high frequency band respectively.
5. An adaptive fusion weight value of the low frequency wavelet coefficients are resolved using PCA, the high frequency wavelet coefficients are fused by local wavelet energy maximum,
6. Finally, fused image is formed by using inverse wavelet transform.

The schematic diagram by Huaixin Chen for wavelet based multi-resolution image fusion is shown in Figure as below.

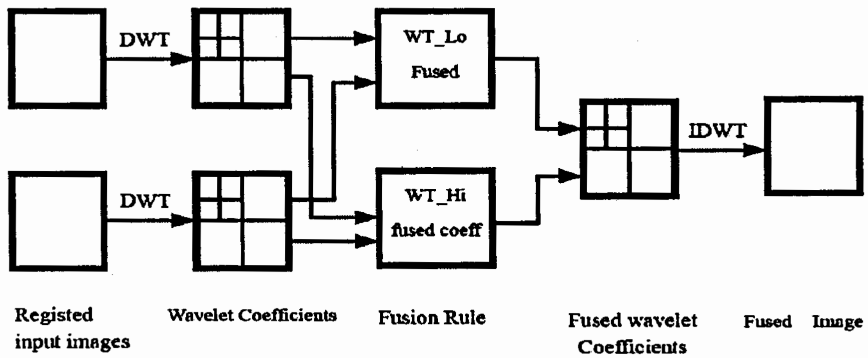


Figure 3-2: Block diagram of the wavelet based image fusion scheme [17]

Advantages

- Different fusion rules are adopted for low frequency wavelet co-efficient and high frequency ones thus treating high and low frequency components differently.
- The resulting fused image not only contains information about the salient features of images such as edges and lines but also about the profile features of images
- The proposed method in this paper not only improves the detail texture but also retains the global structure information from the original images.

Disadvantages

- PCA is an unsupervised technique and as such does not include label information of the data [18].
- The proposed technique needs improvement to deal with different objects of interest in the source images as well.

3.5. A novel image fusion algorithm based on bandelet transform [19]

In this paper a bandelet–based fusion algorithm is proposed. In bandelet transform a geometric flow of vectors is used to form the bandelet bases.

Methodology

- Geometrically register two source images to each other.
- Apply bandelet transform on each registered source image to partition the image into square regions, each region having at most one contour.
- Compute Geometric flow and the bandelet coefficients corresponding to the geometric flow in each region
- Process the fusion rules. For the geometric flow, fusion with the maximum rule is given in eq. (3.3)

$$G_F(i) = \begin{cases} G_1(i), & if \ G_1(i) \geq G_2(i) \\ G_2(i), & if \ G_1(i) < G_2(i) \end{cases} \quad \text{eq. (3.3)}$$

For the bandelet coefficients, fusion with the maximum absolute value rule is given in eq. (3.4)

$$C_F(x,y,i) = \begin{cases} C_1(x,y,i), & if \ abs\left(C_1(x,y,i)\right) \geq abs\left(C_2(x,y,i)\right) \\ C_2(x,y,i), & if \ abs\left(C_1(x,y,i)\right) < abs\left(C_2(x,y,i)\right) \end{cases} \quad \text{eq. (3.4)}$$

- Reconstruct the fused image by the bandelet inverse transform using geometric flow and bandelet coefficients.

The fusion framework using bandelet transform is shown in figure below.

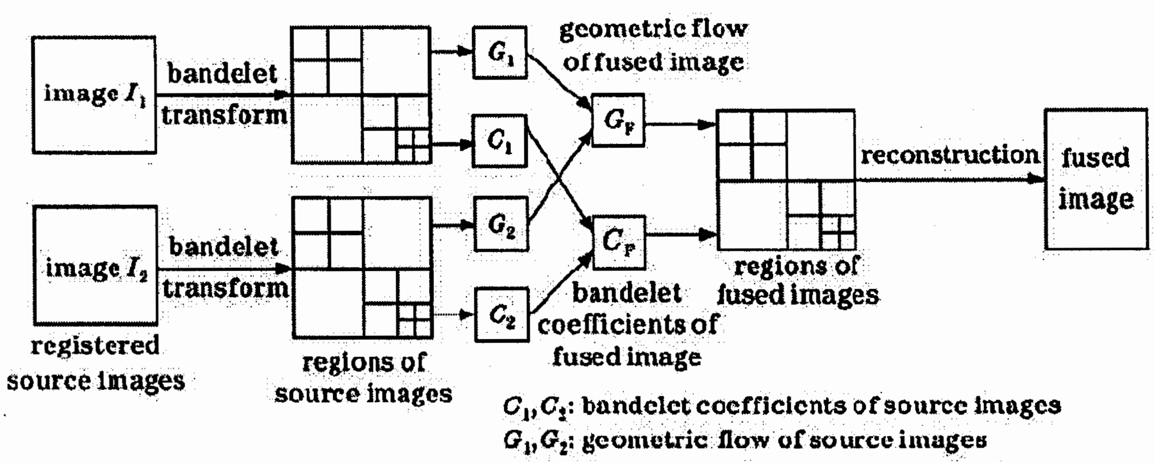


Figure 3-3: Fusion framework using bandelet transform [19]

Advantage

- Bandelet transform is appropriate for the analysis of edges and texture of images

Disadvantage

- Each region in image partitioning must have at most one contour or else the flow is not defined.

3.6. Pixel-based and region-based image fusion schemes using ICA bases [20]

In this paper Mitianoudis et.al describe the use of ICA and topographical ICA bases in the field of image fusion. The bases are obtained by training image samples with similar contents. PCA is used as a pre-processing step to select the k most important vectors which can be used to estimate a finite set of basis vectors with maximum signal structure (energy).

Methodology

- Take T $M1 \times M2$ registered source images
- Select every possible $N \times N$ image patch from each image
- Transform each path into vector using lexicographic ordering
- Transform each of these input vectors to ICA or topographical ICA domain representation.
- Perform optional de-noising by applying "hard" threshold on the coefficients
- Fuse the corresponding coefficients from each image in ICA domain using a fusion rule.
- Move back to the spatial domain and reconstruct the final fused image by averaging the image patches in the same order as they were selected during the analysis step

The input images are segmented (isolating patches) into "active" and "non active" areas. Pixel-based weighted combination rule is applied on the ''active'' areas and the pixel-based ''mean'' rule is applied on ''non-active'' areas for fusion

Advantages

- ICA transforms can be tailored to train the bases for specific application areas so that the trained data can be analyzed efficiently.
- The topographical ICA bases offer more accurate directional selectivity, thus the salient features of the image can be captured more accurately.

Disadvantages

- Increased computational complexity
- ICA transforms are not shift invariant which is considered to be a very important property for the fusion of images with some error of registration.

3.7. Region-based Image Fusion using Energy Estimation [21]

In this paper Yingjie et.al proposed a region based image fusion method for multisensory images. The aim is to apply appropriate fusion rule to every specified region of the image by evaluating the performance of available fusion approaches.

Methodology

- Select an image with most important visual information from the input images.
- Segment the selected image to produce a set of regions
- Find corresponding regions on other images by linear mapping
- Select an appropriate fusion rule for a specified region of the image using an evaluation model based on energy estimation. This model is proposed by the authors to measure the fusion quality of the candidates
- Apply the candidate fusion rule on every region of the image one by one.
- Finally all the fused regions are combined to obtain the resulting fused image.

In order to perform region segmentation a fast algorithm is proposed based on the piecewise smooth Mumford-Shah (MS) energy model. Also to speedup computation of image segmentation a level set based optimal algorithm is integrated with this model.

Advantages

- Regions are segmented in such a way that all relevant information in the images is preserved.
- Different regions are processed with different appropriate fusion rules
- Remove some of the side effects like contrast reduction and sensitive to error of registration

Disadvantages

- Computationally expensive as all the fusion rules in the database have to be tried one by one on each region.
- Selection of segmenting image with most visual information is also a point of concern.
- Only one of the source images is considered for segmentation which may result in loss of some region from other images.
- Combination of fused regions to get the resulting fused image is also an issue to be solved.

3.8. Optimum Multi-resolution Fusion Scheme for CT/MR Images Based on Region Feature [22]

In this paper Wang et.al proposed a multi-resolution fusion scheme for CT/MR images based on region feature. The low frequency band of the image multi-resolution representation is segmented into two important regions.

- The soft tissue information from MR image as region 1
- The line feature of CT image as region 2

Different feature regions are fused with different rules. Three fusion rules are described in this paper.

Rule 1 is applied on line feature of low frequency base-band coefficients of CT image. It emphasizes the skull contour information and is defined in eq. (3.5)

$$C^L(2^j, x, y) = C^L_{CT}(2^j, x, y) \qquad \text{eq. (3.5)}$$

Where,

$C_{CT}^{L}(2^j, x, y)$, is a low frequency base-band coefficient of line feature of CT image.

$C^{L}(2^j, x, y)$, is adopted the fused coefficients.

Rule 2 emphasizes the soft tissue information from MR image and is given in eq. (3.6)

$$C(2^j, x, y) = k_{opt} C_{MR}^{a}(2^j, x, y) + (1 - k_{opt}) C_{CT}^{a}(2^j, x, y) \quad \text{eq. (3.6)}$$

Where,

$C(2^j, x, y)$, represents the fusion value of low frequency base-band coefficients

$C_{MR}^{a}(2^j, x, y)$, represents the data of MR of low frequency sub-band and

$C_{CT}^{a}(2^j, x, y)$, represents the data of CT in the corresponding differentiation 2^j ;

k_{opt}, is the optimized MR weight coefficient. The optimized CT weight co-efficient should be $1 - k_{opt}$

Rule 3 is applied to high frequency sub-bands coefficients and is defined in eq. (3.7)

$$C^k(2^j, x, y) = \begin{cases} C_{MR}^{k}(2^j, x, y) & D_{MR}^{k} > D_{CT}^{k} \\ C_{CT}^{k}(2^j, x, y) & D_{MR}^{k} < D_{CT}^{k} \end{cases} \quad \text{eq. (3.7)}$$

Where,

$C^k(2^j, x, y)$, is the fusion result of high frequency sub-band in differentiation 2^j;

$C_{MR}^{k}(2^j, x, y)$ and $C_{CT}^{k}(2^j, x, y)$ are the corresponding MR/CT image coefficients of high frequency child band and

D_{MR}^{k} and D_{CT}^{k} are the variances based on the 3×3 airspace window in the centre image pixel (x, y) .

The final fused image is achieved by using the inverse multi-resolution transform in the corresponding decomposing layer.

Root mean squared error (RMSE) and edge preservation (EP) are used as quality performance indexes to compare the performance of different image fusion algorithms.

Advantages

- Optimum weight value k_{opt} maintains the information of skeleton and structures in maximum.
- Different fusion rules are defined for different feature regions.

Disadvantages

- Some loss of information from MR image occurs due to redundancy during the fusion process.

3.9. Medical Diagnostic Image Fusion Based on Feature Mapping Wavelet Neural Networks [23]

In this paper Zhang et.al proposed a feature level image fusion technique based on discrete wavelet transform and self organizing neural network. This methodology is termed as self organizing feature mapping wavelet neural network (SOFMWNN). The Self organizing feature mapping neural network (SOFMNN) is a two-layer neural network proposed by Kohonen and has the capability to associate and cluster. The learning method of Kohonen SOFMNN is unsupervised clustering. SOFMN divides feature space of each image into c parts. Fuzzy logic is used to assign membership function to each pixel in every image. As a final architecture of SOFMWNN, the original architecture of SOFMNN is extended by introducing the hidden layers used for wavelet transformation into the architecture of SOFMNN. The fusion process is applied on MR and SPECT images of a same brain

Advantages

- Wavelet based functions used in neural network provide much higher availability of rates of convergence than an ordinary feed forward network.
- Embedding of hidden layers used for wavelet transformation into the architecture of SOFMNN can enhance the forecasting and organizing ability of the feature mapping neural network.

Disadvantages

- Dilation process used in the implementation structure may result in loss of important information.
- Large data set is required for initial training of classifier
- Experimental results show that some information from MR image is lost in the final fused image.

3.10. Matlab Registration-Fusion Technique for Dicom Images [24]

In this paper Apostolou et.al proposed a full clinical tool for the registration and fusion of dicom images of head of single patient from the CT and MR modality. While the routine runs the clinician is asked to choose 3 homologous points from the two dicom images. Each homologous point on the CT image is the bary-centre of a triangle of 3 points from the region of interest. As the routine runs the transformation parameters and the coordinates of the new points are calculated. Then a bilinear interpolation is used to register MR image with reference to CT image. Thresholding is then applied to segment the skull from CT image. Again clinician is asked to choose the intensity threshold. For the understanding of exact position of the brain pathology in relation to the skull by the clinician, the algorithm fuses the skull on MR image automatically. To help the clinician the skull is made colored (either white or green). At the end, the Canny filter on the MR image with suitable threshold and sigma value is applied to reveal the pathological brain contour, whereas the skull is fused around. The routine job lasts less than a minute.

Advantages

- The routine is fast, semiautomatic and computationally inexpensive.
- The MATLAB© platform offers user-friendliness and makes the process quite easy.
- The algorithm is applicable to other rigid parts of the human body and with other imaging modalities.
- The routine is extendable to the three dimensions.

Disadvantages

- Require clinical expert for the selection of homologous points from the two images and the intensity threshold to segment the skull from the CT image
- Thresholding and filtering methods may result in loss of important information.
- Since MRI and CT produce images in a set of slices, there must be some mechanism for the selection of CT slice corresponding to MRI slice or vice versa as the authors claim their work as full clinical tool

3.11. Summary

Registration and fusion of medical images is an ongoing research area of clinical diagnosis to derive useful information from multimodality medical image data. The first step for registration and then fusion of medical images is the data acquisition and preprocessing. Since PET, MRI and CT produce images in a different set of slices, our study starts with the selection of reference slices of these modalities from two different sets. Once the reference slices are selected, the next step is to register two images with same orientation, scale and translation which are discussed in detail in [6]. Then we discuss few papers describing different fusion techniques for already registered images. These include wavelet transform, PCA bases, bandelet transform, ICA bases, energy estimation, Optimum multi resolution and feature mapping wavelet neural networks. At the end we discussed a full clinical tool implemented in MATLAB© for both registration and fusion of dicom images of head of single patient from the CT and MR modality. Each technique has its advantages and disadvantages clearly explained in the survey.

