

**BRAIN MRI IMAGES QUALITY  
ENHANCEMENT USING IMAGE PROCESSING  
TECHNIQUES**

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**BRAIN MRI IMAGES QUALITY  
ENHANCEMENT USING IMAGE PROCESSING  
TECHNIQUES**

by

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## LIST OF SYMBOLS

$\oplus$	Dilation process
$\ominus$	Erosion Process
$\circ$	Composition of functions

## LIST OF ABBREVIATIONS

2D	2-Dimensional
3D	3-Dimensional
AHE	Adaptive Histogram Equalization
AMBE	Brightness Error
ANN	Artificial Neural Network
BBHE	Bi-histogram Equalization
BPDHE	Brightness preserving Dynamic Histogram equalization
CAD	Computer Aided Diagnosis
CDF	Cumulative Distribution Function
CLAHE	Contrast Limited Adaptive Histogram Equalization
CNR	Contrast Noise Ratio
CT	Computed Tomography
DHE	Dynamic Histogram Equalization
DICOM	Digital Imaging and Communications in Medicine
DoG	Difference of Gaussian
FELs	Fuzzy Entropy with a Level Set
GHE	Global Histogram Equalization
LBHE	Local Bi-Histogram Equalization
LHE	Local Histogram Equalization
LoG	Laplacian of Gaussian Operator
MAX	Maximum Fluctuation
MH-FIL	Modified Histogram Based Contrast Enhancement using Homomorphic Filtering

mm	Millimetre
MMBEBHE	Minimum Mean Brightness Error Bi-Histogram Equalization
MRI	Magnetic Resonance Image
ms	Millisecond
MSE	Mean Square Error
PDE	Partial Differential Equation
PET	Photon Emission Tomography
Pmax	Maximum Pixel Value
Pmed	Median Pixel Value
Pmin	Minimum Pixel Value
PSNR	Peak Signal Noise Ratio
RMP	Rotational Morphological Processing
ROI	Region Of Interest
SNR	Signal Noise Ratio
SPECT	Single Photon Emission Computed Tomography
Strel	Structural Element
T	Tesla
TCIA	The Cancer Images Archive
TE	Echo Time
TR	Repetition Time
V	Vector
WHO	World Health Organization

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# **PENINGKATAN KUALITI IMEJ MRI OTAK MENGGUNAKAN TEKNIK PEMROSESAN IMEJ**

## **ABSTRAK**

Kualiti imej MRI penting untuk tujuan diagnostik. Dalam penyelidikan ini, perisian MATLAB versi R2016a digunakan untuk operasi pemprosesan imej yang merangkumi peningkatan kualiti imej, pengurangan kebisingan imej, dan pemprosesan imej morfologi dan teknik segmentasi dan teknik ambang. Imej-imej telah dianalisis secara kuantitatif dan kualitatif dalam eksperimen ini. Perisian ImageJ digunakan untuk menganalisis imej secara kuantitatif. Eksperimen ini dilakukan dengan menggunakan dua imej MRI otak. Imej-imej dalam kajian ini diperoleh daripada platform dalam talian; The Cancer Archive (TCIA) dengan akses awam. Identiti kedua-dua pesakit dirahsiakan dalam domain TCIA. Imej 1 ialah pesakit perempuan berumur 63 tahun dan imej 2 ialah pesakit lelaki berumur 58 tahun. Langkah pertama dalam pra-pemprosesan imej adalah penyaringan dengan median dan penapis min. Dua topeng penapis digunakan iaitu topeng penapis min  $3 \times 3$  dan topeng penapis min  $4 \times 4$  untuk penyaringan imej. Tiga teknik peningkatan kontras imej telah dikaji dalam eksperimen ini. Tiga teknik tersebut adalah kaedah peregangan kontras manual dan MATLAB, kaedah penyamaan histogram dan kaedah Contrast Limited Adaptive Histogram Equalization (CLAHE). Teknik ambang diterapkan pada imej untuk analisis kualitatif imej. Ambang batas dilakukan mengikut kaedah ambang Otsu. Dalam eksperimen ini, beberapa nilai ambang dieksperimen untuk mendapatkan ambang imej terbaik. Operasi morfologi melibatkan proses operasi pelebaran, hakisan, pembukaan dan penutupan. Teknik segmentasi pengesanan tepi Roberts, Canny, Sobel dan Prewitt menggunakan perisian MATLAB telah dikaji dalam eksperimen ini untuk visualisasi tepi dan sempadan struktur anatomi terbaik dalam imej MRI otak. Imej