3.12. Problem Identification

Image Fusion is the process by which two or more images of the same scene acquired from different modalities or techniques and at different times are combined to a single image containing the important features from all source images. The main focus of image fusion is to retain important information from each of the original images in the final fused image. In the recent years many fusion methods have been proposed to represent the whole information contained in the input/source images as a single fused image without distortion or loss of information. However in medical imaging it is practically impossible to retain all the information from input images into a single image. Hence there is always a need to develop some mechanism so that all the relevant information can be preserved in the final fused image. In our work we found wavelet based techniques to be more effective in combining important image features, but still these methods result in square effect at the edges of the final fused image due to processing in low resolution. Moreover, further processing need to be done to improve the contrast of final image. Other methods like PCA, ICA, and bandelet transform increase the computational complexity and introduce many other problems clearly described in the survey.

Chapter 4
Research Methodology

4 Research Methodology

We have divided our work in two major tasks. The first task is to register two medical images belonging to two different modalities. The other task is to fuse these registered images to combine important information present in both the images into a single image.

4.1. Medical Image Registration

In medical diagnostic it is often required to relate information from one image to the information in other image. These images may be taken at different times and by different modalities. Moreover the patient's position may be inconsistent during image acquisition. There must be some method to visually align the images prior to correlate the information. The term Image registration is used to establish a one to one mapping between the points in the source images taken from different sensors. Registration is a fundamental task in image processing used to map pixels from one image, called the *reference image*, to pixels in another image, called the *test image*. In other words Image registration is the process of overlaying two or more images of the same scene taken at different times, from different viewpoints, and/or by different sensors [16].

In image registration the reference image is kept unchanged while the test/target image is geometrically transformed to spatially align with the reference image using some transformation function.

Image registration is necessary for:

- Fusion of Images taken from different sensors
- Construction of 3-dimensional images from multiple 2-dimentional images
- Model based object recognition
- Finding changes in images taken at different times or under different conditions

Although various image registration techniques have been developed over the years for various types of applications but our main concern is of medical image registration.

We take images of brain from different modalities like CT, MRI and PET. We perform registration procedure on MRI images with reference to CT images and PET images with respect to MRI images. Since these images belong to different modalities, they must be taken from different sensors and at different times. Moreover the position of the patient may be inconsistent during image acquisition. All these factors results in different translation, rotation and scaling of the source image. It is necessary to calculate the difference between these parameters and then register the images with same orientation and position.

4.2. Image Registration Techniques

We have studied many techniques for registering two images belonging to different modalities and acquired at different times. We have implemented two different techniques and proposed a new technique to overcome the rotation and translation differences present in other techniques.

4.2.1. Image Registration described by Huang et.al [6]

This technique was proposed by Huang et.al in [6]. The steps that are implemented are as below.

STEP 1 Image Acquisition and Preprocessing

Take the reference slices of brain of same patient from datasets of two different modalities (either CT and MRI or MRI and PET). Call them image1 (base/reference image) and image2 (input/target image). These images were in JPEG format. We perform grey level conversion of these images for further processing

STEP 2 Selecting the Feature Points

Determine two sets of feature points, {a,b} in image1 and {c,d} in image2. These feature points are selected manually using MATLAB© function *cpselect()*. The function *cpselect()* returns base points {a,b} from base image and input points {c,d} from input image.

STEP 3 Calculating the Transformation Parameters

From these feature points, two vectors $\vec{V}ab$ and $\vec{V}cd$ are derived. The angle θ between these two vectors is derived as eq. (4.1).

$$\theta = \cos^{-1}\frac{(\vec{V}ab.\vec{V}cd)}{(|\vec{V}ab||\vec{V}cd|)} \qquad \text{eq. (4.1)}$$

Translation Parameters ***m*** and ***n*** are calculated as:

$$m = |a - c|$$
$$n = |b - d|$$

Scaling Parameter ***S*** is calculated as:

$if\ ab < cd$

$$S = ab/cd$$

$else$

$$S = cd/ab$$

$where,$

$$ab = \sqrt{a^2 + b^2} \ \ and,$$

$$cd = \sqrt{c^2 + d^2}$$

STEP 4 Determining new Index for target/test image

The parameters of scale, rotation and translation derived above are used to find the new index of two images as eq. (4.2) for image registration.

$$\begin{bmatrix} X' \\ Y' \end{bmatrix} = \begin{bmatrix} m \\ n \end{bmatrix} + s\begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}\begin{bmatrix} X \\ Y \end{bmatrix} \qquad \text{eq. (4.2)}$$

Where m, n denote the translation in X and Y direction respectively; s represents the scale and θ specifies the rotation angle.

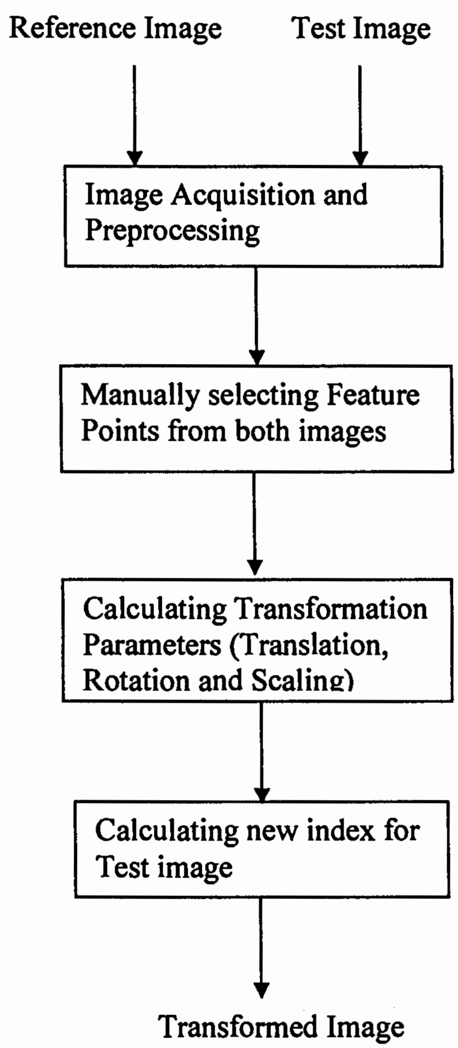


Figure 4-1: Flow Chart for Image Registration described by Huang

4.2.2. Image Registration described in Image Processing Toolbox of MATLAB©

This technique is described in MATLAB© help. This technique is implemented using MATLAB© built-in functions. Steps that we follow in this technique are described as below.

Step 1: Read the Images into MATLAB©

Place the base and input images in MATLAB© workspace. Read the images using MATLAB© function *imread()*. These images were in JPEG format. We perform grey level conversion of these images for further processing using MATLAB© function *rgb2grey()*.

Step 2: Choose Control Points in the Images

MATLAB© provides an interactive tool, called the Control Point Selection Tool, that can be use to manually select pairs of corresponding control points in both images. This tool is started by entering *cpselect()* at the MATLAB© prompt. The *cpselect()* function took two arguments, the input and base images. The input and base images are displayed in which control points are selected by pointing and clicking. Depending upon the type of transformation (linear transformation in our case), we select two control points from each image.

Step 3: Save the Control Point Pairs to the MATLAB© Workspace

Save the control point pairs by choosing **Save Points to Workspace** option in the **File** menu of Control Point Selection Tool.

Step 4: Specify the Type of Transformation and Infer Its Parameters

In this step *cp2tform()* function is used to determine the transformation based on the geometric relationship of the control points. This function takes base points, input points and the type of transformation that you want to perform as arguments and returns the parameters in a geometric transformation structure, called a **TFORM** structure.

Step 5: Transform the Unregistered Image

In order to bring the input image into an alignment with the base image use *imtransform()* function. The *imtransform()* function takes input image and **TFORM** structure as an arguments and returns transformed image.

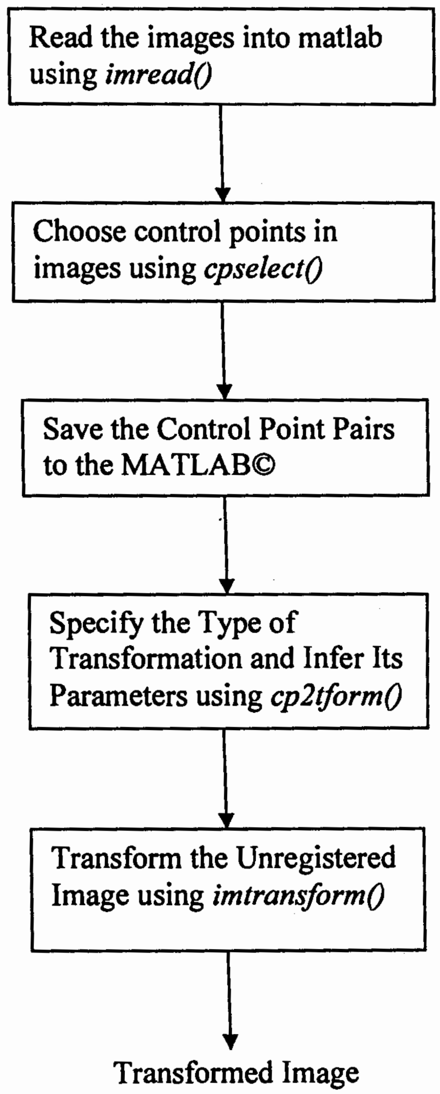


Figure 4-2: Flow Chart for Image Registration described in Image Processing Toolbox of MATLAB©

4.2.3. Proposed Method for Image Registration

In the above techniques the problems regarding rotation and translation of images are still there. In order to improve the registration we have proposed following method.

Step 1: Image Acquisition and Preprocessing

Take the reference slices of specific organ of same patient from datasets of two different modalities (either CT and MRI or MRI and PET). Call them image1 and image2. These images were in JPEG format. We perform grey level conversion of these images for further processing

Step 2: Perform Thresholding to get the binary images

Perform thresholding on grey level images to get the binary images. We perform iterative thresholding algorithm on the two source images.

Iterative Selection of Threshold

Iterative Threshold is a binary search for selecting the best possible gray level threshold. The idea is to provide estimate of the average gray level of both the background (T_b) and the objects (T_o), and to use the average of these two levels as the threshold. The algorithm is as follows:

- Guess values of T_o and T_b respectively
- Take **T** as the mean gray level
- Compute new values of T_b as the mean of all values below **T** and T_o as the mean of all values above **T**
- Threshold: $T = (T_o + T_b)/2$
- Refine the values of T_o and T_b using the threshold **T**
- T_o is recalculated to be the mean value of all the pixels greater than **T**, while T_b is taken as the mean value of all pixels less than **T**
- Re-compute **T** and repeat till there is no change in its value

Step 3: Make Foreground as a Single Region

In order to make the foreground as a single region, first determine the boundary of foreground from each binary image. Then fill out the space inside the boundary to get the images with single object.

Step 4: Rotate the Images to Same Axis

Since we have only one region in each image, hence using MATLAB© built-in function *regionprops()*, we find out the statistics of this region. These statistics also include the *Orientation* of an object with respect to x-axis. We calculate the difference of *Orientation* from the axis and rotate the original images to this orientation so that both the images after rotation lie on the x-axis. If the difference comes out to be more than 45 degrees, the rotation of images is done to y-axis. The images are rotated using MATLAB© built-in function *imrotate()*.

Step 5: Translate the Target Image to Reference Image

After rotating the images, again we find out the statistics of both the images using *regionprops()* function. From these statistics we find out the position of *Centroid* of both the regions. We first calculate the difference of x-coordinates of *Centroids* of both the images. Then move the target image to the x-coordinate of reference image. Similarly we calculate the difference of y-coordinates of *Centroids* of both the images. Then move the target image to the y-coordinate of reference image.

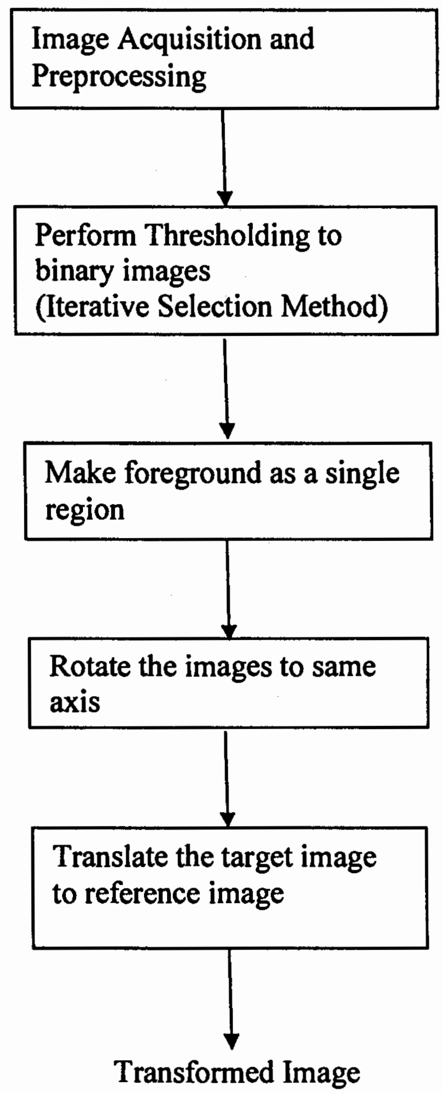


Figure 4-3: Flow Chart of Proposed Method for Image Registration

4.3. Medical Image Fusion

Various Imaging modalities provide complementary information e.g. CT provides useful information about the bone structure but is poor to soft tissue contrast while MRI gives high contrast to soft tissues of the internal organs of the body but is poor to visualize the bone structure. Likewise X-rays, CT, and MR imaging modalities are used to get the anatomical/ morphological information whereas PET and SPECT give better results about the metabolic/functional measurements. Due to such complementary information it is often desired to combine two images acquired differently to enhance the display of various materials or tissues. For example, a CT image and an MRI image from the same patient can be combined to show both bones and fat clearly in a single image. Much more information can be visualized in the combined image than from the individual ones [25]. Image fusion is the process by which two or more images are combined into a single image with intent to retain the important features from each of the original images. This integration of complementary data is done not only to enhance the information present in both images but also to increase the reliability of understanding that we get from the images. Successful fusion of images acquired from different modalities or instruments are valuable in many applications such as medical imaging, microscopic imaging, remote sensing, computer vision, and robotics etc.

In our work, two different image fusion techniques are implemented and applied to Computed Tomography (CT), Magnetic Resonance imaging (MRI) and Positron Emission Tomography (PET). These are Global Energy Merging Scheme using Wavelets, and PCA method to fuse low frequency components of DWT. Fusion results are evaluated according to two measures of performance; the entropy and RMSE (root mean square error). Image fusion techniques were applied to CT, MRI and PET images of brain. The fused images provide better results than using CT, MRI or PET images alone and provide useful information that can be used in clinical diagnosis, in planning surgery, and in image guided surgical interventions. An example is of radiotherapy treatment, where both CT and MR can be used. CT image is needed to accurately compute the radiation dose, while the MRI is usually used for the delineation of tumor tissue [26].

4.4. Image Fusion Techniques

We have studied different techniques for the fusion of medical images. These include Global Energy Merging Scheme using Wavelets, PCA bases, bandelet transform, ICA bases, energy estimation, Optimum multi resolution and feature mapping wavelet neural networks. Out of these we found Global Energy Merging Scheme using Wavelets and PCA based techniques to be more effective in combining important image features.

4.4.1. Global Energy Method (GEM) based on Discrete Wavelet Transform (DWT) [7]

This method is proposed by Zhang et.al in "A Novel Wavelet Medical Image Fusion Method [7]." The general image fusion scheme of this study involves decomposition of input images, calculation of energy of the each 3 × 3 matrix region, calculation of match measure between two images, fusion strategy and reconstruction of new fused image.

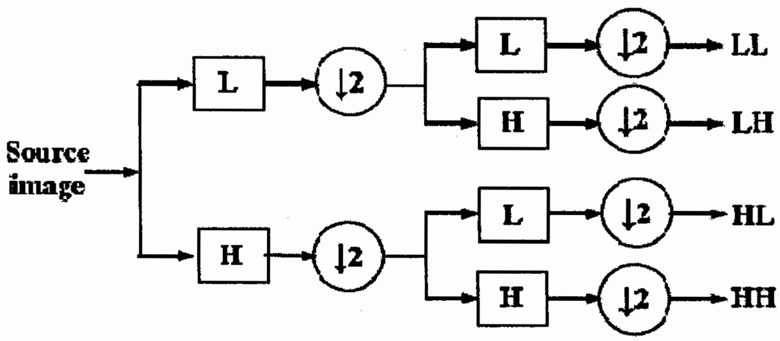
As a first step we apply registration process on input images as discussed earlier. Then we use the following algorithm that performs the fusion process.

Algorithm

1. **Initialization:** We define the area size A as 3 × 3 matrix which is to be used around each location p.
2. **Input:** We take registered images with same dimension as input images and set

   X=Image1, and

   Y= Image2
3. **Decomposition:** The input images are then decomposed by wavelet transformation. In this case each image is decomposed to level 1 using discrete wavelet transform. The wavelet transform decomposes each image into low-low, low-high, high-low and high-high frequency sub-band images representing the detailed information in smooth version and in horizontal, vertical and diagonal directions of the input images respectively. Thus for images X and Y we have $D_{LL}^X, D_{LH}^X, D_{HL}^X, D_{HH}^X$ and $D_{LL}^Y, D_{LH}^Y, D_{HL}^Y, D_{HH}^Y$ representing low-low, low-high, high-low and high-high frequency sub-band images of X and Y respectively.



A Structure of the DWT [7]

4. **Computing Region Energy Values:** For each location p at (x, y) in the transformed sub images, the region energy values are computed using eq. (4.3)

$$E_{ij}^{v}(p) = \sum_{p\in A} W(p) \left(D_{ij}^{v}(p)\right)^2 \qquad \text{eq. (4.3)}$$

Where ij represents a frequency band LL, LH, HL, HH;

$E_{ij}^{v}(p)$ is the energy of the region A,

$W(p)$ is the weight of A.

$D_{ij}^{v}(p)$ is the wavelet decomposition coefficient of each source image and

v tells that actual value of $D_{ij}^{v}(p)$ comes from X or Y

Hence for X and Y images we have,

$E_{ij}^{x}(p)\ and\ E_{ij}^{y}(p)\ \ with\ ij = LL, LH, HL, HH$

5. **Calculating Match Measure:** The fusion algorithm depends upon the similarities between the source images. The match measure is a parameter reflecting the resemblance between the input images [7]. Using wavelet decomposition coefficient and the energy, the match measure is calculated in eq. (4.4)

$$M(p) = M_{LH}(p) \times 0.25 + M_{HL}(p) \times 0.25 + M_{HH}(p) \times 0.5 \quad \text{eq. (4.4)}$$

Where,

$$M_{ij}(p) = \frac{2\sum_{p\in A} W(p) \times D_{ij}^{X}(p) \times D_{ij}^{Y}(p)}{E_{ij}^{X}(p) + E_{ij}^{Y}(p)}, \ ij = LH, HL, HH \qquad \text{eq. (4.5)}$$

6. **Calculating the Weight Factors:** The weight factor selected in this technique is calculated in eq. (4.6):

$$W_{ij}^{X}(p) = \begin{cases} 0.5 - 0.5 \times \frac{1-M_{ij}^{v}(p)}{1-\alpha}, \; if\; E_{ij}^{X}(p) \geq E_{ij}^{Y}(p) \\ 0.5 + 0.5 \times \frac{1-M_{ij}^{v}(p)}{1-\alpha}, \; if\; E_{ij}^{X}(p) < E_{ij}^{Y}(p) \end{cases} \qquad \text{eq. (4.6)}$$

and,

$$W_{ij}^{Y}(p) = 1 - W_{ij}^{X}(p) \qquad \text{eq. (4.7)}$$

7. **Merge:**

- firstly low frequency band is calculated:

$$e_{ll}^{v}(p) = max\left(E_{ll}^{X}(p), E_{ll}^{Y}(p)\right)$$

$$D_{LL}^{v}(p) = D_{LL}^{X}(p) \qquad IF\; e_{ll}^{v}(p)\; come\; from\; X,$$

$$else\; D_{LL}^{v}(p) = D_{LL}^{Y}(p)$$

- Then high frequency bands are calculated:

$$when\; M_{ij}(p) \geq \alpha$$

$$DO$$

$$D_{ij}^{v}(p) = W_{ij}^{X}(p) \times D_{ij}^{X}(p) + W_{ij}^{Y}(p) \times D_{ij}^{Y}(p) \qquad (ij = LH, HL, HH)$$

$$when\; M_{ij}(p) < \alpha$$

$$DO$$

$$e_{ij}^{v}(p) = max\left(E_{ij}^{X}(p), E_{ij}^{Y}(p)\right)$$

$$D_{ij}^{v}(p) = D_{ij}^{X}(p) \qquad IF\; e_{ij}^{v}(p)\; come\; from\; X,$$

$$else\; D_{ij}^{v}(p) = D_{ij}^{Y}(p) \qquad (ij = LH, HL, HH)$$

8. **Inverse Decomposition:** Inverse Discrete wavelet Transform is applied to $D_{LL}^{v}(p), D_{LH}^{v}(p), D_{HL}^{v}(p),$ and $D_{HH}^{v}(p)$ obtaining an image Z with same dimensions as X and Y.

9. **Output:** As an output we get fused Image Z which contains the features of both Image1 and Image2.

Procedure

The procedure used for the fusion of images is described as follow.

1. Multi-resolution wavelet decomposition on each source image is performed.
2. The energy of the each 3*3 matrix region is calculated.
3. Using wavelet decomposition coefficient and the energy, the match measure is calculated. The match measure is a parameter reflecting the resemblance between the input images.
4. The three high frequency coefficients of the fused image are produced by comparing match measure of several source images.
5. The low frequency coefficient lies on the choice of the three high frequency coefficient.
6. Finally, by applying the inverse wavelet transform the final fused image is obtained.

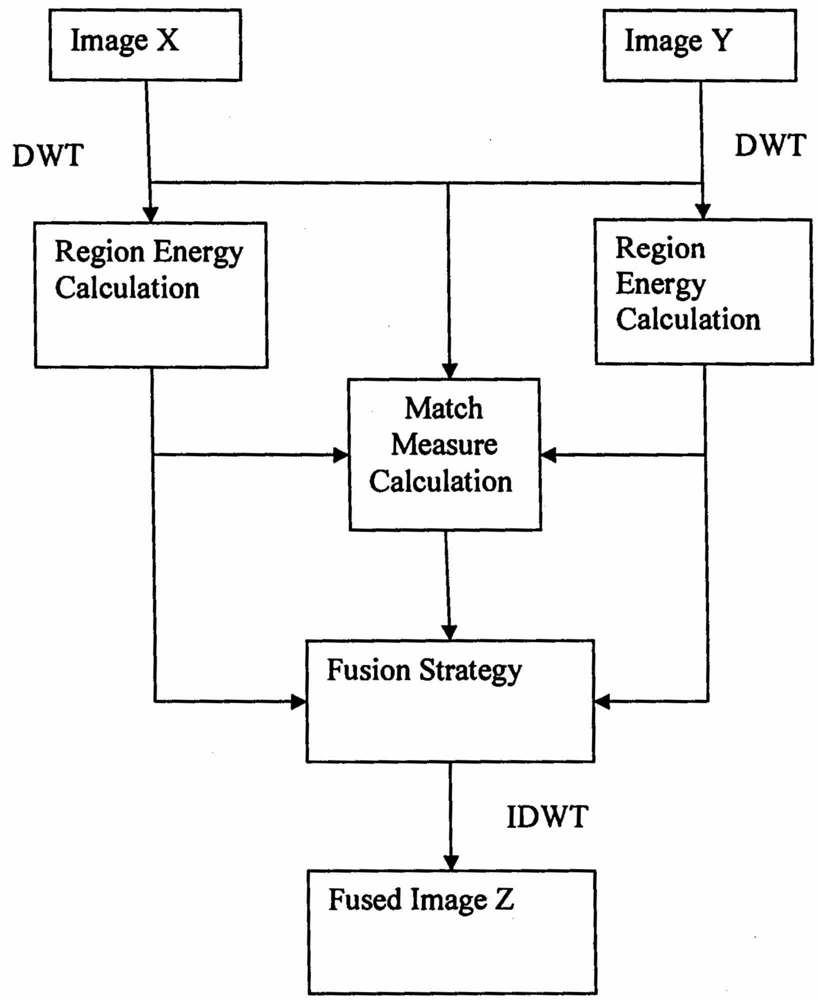


Figure 4-4: Flow Chart for Global Energy Method (GEM) based on Discrete Wavelet Transform (DWT)

4.4.2. PCA (Principle Component Analysis) Method to Fuse Low Frequency Components of DWT

In this technique a pair of registered images are decomposed using discrete wavelet transform. The low frequency wavelet coefficients are resolved using PCA while the high frequency wavelet coefficients are fused by local wavelet energy maximum. Final fused image is formed by using inverse discrete wavelet transform.

As a first step we apply registration process on input images as discussed earlier. Then we use the following method for the fusion process.

Method

Applying Wavelet Decomposition

The registered images (Image1 and Image2) are decomposed using discrete wavelet transform. Let D_{LL}^{X} and D_{LL}^{Y} are low frequency components and $D_{LH}^{X}, D_{HL}^{X}, D_{HH}^{X}$ and $D_{LH}^{Y}, D_{HL}^{Y}, D_{HH}^{Y}$ are high frequency components of Image1 and Image2 respectively.

Resolving Low frequency Components Using PCA

In order to resolve low frequency components using PCA, we convert both D_{LL}^{X} and D_{LL}^{Y} matrices into vectors. Let we call these vectors as X and Y. If D_{LL}^{X} and D_{LL}^{Y} are $n \; x \; n$ matrices, then X and Y are vectors of n^2 elements. Hence we have a data set containing two dimensions (X and Y) and each dimension has n^2 elements. We then apply the following steps to apply PCA on low frequency components of DWT.

Step1: Subtract the Mean

Let $\bar{x}$ be the mean of x values of all the data points in a vector X and $\bar{y}$ be the mean of y values of all the data points in a vector Y. For PCA to work properly we have subtracted $\bar{x}$ from x values of all the data points in a vector X and $\bar{y}$ from y values of all the data points in a vector Y. This produces a dataset whose mean is zero. Let we call this dataset as **DataAdjust.**

Step 2: Calculate the Covariance Matrix

We have used MATLAB© built-in function *cov()* to determine the covariance matrix of dataset **DataAdjust**. Since the data is two dimensional, the covariance matrix will be 2×2.

Step 3: Calculate the Eigenvectors and Eigen-values of the Covariance Matrix

We have used MATLAB© built-in function *eig()* to determine the eigenvectors and eigen-values of covariance matrix. The eigenvectors provide information about the pattern of the data. Since the dataset is two dimensional hence we get two eigen-values with corresponding eigenvectors.

Step 4: Choosing Components and Forming a Feature Vector

Since we know that the principle component of the dataset is the eigenvector with the highest eigenvalue, hence our next step is to sort the eigen-values from highest to lowest and select the eigenvector with highest eigenvalue. Call this vector as a $FeatureVector$.

Step 5: Applying PCA Transform

Once the *principle component* is selected, we take the transpose of both *FeatureVector* and *DataAdjust,* call them *RowFeatureVector* and *RowDataAdjust* respectively. The PCA transform is applied by simply multiplying the *RowFeatureVector* and *RowDataAdjust.* Call this transformation as the *FinalData* defined in eq. (4.8)

$$\text{FinalData} = \text{RowFeatureVector} \times \text{RowDataAdjust} \qquad \text{eq. (4.8)}$$

Step 6: Getting the Data Set transformed by PCA

After applying PCA transform we get new dataset by taking transpose of *RowFeatureVector* and multiplying it with the *FinalData*. But, to get the actual original data back, we need to add on the mean of that original data that we have subtracted at the start. Let call this dataset as *RowOriginalData* given in eq. (4.9)

$$RowOriginalData = (RowFeatureVector^T \times FinalData) + OriginalMean \qquad \text{eq. (4.9)}$$

Step 7: Applying Fusion Rule to PCA transformed co-efficients

RowOriginalData is a two dimensional vector each dimension having n^2 elements. We apply simple weighted combination fusion rule to *RowOriginalData* dimensions to get the final fused data. This fused data is a one dimensional vector with n^2 elements. We convert this vector into n x n matrix by using MATLAB© built-in function *reshape()*. Let we call it D^{v}_{LL}.