dalam eksperimen dianalisis secara kuantitatif dan kualitatif. Untuk analisis kuantitatif, nilai kebisingan, kontras, kontras dengan nisbah kebisingan (CNR) dan entropi dihitung. Analisis ROI dilakukan untuk menentukan nilai kontras dan kebisingan imej. Penapis terbaik untuk mengurangkan bunyi, meningkatkan kontras, dan mengurangkan kekaburan Imej ialah penapis median. Bagi teknik peningkatan kontras, kaedah CLAHE memberikan analisis CNR yang baik untuk imej yang disaring dan tidak ditapis. Dengan analisis kualitatif juga, imej yang diterapkan CLAHE mempunyai peningkatan kontras yang baik, kecerahan imej yang baik dan pemeliharaan tepi imej. Nilai ambang terbaik dikenal pasti sebagai 0.35 untuk imej yang disaring dan tidak ditapis dengan kaedah regangan kontras dan kaedah CLAHE. Bagi Imej yang disaring dan tidak disaring dengan kaedah pemerataan histogram, nilai ambang optimum adalah 0.65. Keempat-empat kaedah pengesanan tepi berdasarkan pengendali memberikan segmentasi tepi yang baik dari imej perdua ambang. Operator pengesanan terbaik dalam eksperimen ini adalah pengendali Canny. Pengendali ini memberikan pengesanan tepi yang baik dalam semua imej yang disaring dan tidak ditapis. Kesimpulannya, melakukan teknik pra-pemprosesan dan pemprosesan kepada imej perubatan akan memberikan imej dengan kualiti imej yang baik untuk diagnosis dan rawatan penyakit yang tepat.

# **BRAIN MRI IMAGES QUALITY ENHANCEMENT USING IMAGE PROCESSING TECHNIQUES**

## **ABSTRACT**

Image quality of MRI images is important for diagnostic purposes. In this research, MATLAB software version R2016a is used for image pre-processing and processing operations which includes image enhancement, noise reduction, and morphology image processing and thresholding and edge segmentation techniques. The images were analysed quantitatively and qualitatively in this experiment. ImageJ software was used to analyse the images quantitatively. This experiment was done using two brain tumour MRI images. The images are acquired from an online platform; The Cancer Images Archive with public access. The two patient's identities were kept discreet in the TCIA domain. Image 1 is of a female patient of 63 years old and image 2 is of a male patient of age 58 years old. The first step in image pre-processing is filtration with median and mean filters. Filtration aims to reduce the noise present in images. Two filter masks were used for mean filtering. They are 3×3 mean filter mask and 4×4 mean filter mask. Three image contrast enhancement techniques were studied in this experiment. They are the manual and MATLAB contrast stretching method, histogram equalization method and Contrast Limited Adaptive Histogram Equalization (CLAHE) method. The thresholding technique was applied to the images for the qualitative analysis of the images. The thresholding was conducted according to Otsu's thresholding method. In this experiment, several threshold values were experimented with to obtain the best image thresholding. The morphology operation involves the processes of dilation, erosion, opening and closing operations. Roberts, Canny, Sobel and Prewitt edge detection segmentation techniques using MATLAB

software were studied in this experiment for the best visualization of edges and borders of the anatomical structures in the brain MRI image. The images in the experiment were analysed quantitatively and qualitatively. For quantitative analysis, the noise, contrast, contrast to noise ratio (CNR) and entropy values were calculated. ROI analysis was conducted to determine the contrast and noise value of the images. The best filter to reduce noise, enhance contrast, and reduce image blurriness is the median filter. As for the contrast enhancement technique, the CLAHE method provided good CNR analysis for the filtered and grayscale images for brain MRI image 1. By qualitative analysis too, CLAHE-applied images have good contrast enhancement, good image brightness and image edge preservation for brain MRI image 1. As for brain MRI image 2, the contrast stretching method provided good CNR value and enhanced contrast. The best threshold values were identified as 0.35 (image 1) and 0.30 (image 2) for filtered and grayscale images with contrast stretching method and CLAHE method. As for filtered and grayscale images with the histogram equalization method, the optimum threshold value was 0.65 for image 1 and image 2. All four operator-based edge detection methods provide good edge segmentation of the thresholded binary images. The best edge-detecting operator in this experiment was the Canny operator. This operator provided good edge detection in all the filtered and grayscale images. In conclusion, conducting pre-processing and processing techniques to the medical images will provide images with good image quality for accurate diagnosis and treatment of disease.