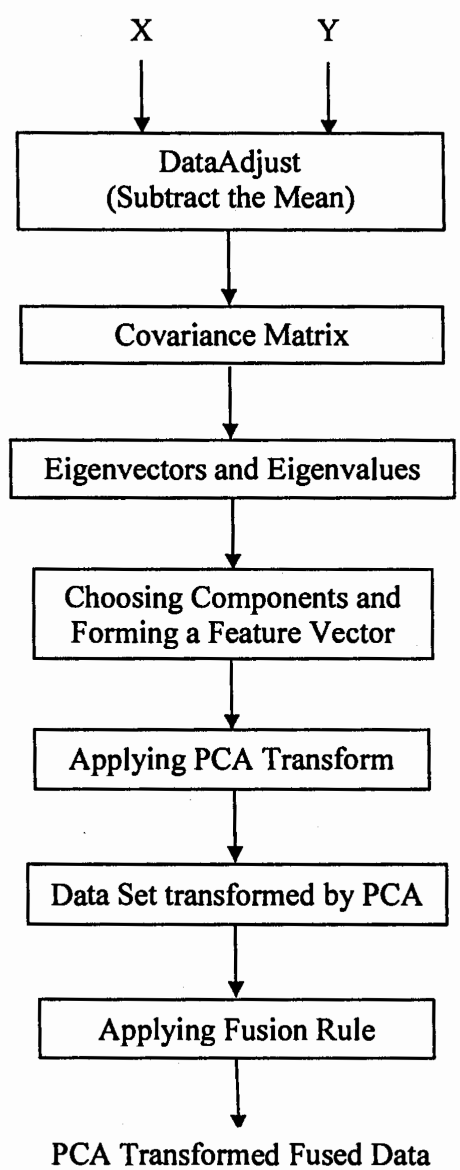


Figure 4-5: Flow Chart for PCA Method to Fuse Low Frequency Components of DWT

Resolving High Frequency Wavelet Co-efficients

The high frequency wavelet co-efficients $D^{X}_{LH}, D^{X}_{HL}, D^{X}_{HH}$ and $D^{Y}_{LH}, D^{Y}_{HL}, D^{Y}_{HH}$ are resolved by local wavelet energy maximum as discussed in Global Energy Method based on DWT. Let we call these resolved co-efficients as $D^{v}_{LH}, D^{v}_{HL}, D^{v}_{HH}$.

Applying Inverse Discrete Wavelet Transform

Inverse Discrete wavelet Transform is applied to $D^{v}_{LL}, D^{v}_{LH}, D^{v}_{HL}$ and D^{v}_{HH} obtaining final Fused Image with same dimensions as Image1 and Image2.

Chapter 5
Experimental Results

5 Experimental Results

In our experiments, we choose four sets of images belonging to 3 different modalities. These images were obtained from two websites for medical images: "The Visible Human Project [27]" and "The Whole Brain Atlas [13]."

- First set consists of CT and MR images of Pelvis [27]
- Second set consists of CT and MR images of Chest [27]
- Third set consists of CT and MR images of Brain [27]
- Fourth set consists of MR and PET images of Brain [13]

Since fusion of images requires a prior registration, we shall first discuss the results obtained for registration and then discuss the results obtained for fusion.

5.1. Results for Image Registration

We have implemented three techniques for registration process. These are

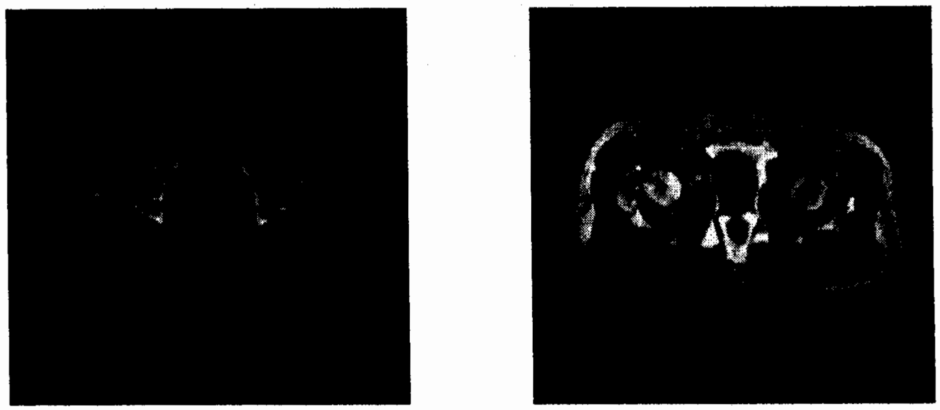
- Image Registration described by Huang et.al in [6]
- Image Registration described in Image Processing toolbox of MATLAB©
- Proposed Method for Image Registration

  Let us discuss the experimental results of these techniques on each dataset.

5.1.1. Image Registration described by Huang et.al [6]

5.1.1.1. Results for Dataset1

The first dataset consists of CT and MR images of Pelvis [27]. Call them image1 (CT image) and image2 (MR image). These images were in JPEG format which were converted to grayscale and given in figure 5.1.



(a) CT image of Pelvis (b) MR image of Pelvis

Figure 5-1: Dataset1-CT and MR images of Pelvis

Two feature points were selected in each image using "Control Point Selection Tool" in MATLAB©. These feature points are selected manually by pointing and clicking on the corresponding areas of CT and MR image. These are called "*base points*" for CT image and "*input points*" for MR image. For the figure 5.2 these points are indicated by crosses and the coordinates of these points are given below:

Base points: {(21.617 ,153.05), (236.38 ,156.49)}

Input points: {(21.181, 144.9), (233.23, 152.05)}

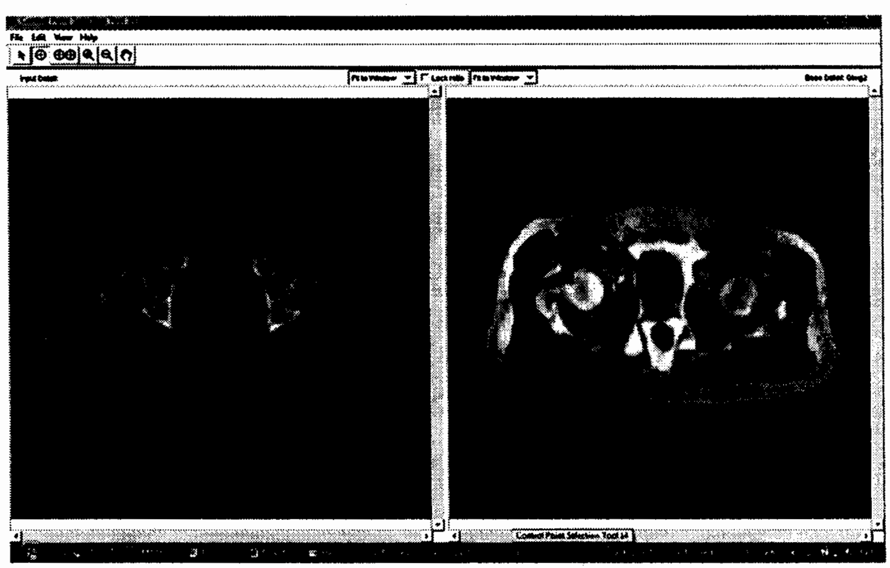


Figure 5-2: Feature Points selection from Dataset1

The registration process is done on MR image. This image is registered with respect to CT image, i.e. the rotation, scaling and translation of MR image is changed according to CT image which is kept unchanged. The transformed MR image after the registration process is given in figure 5.3.

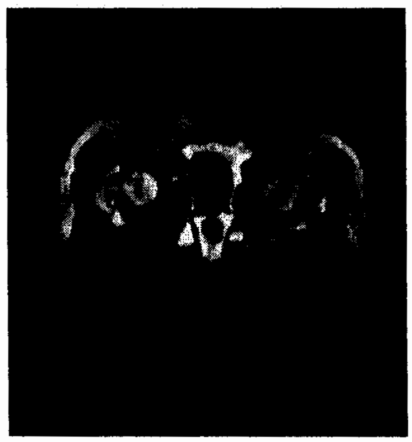
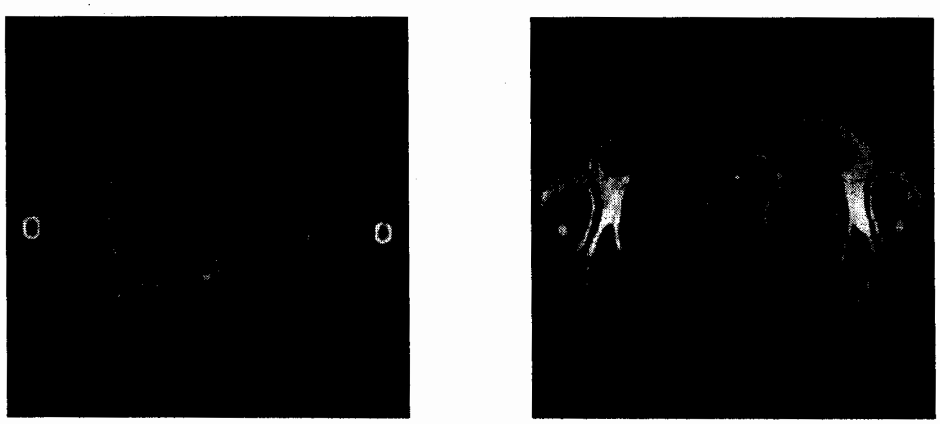


Figure 5-3: Registered MR image of Pelvis by Image Registration described by Huang et.al

5.1.1.2. Results for Dataset2

This dataset consists of CT and MR images of Chest [27]. The grayscale representation of these images is presented in fig 5.4.



(a) CT image of Chest (b) MR image of Chest

Figure 5-4: Dataset2-CT and MR images of Chest

The feature points from these images are selected manually by pointing and clicking on the specific areas of two images. Figure 5.4 shows the feature points indicated by crosses and the coordinates of these points are given below:

Base Points: {(18.928, 135.75), (237.74, 133.08)} for CT image

Input Points: {(16.427, 136), (240.32, 137.92)} for MR image

Figure 5-5: Feature Points selection from Dataset2

After applying the registration process described in section 4.2.1 of chapter 4, the registered MR image of chest with respect to CT image of Chest is given in figure 5.6

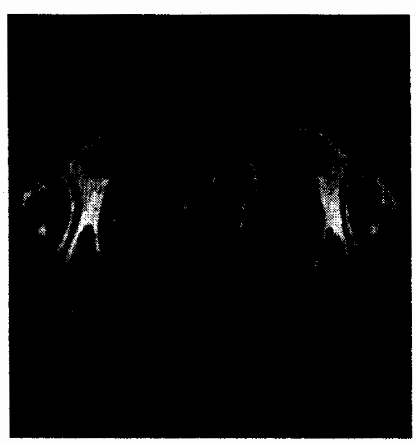
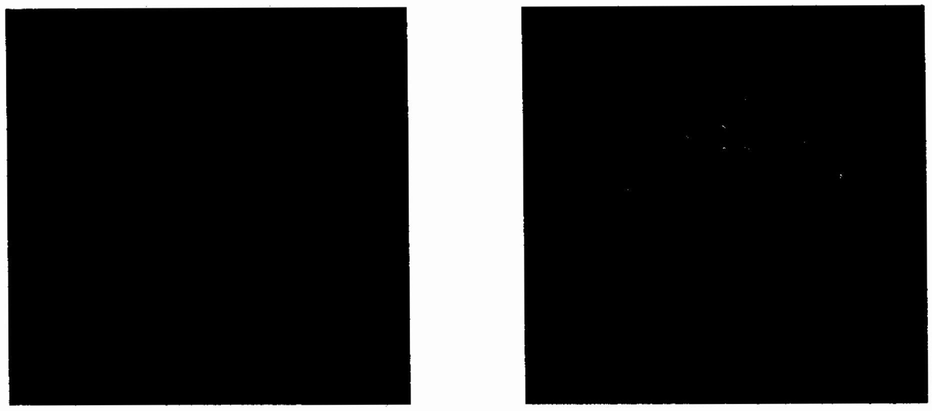


Figure 5-6: Registered MR image of Chest by Image Registration described by Huang et.al

5.1.1.3. Results for Dataset3

This dataset consists of CT and MR images of brain [27]. The grayscale representation of these images is presented in figure 5.7



(a) CT image of Brain (b) MR image of Brain

Figure 5-7: Dataset3-CT and MR images of Brain

The feature points selection of these images is shown by crosses in figure 5.8 and the coordinates of these points are given below:

Base Points: {(135.67, 25.182), (151.93, 247.41)} for CT image

Input Points: {(156.52, 19.345), (164.02, 241.99)} for MR Image

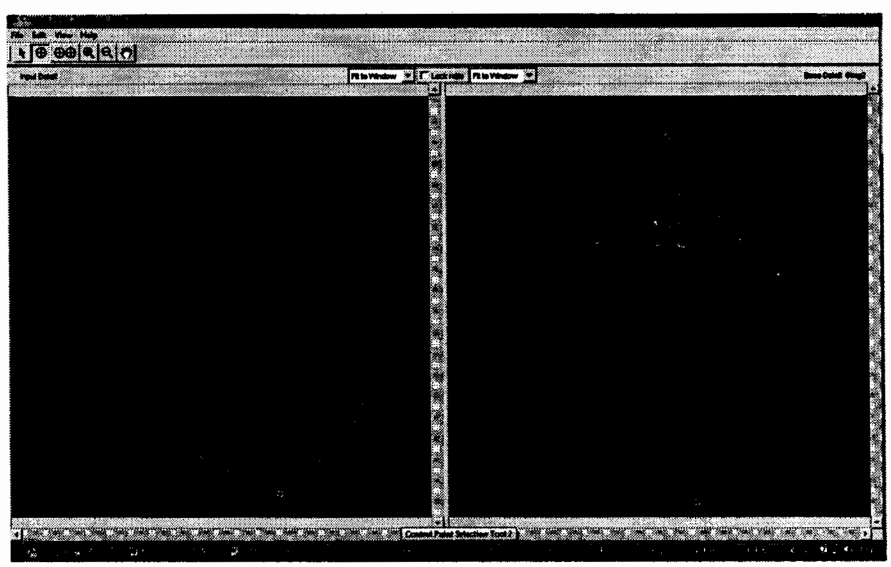


Figure 5-8: Feature Points selection from Dataset3

The registered MR image with respect to CT image by procedure described in 4.2.1 is shown in figure 5.9

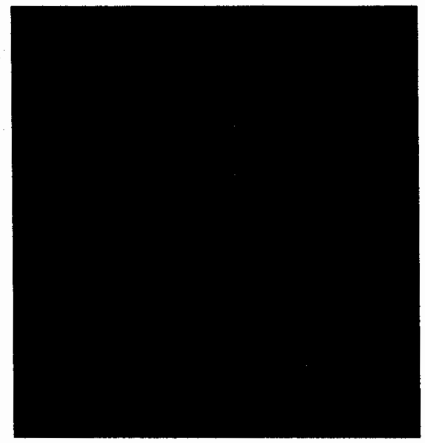
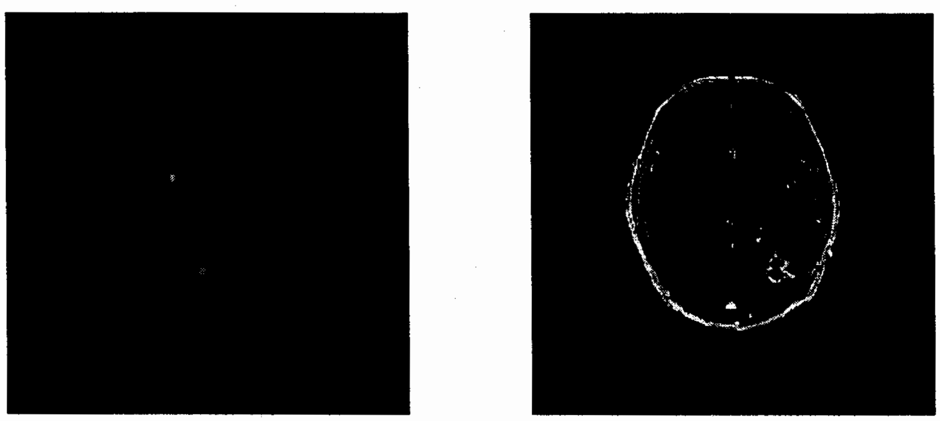


Figure 5-9: Registered MR image of brain with CT by Image Registration by Huang et.al

5.1.1.4. Results for Dataset 4

This dataset consists of PET and MR images of brain [13]. Figure 5.10 represents the grayscale representation of these images as:



(a) PET image of brain (b) MR image of brain

Figure 5-10: Dataset4-PET and MR images of Brain

In this dataset input PET image of brain is taken as input image and MR image is taken as base image. The manually selected feature points for these images are shown in figure 5.11 indicated by crosses and their x and y coordinate are given below:

Base Points: {(132.75, 42.694), (133.5, 200.21)} for CT Image

Input Points: {(132.5, 40.609), (134 , 199.05)} for MR Image

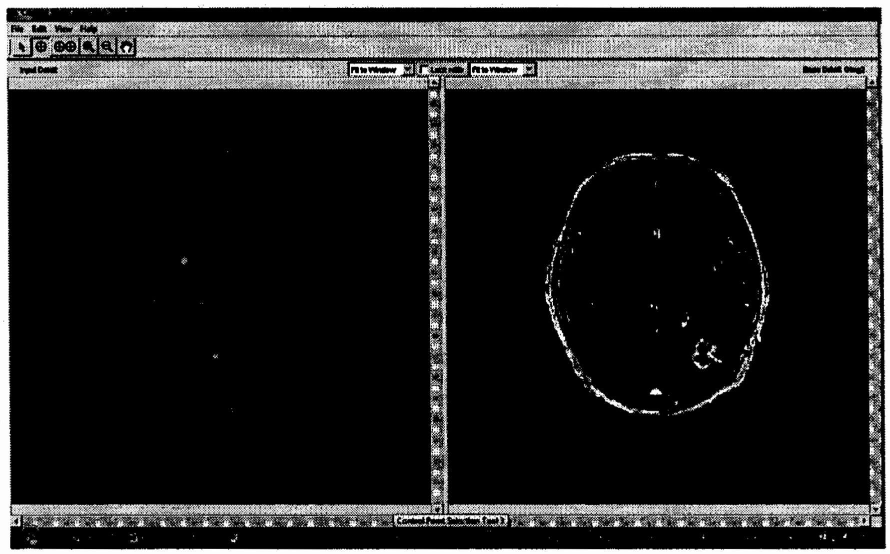


Figure 5-11: Feature Points Selection from dataset4

After the selection of feature points the registration process described in 4.2.1 is applied. The result of this registration process is the registered MR image shown in figure 5.12

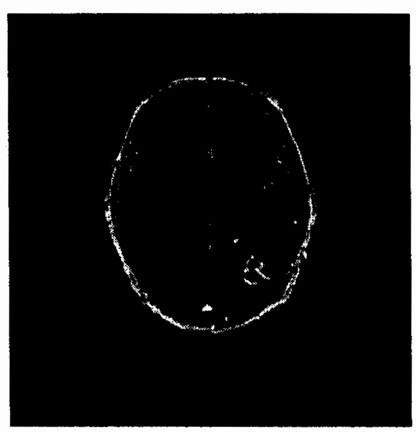


Figure 5-12: Registered MR image of brain with PET by Image Registration described by Huang et.al

5.1.2. Image Registration described in MATLAB© Image Processing Toolbox

In this technique the selection of feature points; "base points" and "input points "are done similar to that in Technique proposed by Huang et.al. However in this technique the registration process is done on Base Image (Image1). The registered images from given four sets are given in figures 5.13 to 5.16:

Figure 5-13: Registered CT image of Pelvis with MRI by Image Registration described in MATLAB©

Figure 5-14: Registered CT image of Chest with MRI by Image Registration described in MATLAB©

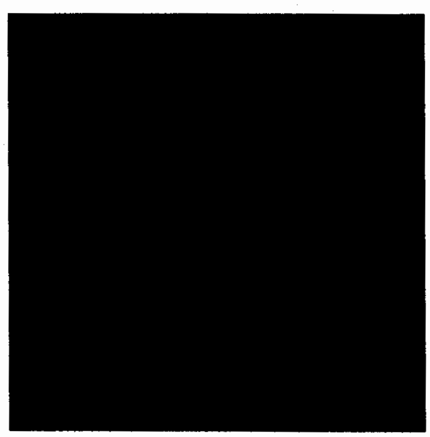


Figure 5-15: Registered CT image of Brain with MRI by Image Registration described in MATLAB©

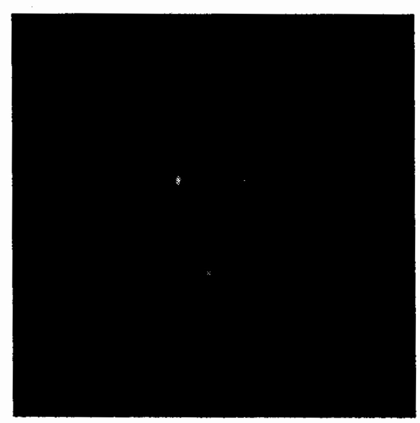


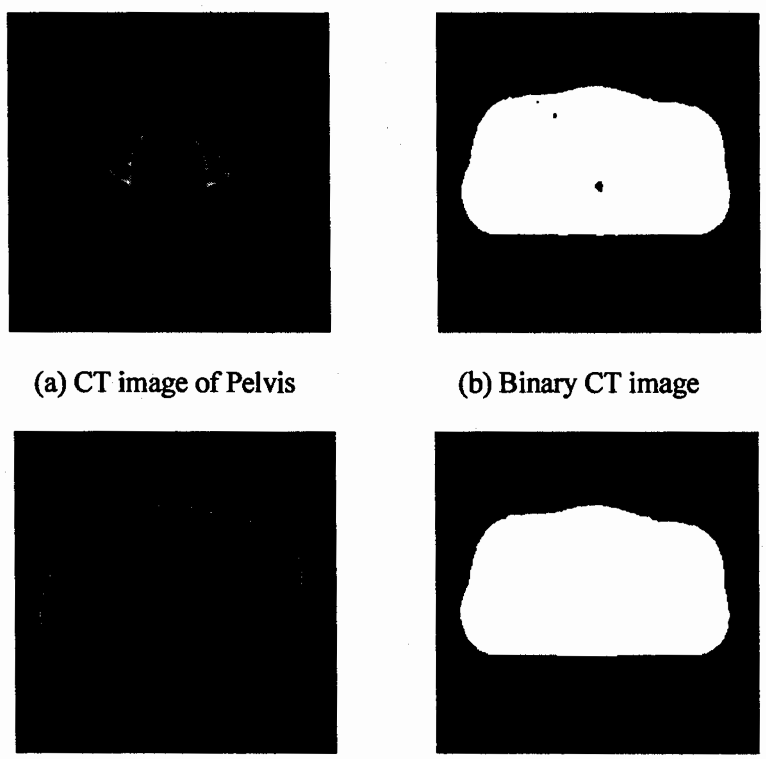
Figure 5-16: Registered PET image of Brain with MRI by Image Registration described in MATLAB©

5.1.3. Proposed Method for Image Registration

The above two methods for registration still contain translation and rotation problems. To solve these problems proposed a new method for registration have been proposed. This method works well for any two images in which a complete boundary of foreground can be determined. This method is applied on given four datasets and the results are given below:

5.1.3.1. Results for Dataset1

The first step in this method is to make the foreground in an image as a single region. For example in the figure 5.17, the steps for making pelvis region in CT image as a single region have been shown. These steps involve the conversion of an image from grayscale to binary by iterative thresholding method, determination of boundary of pelvis region from the binary image and finally the filling of area inside the boundary to white pixels so that we are left with only one region in whole image.



(a) CT image of Pelvis (b) Binary CT image

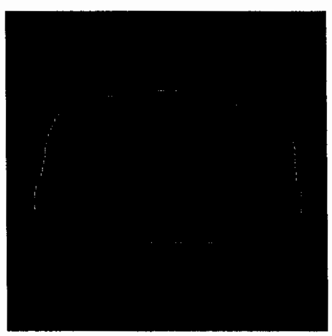
(c) Boundary of CT image (d) Filled Boundary of CT image

Figure 5-17: Steps to make foreground as a single region in CT image of Pelvis

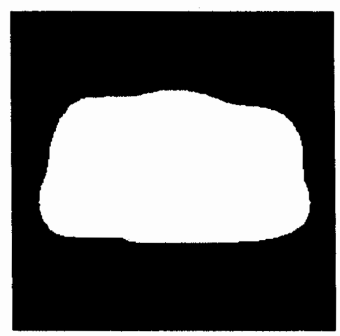
Similarly the pelvis region in MR image was made as a single region following the same steps as done for CT image. Figure 5.18 shows the grayscale MR image which is converted to binary image by iterative thresholding, the boundary detection of pelvis region in MR image and finally the filled portion inside the boundary making the foreground (pelvis) in MR image as a single region.

(a) MR image of Pelvis

(b) Binary MR image



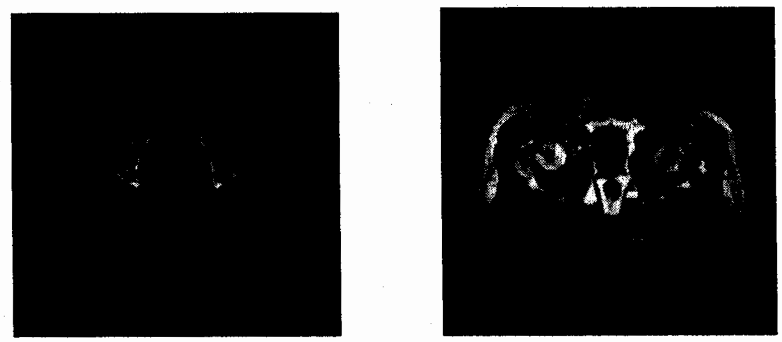
(c) Boundary of MR image



(d) Filled Boundary of MR image

Figure 5-18: Steps to make foreground as a single region in MR image of Pelvis

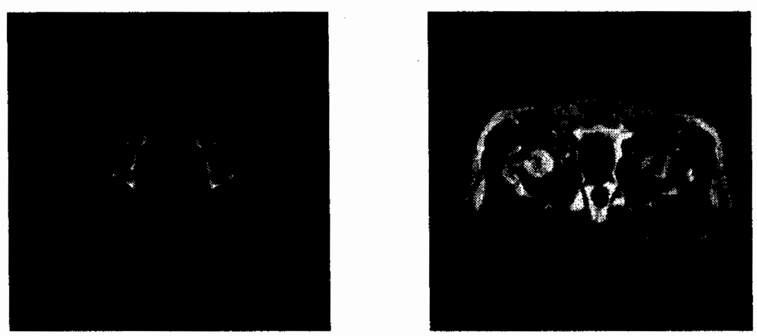
After making the foreground of two images as a single region, the statistics of this region is determined using Matlab function "*regionprops().*" These statistics also include Orientation of an image with respect to x-axis. Using this statistic the two images are rotated so that they both lie on the same axis. The rotation of images is done depending upon their natural alignment towards either x-axis or y-axis. Since the both CT and MR images of pelvis are nearly aligned to x-axis, hence the rotation is done to completely align the images to x-axis as shown in figure 5.19



(a) Rotated CT image (b) Rotated MR image

Figure 5-19: Rotated CT and MR Images of Pelvis by Proposed Method

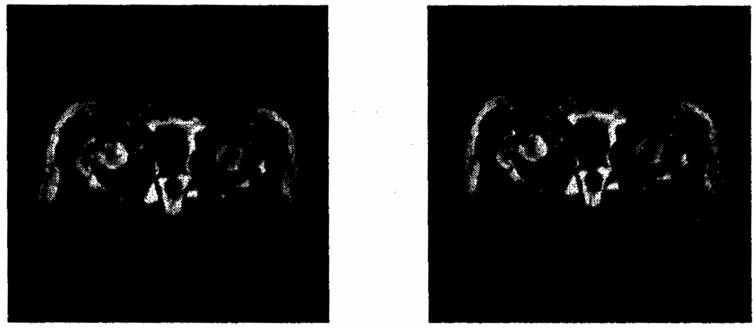
After rotation the resolution of images was disturbed. The next step is to bring the images to same resolution as was before the rotation. This is done by simply adding or removing black pixels to the right and bottom of rotated images. Figure 5.20 shows scaled images in terms of their resolution (256 by 256).