## CHAPTER 1 INTRODUCTION

### 1.1 Background of Study

Most of the diagnoses of diseases in patients are determined using medical imaging procedures such as X-ray imaging, Computed Tomography (CT) imaging, Magnetic Resonance Imaging (MRI), Ultrasound and Nuclear Medicine. Accurate diagnosis of disease and treatment planning leads to proper treatment and this improves the quality of public health. MRI is an important imaging tool for the diagnosis of diseases especially to image the brain and soft tissues in the body. MRI is also a safe imaging procedure which does not use any radiation.

Many medical images are subjected to degradation of image quality. An optimum image should provide precise information about the objects present in the medical images. This information includes the size, volume and contrast of different density structures in the body such as bone, soft tissue, and tumour tissue. Medical image quality degradation occurs during the imaging process, equipment used during imaging, and during image acquisition. Image quality is represented by various factors such as; contrast, blur, noise, artefacts, and distortion (Sprawls, 2014).

Computer Aided Diagnosis (CAD) system helps physicians and radiographers with disease diagnosis in medical images. CAD system provides a second opinion to radiologists and physicians to achieve highly accurate diagnosis and treatment of disease (Doi, 2007). Proper digital image pre-processing and post-processing of medical images improves the quality of an image. Many image processing software is available in the medical field nowadays. Digital image processing software can be used to enhance the image quality of medical images.

Many image enhancement techniques are available in image processing software to improve the image quality of medical images. In this research, the mean filtering technique, contrast adjustment techniques which include contrast stretching, histogram equalization technique, CLAHE, and processing techniques such as thresholding technique, morphological operation, and edge detection are applied to enhance the medical image quality.

Medical image analysis is an important aspect to determine medical image quality. This analysis will play a significant role not only in the diagnosis of the disease but also in the treatment of the disease. Medical image analysis can be characterized by quantitative analysis and qualitative analysis. The quantitative analysis of the medical images is numerical-based. This is done by calculating the pixels, noise and contrast in the Region Of Interest (ROI). Qualitative analysis, on the other hand, is the human observation of medical images such as the edge observation, brightness of the image and more. This is done by the experience radiographers and physicians.

## **1.2 Problem Statement**

MRI imaging is a powerful imaging and preferred medical imaging modality, especially for soft tissue imaging. The artefacts present in MRI images affect the image quality of MRI images. Enhancing the image quality of MRI images will improve the diagnosis and treatment of diseases. The common image artefacts in MRI images are due to hardware limitation, magnetic field inhomogeneity, patient motion and during image processing (Budrys et al., 2018; Havsteen et al., 2017)

Medical image processing is the technique to modify and improve low-diagnostic quality medical images with the usage of computational systems. Image processing allows corrections of unwanted distortions and improves the quality of an

image. Noise can be removed, the brightness of the image can be adjusted and volume of interest can be highlighted. However, it has always been a great challenge in the field of medical imaging to remove noise present in images while preserving other important features in the image such as the tumour volume and edges of the image. In MRI medical image acquisition, the quality of image contrast is prone to be compromised. While the contrast enhancement technique is a commonly applied method in medical imaging, past studies showed that over-enhancement or over-stretching of an image, contrast may manipulate the essence and pixel-by-pixel information of medical images which might lead to physicians missing detailed information for diagnosis (Mahmood et al., 2019)

Morphology refers to the structure or form of an object. Mathematical morphology in the image processing context refers to the study of the shape, lattice and geometry of the image. The morphological operations are a set of strong and broad mathematical functions that are applied either in image processing or the post-processing stage. Morphology enhancement is known to enhance the appearance of masses, lesions, tumours and other abnormalities present in medical images. Although the method can enhance target tissues without disrupting the image quality of background tissue, the method changes the size and shape of the structuring element of medical images. However, several studies have shown that the morphology enhancement technique is challenging in MRI due to the main tissues in concern being various soft tissues with proximity in physical properties (Kulshreshtha and Nagpal, 2021). Therefore, the investigation of morphology enhancement technique in MRI will provide significance to study the reliability of morphology enhancement technique in MRI imaging.