(a) Scaled CT image (b) Scaled MR image

Figure 5-20: Scaled CT and MR Images of Pelvis by Proposed Method

After rotation and scaling the final step is the translation of images. For this purpose again the statistics of foreground region of two images is determined. From these statistics the position of centroid of two regions is compared. The difference in x-coordinates of centroids of two regions is used to translate test/target image to x-axis and the difference of y-coordinates of centroids is used to translate target image to y-axis. In our experiments MR image is used as target/test image and its translation to x-axis and y-axis is shown in figure 5.21

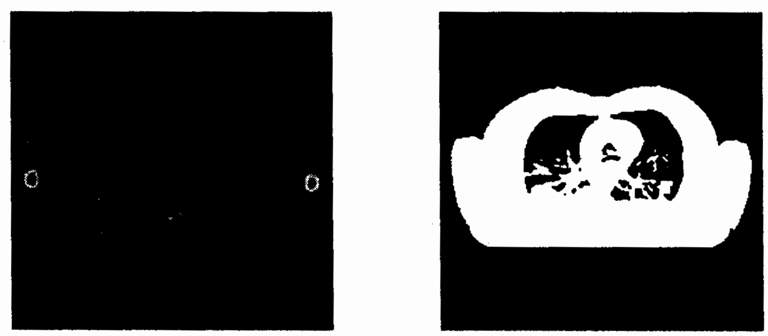


(c) Translated MR image by x-axis (d) Translated MR image by y-axis

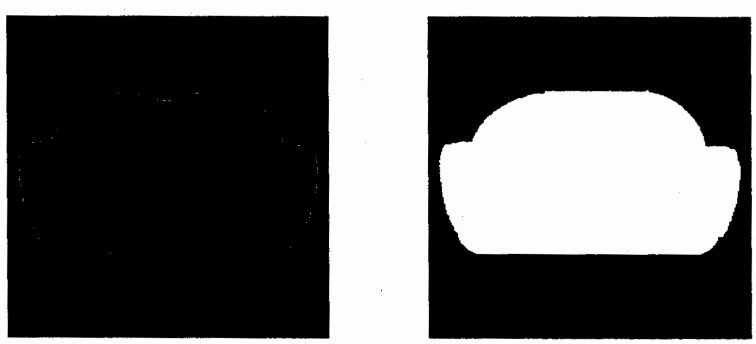
Figure 5-21: Translated CT and MR Images of Pelvis by Proposed Method

5.1.3.2. Results for Dataset2

Figures 5.22 to 5.26 show the experimental results for the registration of CT and MR images of chest by proposed method.

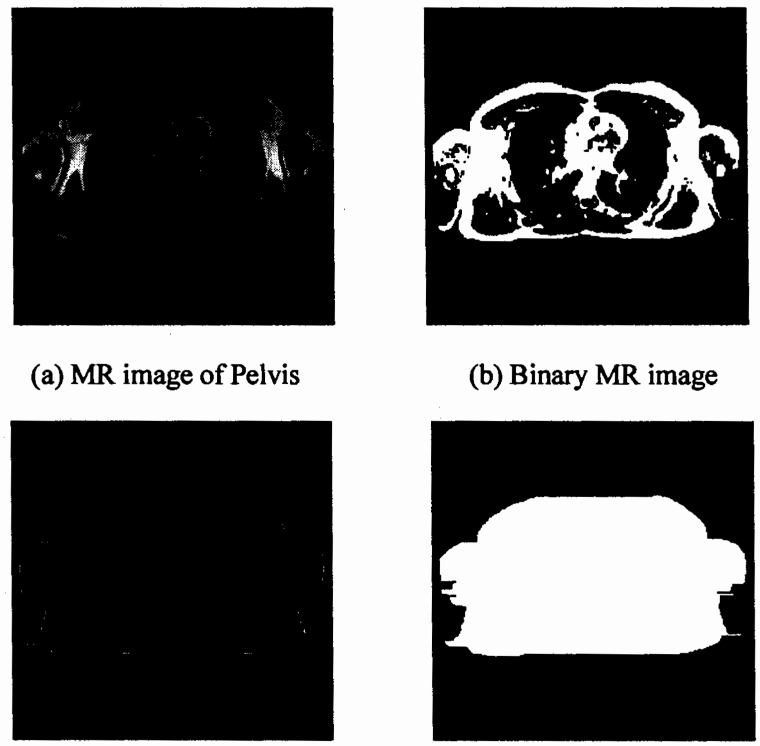


(a) CT image of Chest (b) Binary CT Chest



(c) Boundary of CT image (d) Filled Boundary of CT image

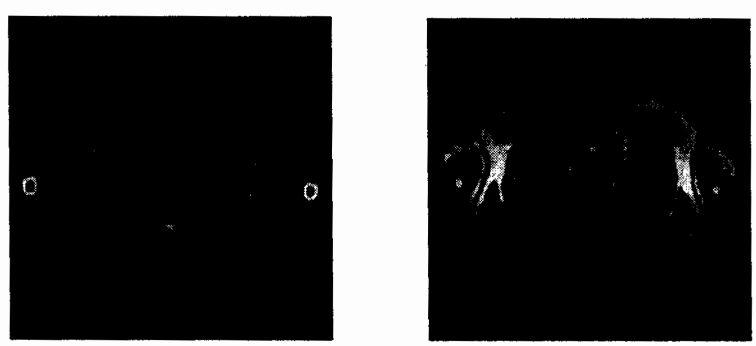
Figure 5-22: Steps to make foreground as a single region in CT image of Chest



(a) MR image of Pelvis (b) Binary MR image

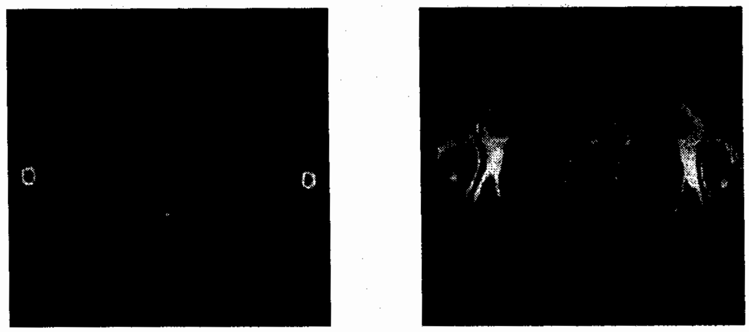
(c) Boundary of MR image (d) Filled Boundary of MR image

Figure 5-23: Steps to make foreground as a single region in MR image of Chest



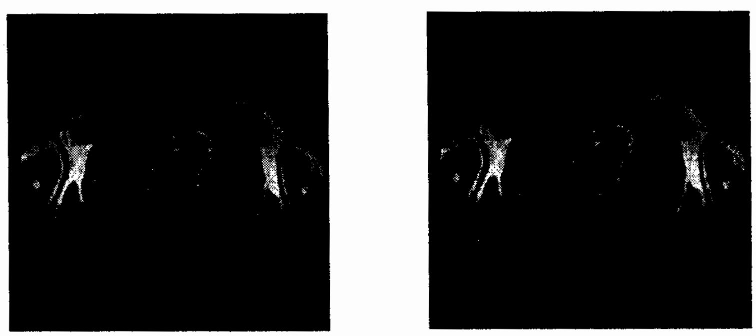
(a) Rotated CT image (b) Rotated MR image

Figure 5-24: Rotated CT and MR Images of Chest by Proposed Method



(a) Scaled CT image (b) Scaled MR image

Figure 5-25: Scaled CT and MR Images of Chest by Proposed Method

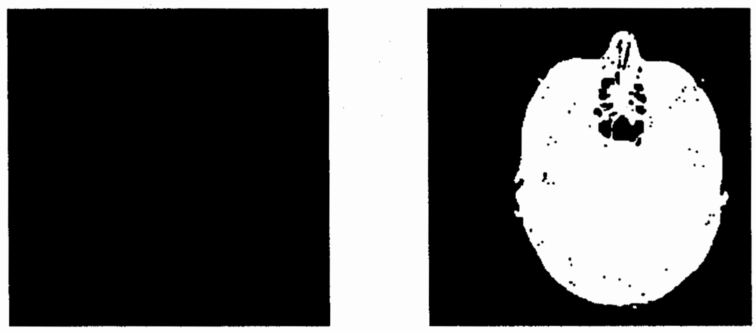


(c) Translated MR image by x-axis (d) Translated MR image by y-axis

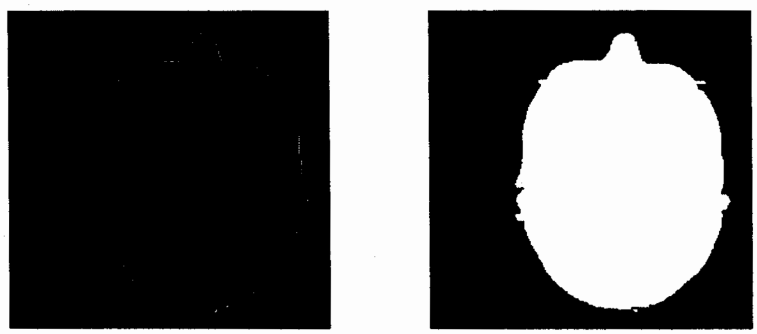
Figure 5-26: Translated CT and MR Images of Chest by Proposed Method

5.1.3.3. Results for Dataset3

Experimental results for the registration of CT and MR images of brain by proposed method are shown in figures 5.27 to 5.31. Since CT and MR images of brain are more oriented to y-axis, hence the rotation of these images is done so that the two images after rotation completely lie on y-axis as shown in figure 5.29



(a) CT image of Brain (b) Binary CT Brain



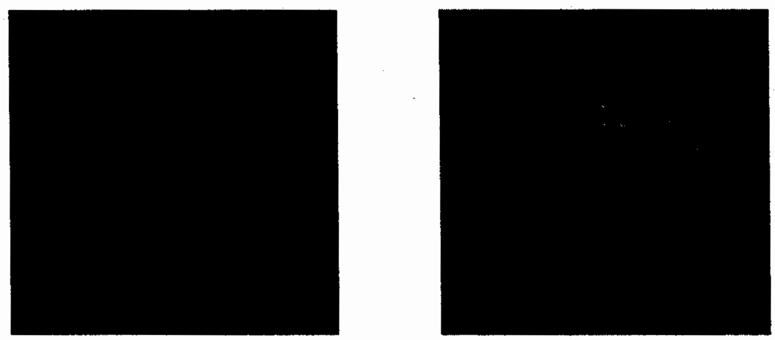
(c) Boundary of CT image (d) Filled Boundary of CT image

Figure 5-27: Steps to make foreground as a single region in CT image of Brain

(a) MR image of Brain (b) Binary MR Brain

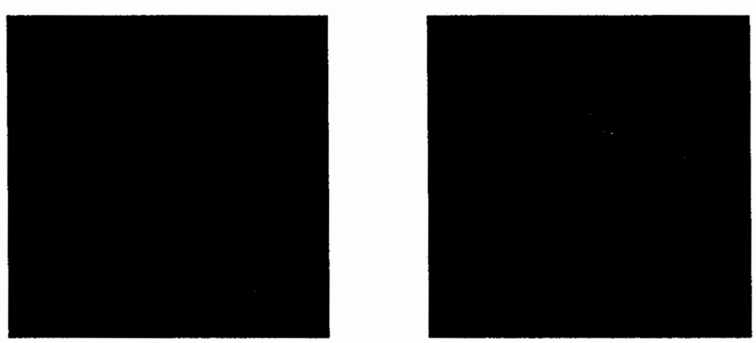
(c) Boundary of MR image (d) Filled Boundary of MR image

Figure 5-28: Steps to make foreground as a single region in MR image of Brain



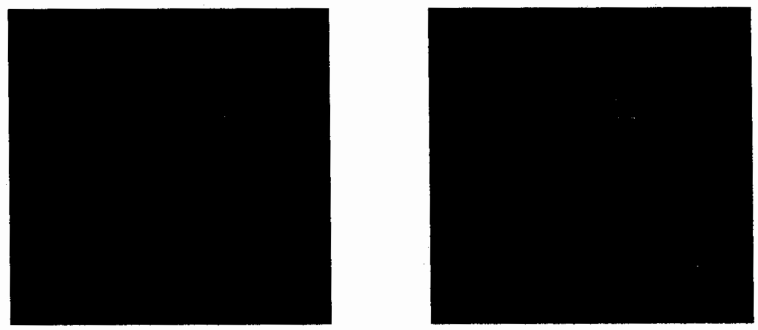
(a) Rotated CT image (b) Rotated MR image

Figure 5-29: Rotated CT and MR Images of Brain by Proposed Method



(a) Scaled CT image (b) Scaled MR image

Figure 5-30: Scaled CT and MR Images of Brain by Proposed Method



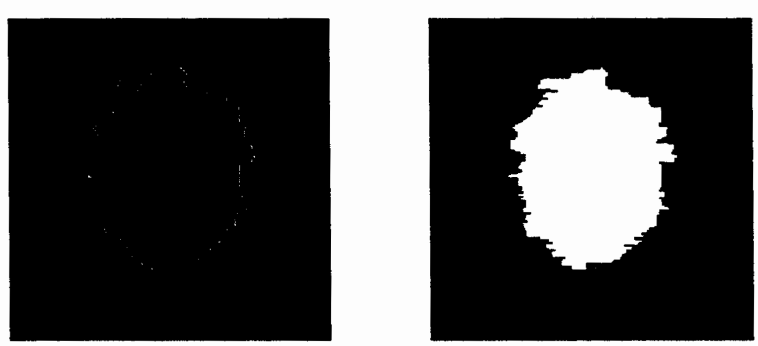
(c) Translated MR image by x-axis (d) Translated MR image by y-axis

Figure 5-31: Translated CT and MR Images of Brain by Proposed Method

5.1.3.4. Results for Dataset4

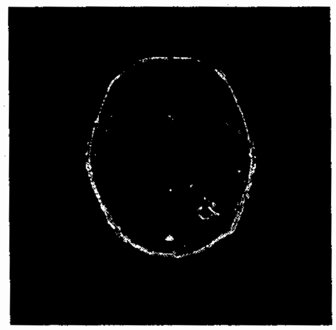
PET and MR images of brain have also been tested by the proposed method of registration. Their experimental results are shown in figures 5.32 to 5.36

(a) PET image of Brain (b) Binary PET Brain



(c) Boundary of PET image (d) Filled Boundary of PET image

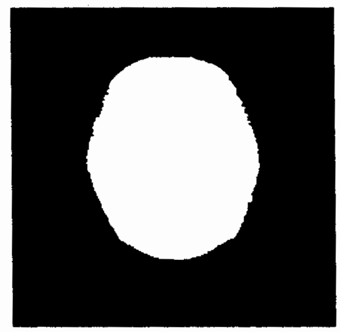
Figure 5-32: Steps to make foreground as a single region in PET image of Brain