Detection of edges in an image is important in medical image processing, image analysis, detection of the size, shape and perimeter of the edges, segmentation and feature extraction. However, past studies show that the technique is sensitive to noise and usually provides inaccurate detection of edges especially the application Roberts operator (Amer and Abushaala, 2015; Ansari et al., 2017). Some operators are too sensitive to noise and some edges may be undetected due to the increased noise. The canny edge detector is one of the techniques applied in edge detection but is it known to be time-consuming. Thus, a study on edge detection in the field of MRI is deemed significant to outline errors and limitations in edge detection for MRI images.

The non-existence of fundamental limits to image processing techniques in MRI may lead to false-positive and false-negative image diagnoses. Therefore, it is crucial to study various image processing techniques to suggest the fundamental limit of medical image enhancement allowed in MRI imaging without distorting the true value of its underlying anatomical and physiological information.

### **1.3 Objectives of Study**

The objectives of this study are:

- i. To study the significance of MATLAB algorithm to improve various image quality metrics of brain MRI images.
- ii. To evaluate image filter and contrast enhancement techniques in improving contrast and reducing image noise in brain tumour MRI images.
- iii. To analyse image quality metrics of brain tumour MRI images post segmentation via thresholding technique

- iv. To evaluate the effect of morphological operations and operator-based segmentation for edge detection on brain MRI images using MATLAB software.

#### **1.4 Scope of Study**

The brain tumour is a complicated tumour to detect and diagnose due to the complexity of the tumour size and location. This research focuses on, improving the image quality of brain tumour MRI images using MATLAB algorithms. In this study, two grayscale brain tumour MRI images from the online platform The Cancer Images Archive (TCIA) with Public Access will be studied. The mean filter and median filter were used to reduce the noise in the MRI images. As for image contrast enhancement, four methods were applied to the MRI images. They are manual contrast stretching, MATLAB contrast stretching, Histogram Equalization (HE) and Contrast Limited Adaptive Histogram Equalization (CLAHE). As for image segmentation, Otsu's global thresholding method will apply to the grayscale and filtered images. To study the edge detection in the images two operations will be conducted. They are mathematical morphological operations and operator-based edge detection. The morphological operations consist of dilation, erosion and a combination of these operators which are opening and closing operators. Operator-based segmentation are the Roberts, Sobel, Canny and Prewitt operators. The data analysis in this study was performed qualitatively and quantitatively. Image brightness, edge discontinuity, image blur, and contrast are the aspect that will be studied for qualitative image analysis. Quantitatively image contrast, noise, Contrast to Noise Ratio (CNR) and entropy will be studied. Image quantitative analysis was conducted using ImageJ software.

## **1.5 Significant of Study**

This work focuses on the various techniques studied to improve the quality of MRI brain images. The purpose of this research is to enhance the quality of medical images by improving the image contrast, reducing the image noise and detecting the image edges with image segmentation and thresholding. Noise-removing filters, contrast enhancement techniques and edge detection methods were studied in this research. The presence of noise and low-contrast images will be among the challenges for physicians to accurately and effectively diagnose a disease. The pre-processing, processing and post-processing techniques that were conducted in this research using MATLAB software will be useful for the medical imaging team to improve the quality of the medical image. The outcome of this research will be very helpful for physicians and will improve the quality of public health in Malaysia.

## **1.6 Thesis Outline**

This thesis consists of five chapters. Chapter 1 is the introduction of this study. It consists of the background of the study, problem statement, objectives, significance of this study and thesis outline. Chapter 2 highlights the literature review which covers the theory and previous studies on image pre-processing, processing and analysis of images. The image processing techniques such as image filtering, contrast enhancement techniques, thresholding, morphological operations and edge detection segmentation were discussed in Chapter 2. Chapter 3 covers the steps in conducting the image pre-processing, processing and analysis of the medical images using MATLAB and ImageJ software. In Chapter 4, the images that were processed and analyzed were provided and the results of the images were discussed qualitatively and

quantitatively. The final chapter, Chapter 5 discusses the finding of this study and the significance of this study for further and future research.

## CHAPTER 2 LITERATURE REVIEW

### 2.1 Brain MRI Images

The brain tumour is the most difficult tumour to be treated even though it's not the most common tumour in humans (DeAngelis, 2001). Accurate diagnosis and treatment of the tumour is important due to the complicity of the position of the brain tumour. Brain tumours can be classified into many types according to the WHO classifications (Louis et al., 2016). But the location-based tumour is the most common and basic classification of the brain tumour. The two sets of brain tumour classifications are the primary and the metastatic brain tumour. The primary is the brain tumour arising from the brain organ while metastatic is the tumour arising from different parts of the body but travelling and depositing in the brain (Bauer et al., 2013)

MRI is an imaging procedure that plays a vital role in neuroimaging and diagnosing brain tumours. MRI is the preferred imaging method because the images provide comprehensive data on anatomical structures and also soft tissues of the brain and head (Nelson, 2008). MRI uses a strong magnetic field and radio frequency waves to capture the image of the inner parts of the human body. This imaging procedure is non-invasive. This imaging technique too does not use any type of radiation as compared to other medical imaging modalities such as X-ray imaging, CT scan, Mammography, Fluoroscopy and nuclear medicine. This makes MRI a safe imaging modality for children and pregnant patients.

An MRI hardware system consists of a magnet, gradient coils, a radio-frequency system, and a computer system. The magnet is the core of the MRI unit and the magnet coils produce a strong magnetic field (Carpenter and Williams, 1999). The magnetic field of strength up to 3T has been widely used clinically. The gradient

system consists of three types of gradient coils (X, Y and Z coils) which are responsible for the spatial encoding of the MRI signal (Hidalgo-Tobon, 2010). The radio frequency system has coils which are responsible to transmit and receive nuclear magnetic resonance signal that forms the scanned image.

Most of the human body is made up of water with hydrogen atoms. The hydrogen atom carries protons in its nucleus. Each proton has magnetic properties and they spin in their own axis. When a strong magnetic field is introduced to tissue, all the protons in the area of exposure will be aligned in the same arrangement. Then, when radio frequency waves were applied to the same protons, the alignment of protons will be disrupted. The protons will transmit radio frequency waves when the radio frequency waves from the MRI unit are stopped. This is known as tissue magnetization. The waves transmitted by the protons will form the MRI image (Berger, 2002).

## **2.2 Computer Aided Diagnosis (CAD)**

Computer Aided Diagnosis (CAD) is a diagnosis method which has equal involvement of both physicians and computer-manipulated medical images. The diagnosis made by physicians is based on the output from the digital analysis of medical images (Nishikawa, 2006; Doi, 2007). The automatic detection method is the diagnosis of a disease that solely depends on the data from digital image analysis and is not subjected to data interpretation by physicians.

The CAD method is proven to be a much more convenient and preferred method of diagnosis. This is because the digitally analysed images not only reduce the time taken to manually interpret medical images data by medical imaging technologists and physicists but also act as a 'second opinion' to physicians, while

detecting and diagnosing diseases (Suzuki, 2012; Firmino et al., 2016). Figure 2.1 shows the flow of a clinical implementation of CAD for medical images obtained both digitally and through an analogue imaging system (Doi, 2007).

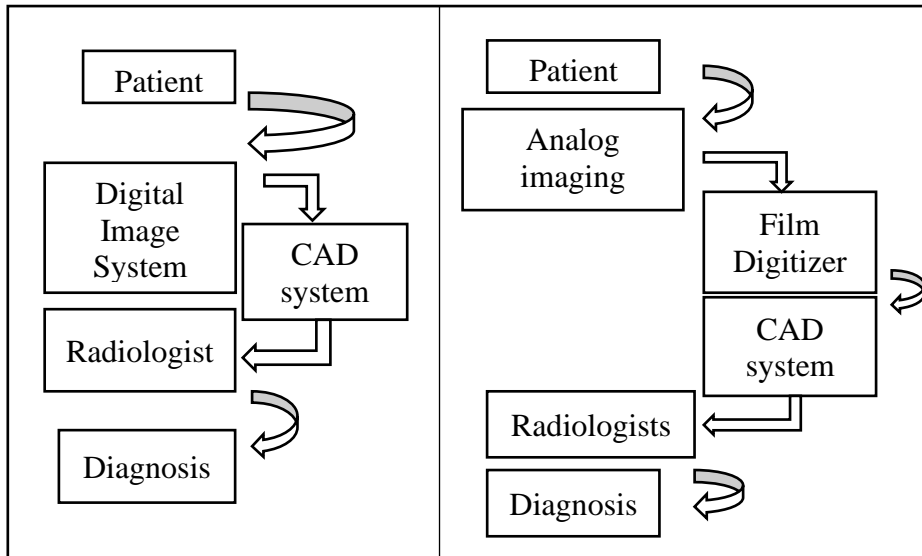


Figure 2.1: The flowchart of clinical interpretation of CAD for images acquired from digital system and analog system (Doi, 2007).