(a) MR image of Brain

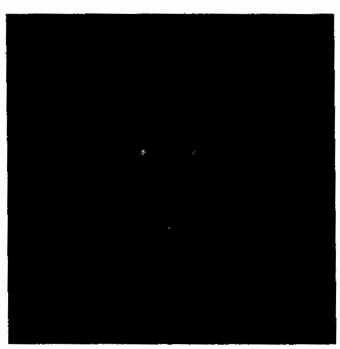
(b) Binary MR Brain

(c) Boundary of MR image

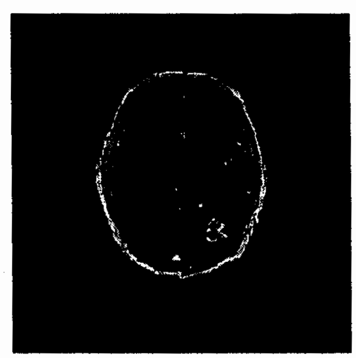


(d) Filled Boundary of MR image

Figure 5-33: Steps to make foreground as a single region in MR image of Brain



(a) Rotated PET image

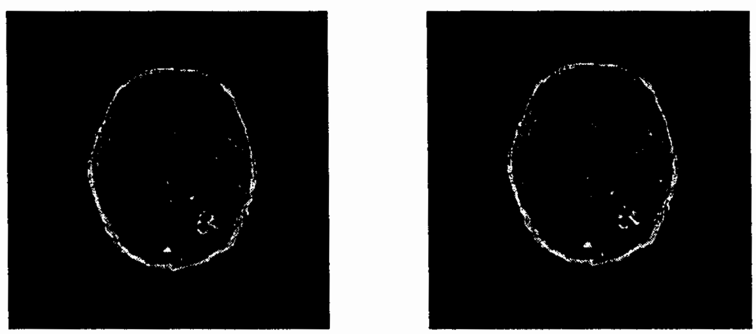


(b) Rotated MR image

Figure 5-34: Rotated PET and MR Images of Brain by Proposed Method

(a) Scaled PET image (b) Scaled MR image

Figure 5-35: Scaled PET and MR Images of Brain by Proposed Method



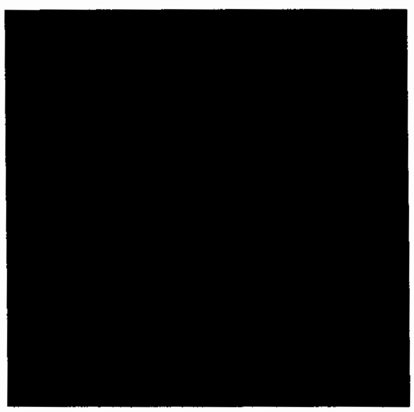
(c) Translated MR image by x-axis (d) Translated MR image by y-axis

Figure 5-36: Translated PET and MR Images of Brain by Proposed Method

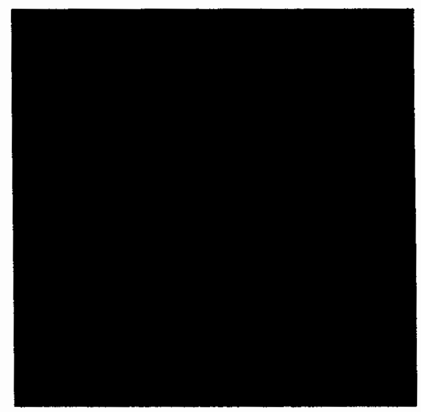
5.1.4. Comparison of Registration Techniques

We compare these three registration techniques by fusing the registered image with its reference image. We here apply simple averaging rule for fusion to all images. Figures 5.37 to 5.40 shows the comparison of three implemented registration methods on four different datasets

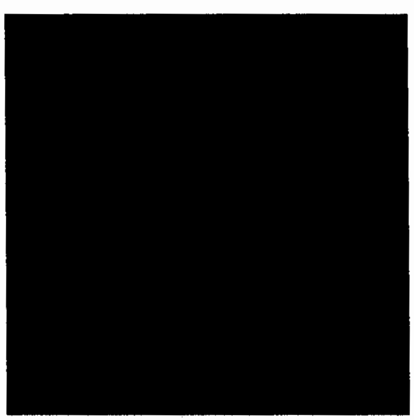
5.1.4.1. DataSet1-CT and MR images of Pelvis



(a) Unregistered Images



(b) Image Registration by Huang et.al [6]

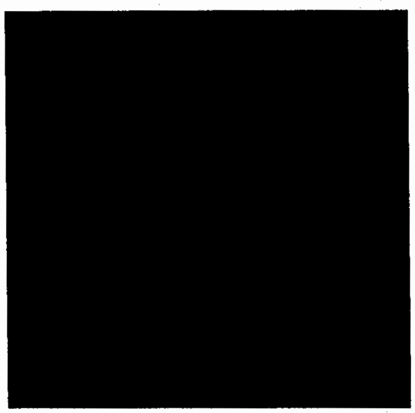


(c) Image Registration described in MATLAB©

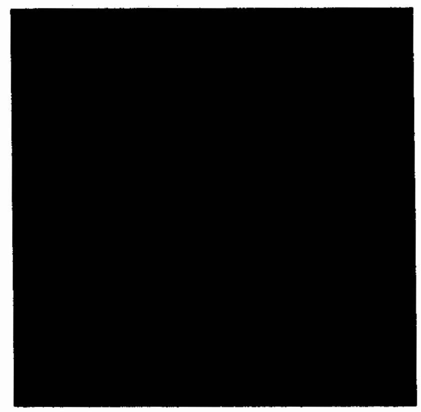
(d) Proposed Method

Figure 5-37: Comparison of Registration Techniques for Dataset 1

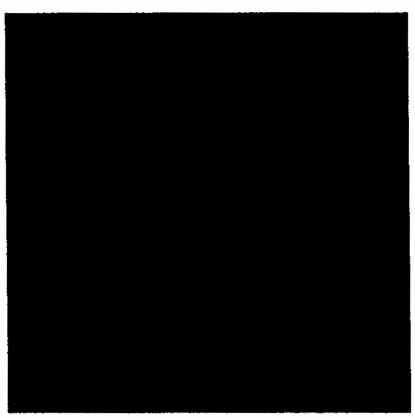
5.1.4.2. DataSet2-CT and MR images of Chest



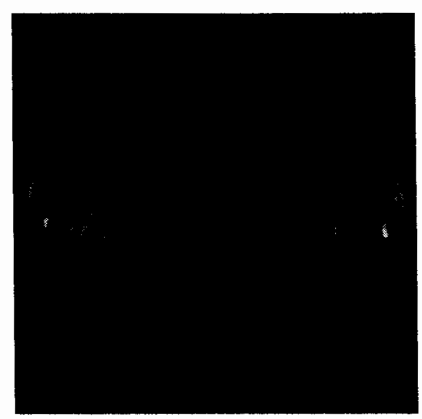
(a) Unregistered Images



(b) Image Registration by Huang et.al [6]



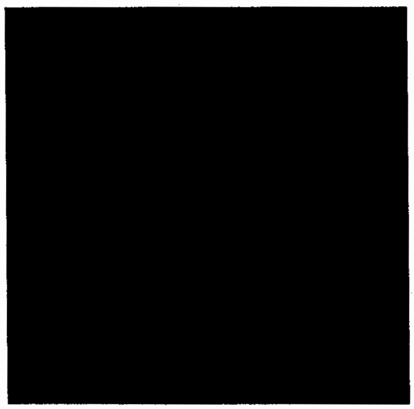
(c) Image Registration described in MATLAB©



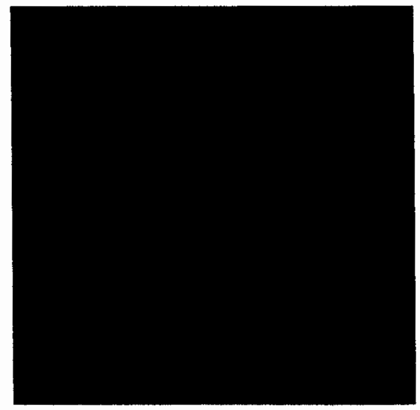
(d) Proposed Method

Figure 5-38: Comparison of Registration Techniques for Dataset 2

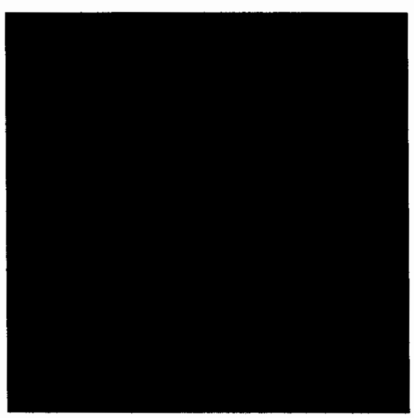
5.1.4.3. DataSet3-CT and MR images of Brain



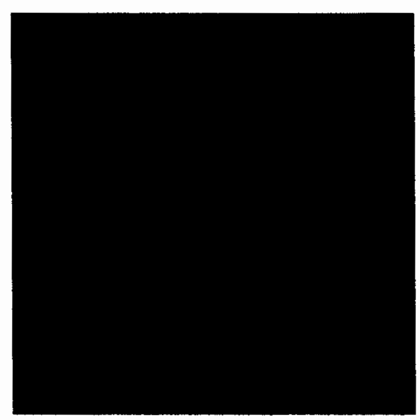
(a) Unregistered Images



(b) Image Registration by Huang et.al [6]



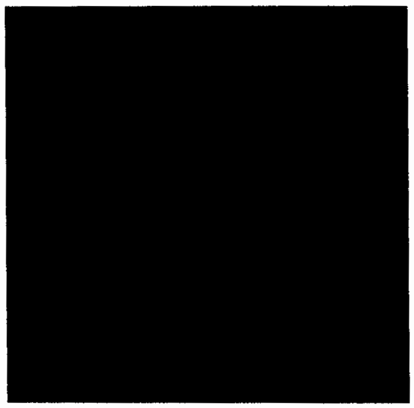
(c) Image Registration described in MATLAB©



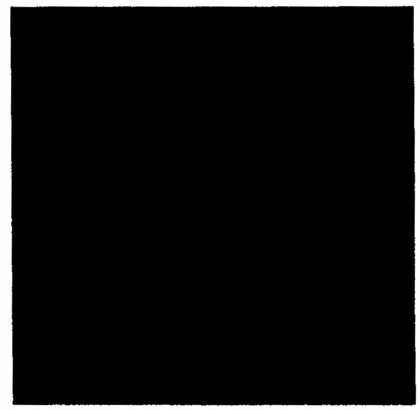
(d) Proposed Method

Figure 5-39: Comparison of Registration Techniques for Dataset 3

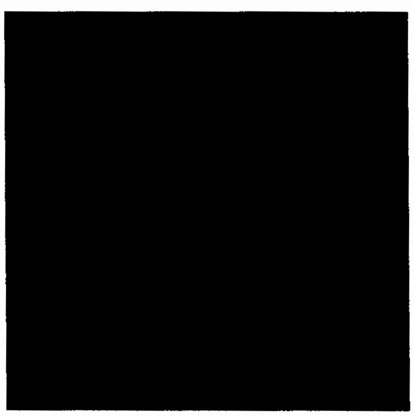
5.1.4.4. DataSet4-PET and MR images of Brain



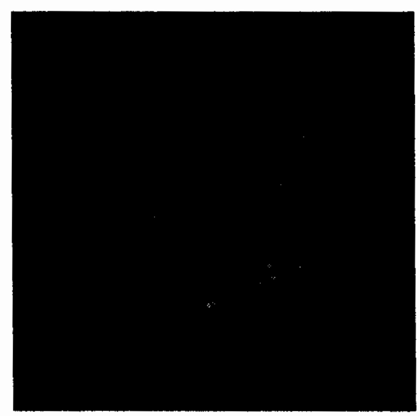
(a) Unregistered Images



(b) Image Registration by Huang et.al [6]



(c) Image Registration described in MATLAB©



(d) Proposed Method

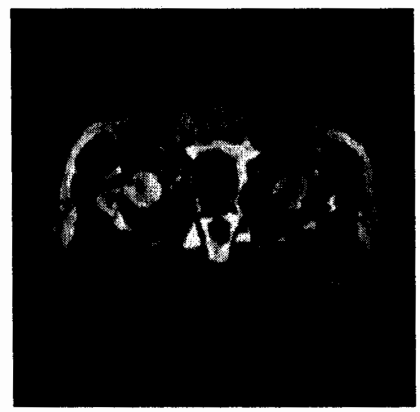
Figure 5-40: Comparison of Registration Techniques for Dataset 4

5.2. Results for Image Fusion Techniques

We have implemented two Fusion techniques. One is "Global Energy Method (GEM) based on Discrete Wavelet Transform (DWT)" and other is "PCA (Principle Component Analysis) Method to Fuse Low Frequency Components of DWT". These techniques have been implemented on registered images processed by the proposed method for registration. Figures 5.41 to 5.48 show the comparison of GEM and PCA methods for the fusion of two registered images from the given four datasets.

5.2.1. Comparison of GEM and PCA methods for Dataset 1

CT image of Pelvis



MR image of Pelvis

Figure 5-41: Fusion of CT and MR images of Pelvis by GEM

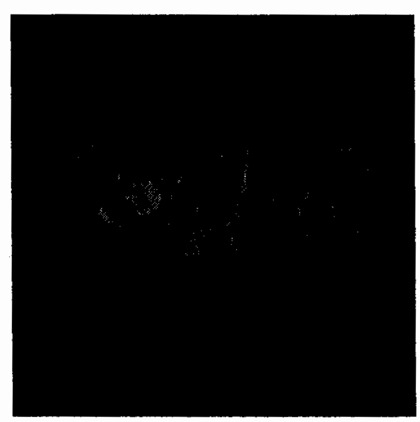
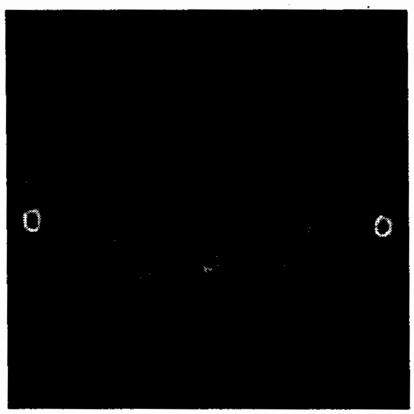
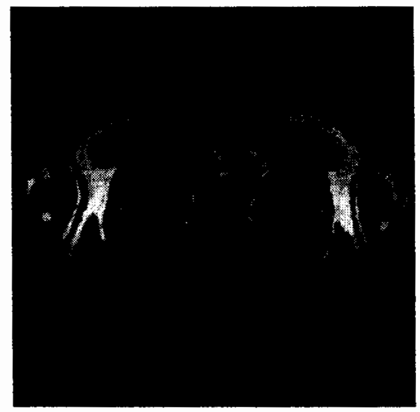