### 2.3 Medical Image Processing Software

Processing and post-processing medical images are useful and very common method these days to boost the image quality of the grayscale images in medical field. Image processing is conducted by applying mathematical operation which manipulates the input digital image to form an image with improved image quality or to transform to different image based on the requirement of the user. Medical imaging software are able to process images in the form 2D and also 3D. Image processing and post processing are performed using image processing software. Many image post-processing software are commercially available these days and widely used in medical field. Some software with image processing toolbox such as MATLAB can be easily installed in personal computers and laptops and can be used to perform image post

processing. The post processing of image includes the application of image filtering, segmentation, thresholding, image visualization, noise reduction, edge detection, image analysis and many more (Gokilavani et al., 2018; Widodo et al., 2020)

Post processing of medical images are usually conducted by software such as MATLAB, ImageJ, OpenCV, Python, Ruby, Amirah, LabView and few more. All software have the advantages and also disadvantages in performing post processing on medical images.

MATLAB is a computer software which has algorithm and toolbox for image processing. Many of the image processing methods in the MATLAB software has the built-in function where the algorithms for the techniques are provided in the software. This method is time efficient and lessens the complexity of processing the medical images in this software (Meng, 2018).

MATLAB image processing toolbox provide functions such as filtering, contrast improvement techniques, morphological operations, segmentation, thresholding, and many more. Image analysis such as histogram analysis, noise evaluation, detect and calculation of pixel intensities, texture analysis, feature extraction and more also provided in the software. 2D images and 3D images can be processed in the software. There are grayscale, true colour, binary, indexed and uint8 types of digital images can be read and processed in MATLAB software (MathWorks, 2020; Abdullah et al., 2016).

Many studies on medical imaging processing and analysis using MATLAB software conducted previously (M.Gokilavani, 2018; Mittal, 2012; Pandey, 2017). In a study by Seletchi (2008) , by using MATLAB visualization tool, functions such as histograms, contour plots, texture mapping were calculated in the CT and X-ray medical images. The Signal Processing Toolbox from MATLAB also used in this



study to process and analysis of the signal functions. In another study by Pandey and Sahu (2017), brain tumour detection, enhancement and extraction is studied using brain MRI images. Image processing applications such as image enhancement, morphological operation, segmentation were processed and calculated using the MATLAB image processing toolbox. Image analysis such as calculation of tumour area and the extraction of tumour volume were calculated using the MATLAB software.

Another important image processing and analysis software for medical images is the ImageJ software. ImageJ is a free and open source program developed by Wayne Rasband. ImageJ software also known as speed software where the image processing and analysis can be calculated in a very short time. This software is user friendly as the software can operate in any computer system such as Windows, Linux, Mac, Unix and more. Similar to MATLAB software, ImageJ software can display, process, analyse 2D and 3D medical images (Abràmoff et al., 2004; Bajaj et al., 2013; West and Cameron, 2006)

## **2.4 Medical Image Processing**

Computer and software to manipulate medical images has many advantages such as lesser time consumption to process and collect data from input image, effective storage of data and the flexibility to convert the images to different images and produce different data set (Abdallah and Alqahtani, 2019).

A digital image is an electronic document that made of picture elements known as pixels. The pixels are arranged in array and presented in the x and y plane. There are plenty of pixels in an image. The pixels in the digital image have their own direction and magnitude (Gupta, 2011). The process of medical image processing and

post-processing begins with the acquisition of images from the imaging modalities. Most commonly used imaging procedures in healthcare facilities are MRI, Ultrasound, Computed Tomography (CT), X-ray, Single Photon Emission Tomography (SPECT) and Photon Emission Tomography (PET). The common workflow of medical image processing and post-processing using medical image processing software given in Figure 2.2. However, this workflow is just a general order of image processing stages and may differ to the requirement and the purpose of the user and the medical images.

The medical analogue images are converted to digital images. These digital images are then undergoes series of processes known as pre-processing, image enhancement and post-processing. Based on the requirement of the user, digital images are converted to grayscale image or colour image. During pre-processing, the digital image is read and resized into the software. The main objective of pre-processing of image is to remove unwanted distortions and improve the quality of image before the images are further processed to image processing stage. The noise is removed, brightness of image is adjusted and filter is applied during pre-processing of medical image (Selvanayaki and Karnan, 2010; Pandit and Shah, 2011).

Digital image that has pre-processed will be further processed to improve the quality of the image. The enhancement of image includes the process of histogram equalization, edge detection, and many more techniques to produce an image with superior image details (Altarawneh, 2012).

Medical image post processing is the process of analysis of image to obtain details important for diagnosis and treatment of disease. During image post processing process, important details from the image is extracted by identifying the region of interest (ROI). The extracted details are useful information that will aid in diagnosis and also the treatment of disease (Chinmayi et al., 2018). The extraction of feature and

image registration commonly conducted via several methods such as segmentation, thresholding. The post processing stage where image registration and feature extraction also known the stage of image analysis.

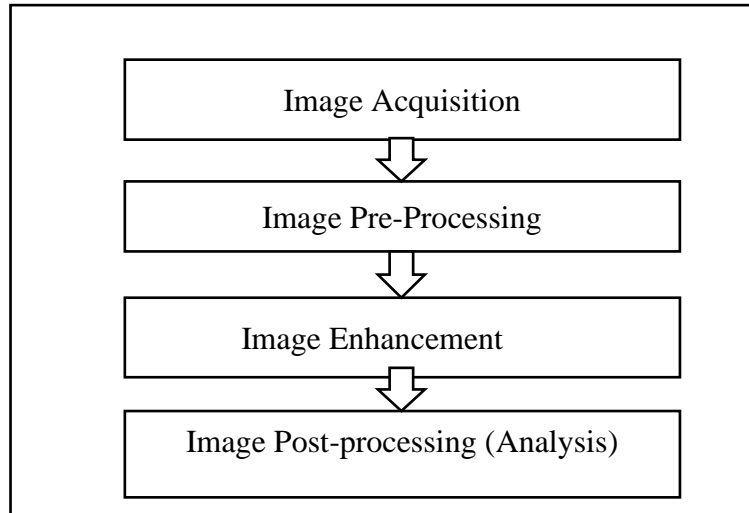


Figure 2.2: The general workflow of image processing of medical images using image processing software.

#### 2.4.1 Image Filtering

Filtering is one of the method of image improvement that plays an important role in noise removal. Image filtering is also one of the most basic and most fundamental process in image processing. Image filtering process is also known as denoising technique (Narasimha and Rao, 2015).

The medical images that need to be processed in the image processing software can be categorized into two domains. One is the spatial domain and the other one is frequency domain. The filtering process is based on the image domains. Spatial means space and the spatial domain image filtering is the simple form of image filtering which deals with the filtering in its plane. In spatial domain, images are filtered with direct manipulation of pixel values in the neighbourhood of the digital image. The spatial domain filters can further divided into linear and non-linear filters (Narasimha and Rao, 2015; Gonzalez and Woods, 2006; Yushkevich, 2014). In the frequency domain, images are converted to frequency mode. These digital images which are in spatial

domain originally, is converted to frequency domain and filtered. Filters in frequency domain act mainly to remove high frequency or low frequency signals to produce a smooth image (Shahnawaz et al., 2016). Simple representation of the spatial domain and frequency domain image filtering is illustrated in Figure 2.3.