Figure 5-42: Fusion of CT and MR images of Pelvis by PCA

5.2.2. Comparison of GEM and PCA methods for Dataset 2



CT image of Chest



MR image of Chest

Figure 5-44: Fusion of CT and MR images of Chest by GEM

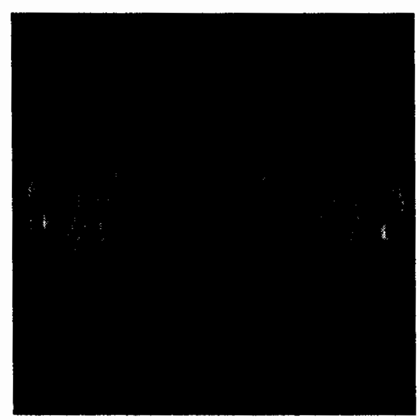
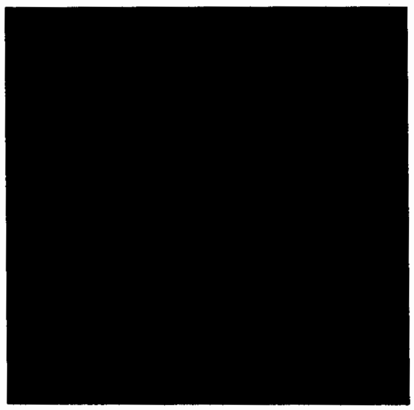
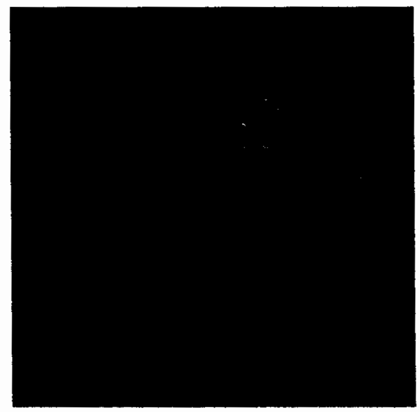


Figure 5-43: Fusion of CT and MR images of Chest by PCA

5.2.3. Comparison of GEM and PCA methods for Dataset 3



CT image of Brain



MR image of Brain

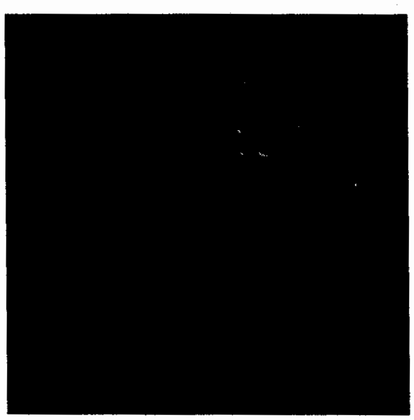


Figure 5-46: Fusion of CT and MR images of Brain by GEM

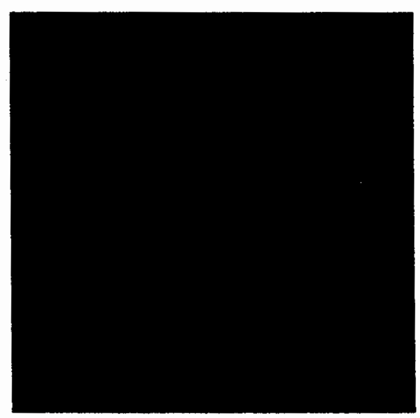
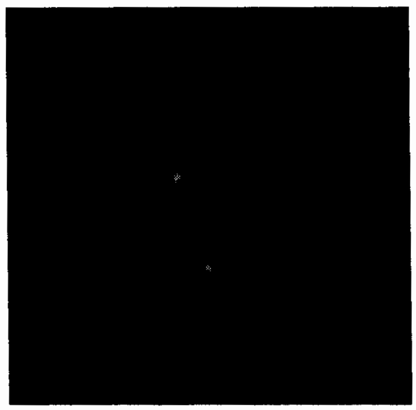
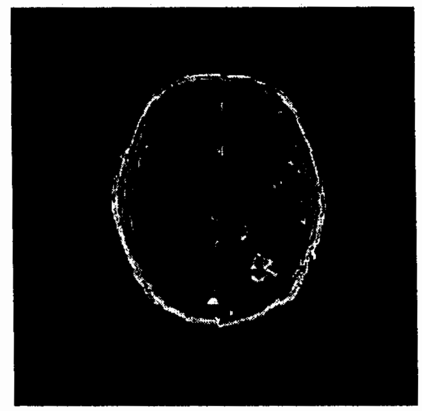


Figure 5-45: Fusion of CT and MR images of Brain by PCA

5.2.4. Comparison of GEM and PCA methods for Dataset 4



PET image of Brain



MR image of Brain

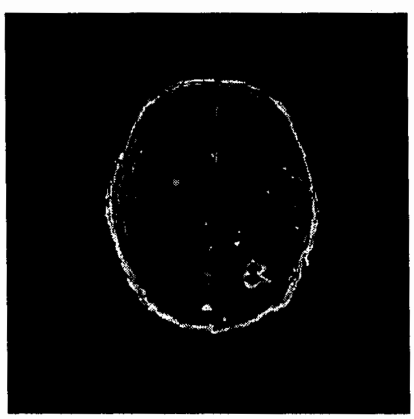


Figure 5-47: Fusion of PET and MR images of Brain by GEM

Figure 5-48: Fusion of PET and MR images of Brain by PCA

5.3. Performance Evaluation of Fusion Techniques

The performance of GEM and PCA methods were evaluated both qualitatively and quantitatively. The quantitative performance measurements used in our work are "Root Mean Square Error (RMSE)" and "Entropy". The quality measures of fused images are evaluated by valuable comments of a physician on images fused by GEM and PCA. These measures are discussed below in detail.

5.3.1. Root Mean Square Error (RMSE)

Root Mean Square Error is expressed as:

$$RMSE = \left[\frac{1}{MN}\sum_{n=1}^{N}\sum_{m=1}^{M}\left(x_R(n,m) - x_F(n,m)\right)^2\right]^{1/2}$$

Where x_R is the ideal reference, x_F the obtained fused image, and M, N are the dimensions of the images. Root mean square error indicates how much error the fused image x_F conveys about the reference image x_R. Thus the lower the RMSE between x_F and x_R, the more likely resembles the ideal x_R [7].

In our implementation we consider original images as the ideal ones. We first compute RMSE of fused image with respect to Image1 and then with respect to Image 2.

These measurements for the given four sets are given in table 5.1 and their graphical representation is given in figure 5.49 :

Sets	GEM with Image1	PCA with Image1	GEM with Image2	PCA with Image2
1	33.7231	21.8234	15.9644	16.1458
2	24.8558	20.0479	30.3326	20.0360
3	36.4956	27.2557	14.5074	12.9607
4	37.1476	26.4020	17.8755	17.0778

Table 5-1: RMSE values of fused images with respect to source images

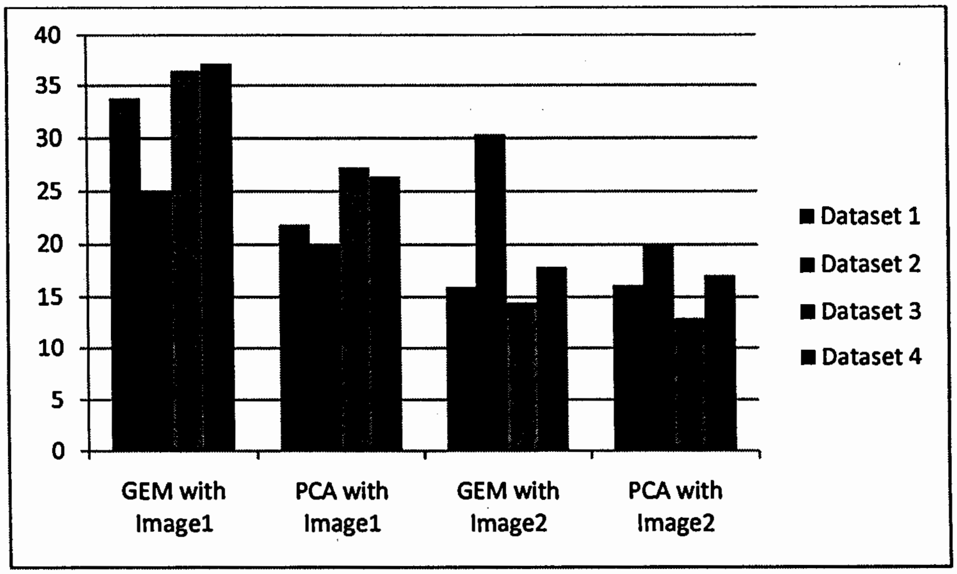


Figure 5-49 Graph of RMSE values of fused images with respect to source images

5.3.2. Entropy

Entropy is a common concept in many fields, mainly in signal processing. The entropy E must be an additive cost function such that E(0) = 0 and

$$E(s) = \sum_i E(s_i)$$

In our experiments we have used MATLAB© built-in function *wentropy(X,T)* to calculate the entropy of an image, where X is an image whose entropy is to be calculated and T is a string containing the type of entropy. We used entropy type "log energy" which is mathematically expressed asgiven in equation #:

$$E(s) = \sum_i log(s_i{}^2)$$

with the convention log(0) = 0.

In our experiments we have computed the entropy of original images (both Image 1 and Image 2) and the fused images. These measurements for the given four sets are given in table 5.2 and their graphical representation is shown in figure 5.50:

Sets	Image 1	Image 2	Fused image by GEM	Fused Image by PCA
1	2.1704e+005	2.3002e+005	2.2561e+005	1.9922e+005
2	2.4338e+005	2.3492e+005	2.4906e+005	2.3746e+005
3	2.1343e+005	2.4802e+005	2.3513e+005	2.3579e+005
4	1.5135e+005	1.4861e+005	1.3049e+005	1.5215e+005

Table 5-2: Entropy values of original images and the fused images

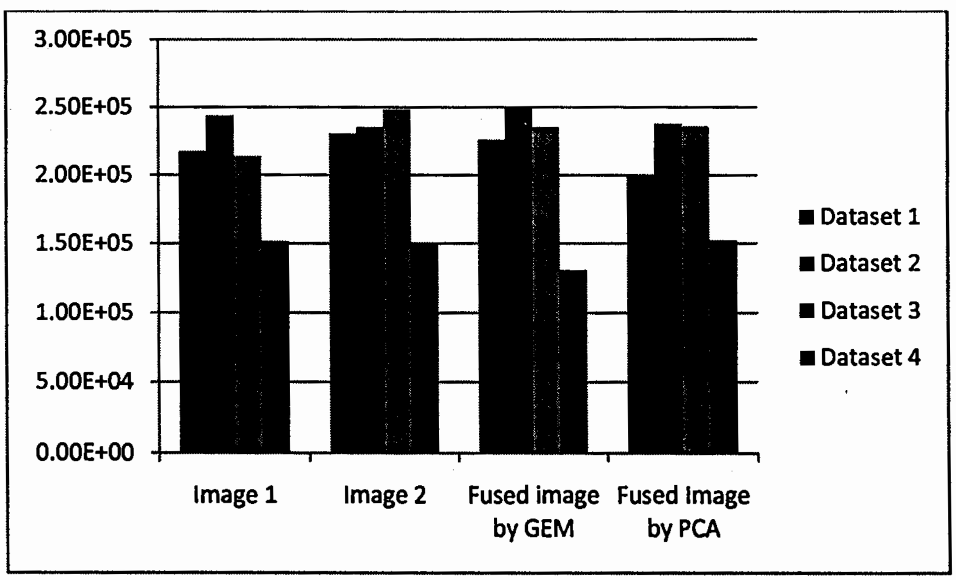


Figure 5-50 Graph of Entropy values of original images and the fused images

5.3.3. Remarks of a Physician on results of GEM and PCA

1) In the CT scan of Chest, the soft tissues for example lung fields, hilum, bronchi and blood vessels were much clearer in images fused by PCA method compared to the ones fused by GEM method. On the contrary, the ribs, vertebra and other calcified structures were more prominent in those fused by GEM images than those fused by PCA method.

2) In the CT brain images again the soft tissues like sulci and gyri of the cerebral cortex and also the ventricles and other areas of the brain were more visible in the image fused by PCA method compared to the one fused by GEM method. On the other hand the bones like cranial vault and other calcified structures were more prominent in images fused by GEM method.

3) Similarly, in the CT pelvis, the images fused by PCA method were showing the soft tissues like pelvic organs in more detail than those fused by GEM method. Again the images fused by GEM methods were more instructive in defining the bones and calcified tissues.

In conclusion, every method has its own advantages and disadvantages, but I think that image Fusion by PCA method is more helpful in defining soft tissues in detail and detecting medical conditions like Ischemic changes and cysts, etc. On the other hand, images Fused by GEM method will be more useful for detecting fractures and calcified vessels and heamtoma.

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Chapter 6
Conclusion and Future Work

6 Conclusion and Future Work

Based upon the experimental results the conclusions drawn are discussed in the following sections along with identification of future work in this direction.

6.1. Conclusion

Medical images from different modalities often provide complementary information. To integrate this complementary information we often need to combine useful information in both of these images. Therefore images of the same patient obtained through different modalities need to be integrated into a single fused image. For Fusion process to be successful, source images need to be properly aligned with each other in their orientation, scaling and translation. For this purpose, we have studied different registration techniques and implemented a few of them in our work. The first one was proposed by Huang et. al [6]. Our results have shown that this technique does not work well for images with poor orientation and translation. Another technique for registration of two images is discussed in the image processing toolbox of MATLAB©. This technique also does not work well for images without prior positioning, i.e., it is translation dependent. We then proposed a new method for registering images. This technique is rotation, translation and scale independent but requires prior foreground boundary detection. The results obtained by our proposed registration method are better as compared to both the other two techniques considered above.

For Fusion purpose we have studied different techniques. We found wavelet based techniques to be more effective and implemented two different techniques based on wavelets. These include "Global Energy Method (GEM) based on Discrete Wavelet Transform (DWT)" and "PCA (Principle Component Analysis) Method to Fuse Low Frequency Components of DWT". These two techniques are performed on four different datasets. We have evaluated our results both on the quantitative as well as the clinical measures.

We have measured the objective quality of the fused images by two different performance measures. These were the "Root Mean Square Error (RMSE)" and "Entropy".

The RMSE and Entropy values show that PCA method produces more effective results than GEM method.

From the qualitative or clinical point of view, GEM method works well to enhance the brighter portion while PCA method gives more detail about the soft tissues and shows the pattern in an image well than GEM method.

6.2. Future Work

There is a lot of scope in this area. Some of the directions of further study are as follows:-

- Finding registration method for images where boundary of foreground cannot be obtained.
- Work for the automatic selection of feature points for registration
- Use of tagged images for fusion
- Applications to medical imaging from more than two modalities
- Applications to images other than medical images.

Appendices

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