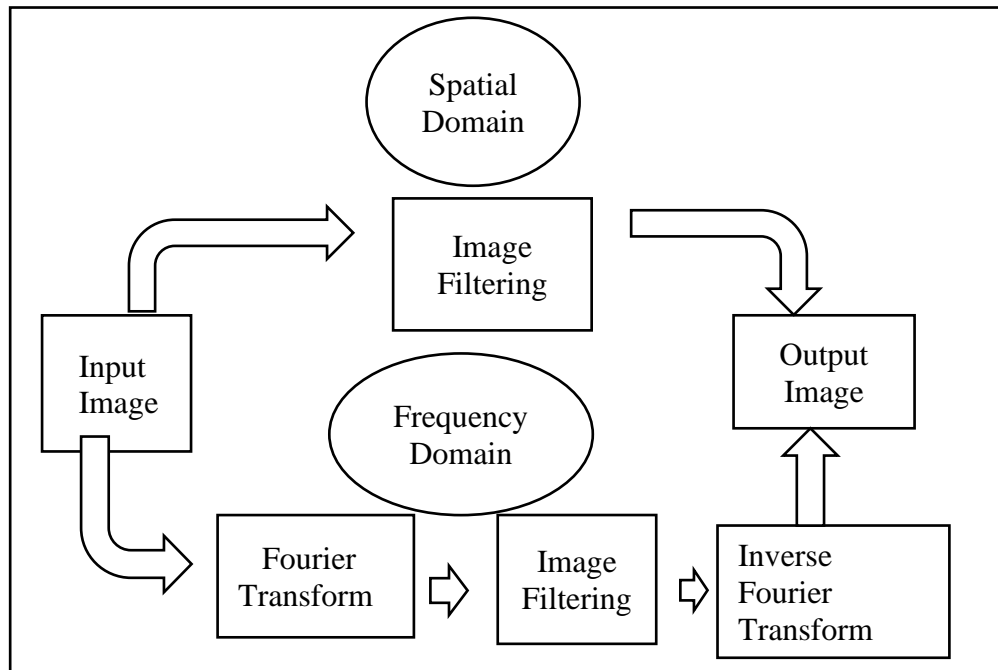


Figure 2.3: The overview of image filtering in spatial domain and frequency domain

There are many digital image filters and filtering techniques applied to medical images on using image processing software. Several past studies on types of digital image filters will be discussed in this subtopic. In a research conducted by Karuppanagounder and Palanisamy (2012), five spatial domain non-linear mean filters performance were studied and compared. The filters were studied on five different medical images of MRI, CT and X-ray imaging.

The aim of this research is to determine best filter that can reduce Gaussian noise which was artificially introduced to the medical images. The non-linear mean filters used in this research were geometric, arithmetic, contra-harmonic, harmonic and

alpha-trimmed mean filters. The analysis method used for quantitative analysis was the canny edge detection method. The canny edge detection value for the noisy image is compared to the edge values of the initial medical image. In this research, the alpha-trimmed mean filter and harmonic mean filter provided better edge values and effective in removing Gaussian noise present in the medical images.

In a research conducted by Narasimha and Rao (2015), spatial domain filters were used to enhance the digital images. Noise was applied to the medical images in this research. Noise was introduced using two noise models which are adaptive noise model and multiplicative noise model in this research. Speckle noise, Salt and pepper noise and Gaussian noise were applied to the medical images. Three filters were then applied to denoise the medical images. The filters used were, Wiener filter, mean filter, and median filter.

Mean filter provided best filtration for the medical image with Gaussian and Speckle noise compared to other the image filtered with Wiener filter and Median filter. The Median filter, filtered the best for medical image with salt and pepper noise. The MSE calculated for the median filter with salt and pepper noise is only about 2%. However, the author concluded that, Median filter provides better filtration for all the noise studied in this research even though mean filter provided better results for Gaussian noise and Speckle noise.

In another research conducted by Gupta (2011), similar analysis methods were used as the previous study which is the MSE and PSNR analysis. In this research, a comparison study was conducted to digital images using three spatial domain filters. The image of a female called 'Lena' and house image were used in this study. The spatial domain filters used were, mean filter, median filter and improved median filter. Gaussian noise and salt and pepper noise added to the input image using the adaptive

noise model. Nine levels of noise density from 10% till 90% were applied to the input images.

In this improved median filter, 2D window size of  $3 \times 3$  was selected adjacent to the pixel value in the artificially added noise image. The pixel values in the chosen 2D window are categorised in the manner of ascending value. The maximum pixel value ( $P_{max}$ ), minimum pixel ( $P_{min}$ ) value and median pixel value ( $P_{med}$ ) were identified and these values were sorted into a vector ( $V_0$ ). If the pixel value in the selected 2D window is more than  $P_{min}$  and less than  $P_{max}$ , with  $P_{min}$  value more than 0 and  $P_{max}$  value lesser than 255, then the pixel value is categorized as not corrupted or no noise included to the pixel. When pixel amount does not meet the criteria said above, then the pixel has noise. The corrupted pixels can further divided into 2 groups. The first one is when the  $P_{med}$  value is more than 0 and less than 255, the pixel value can be replaced by the  $P_{med}$ . In the second group, when the pixel value does not meet the criteria said above, then the difference between 2 adjacent pixel pair is calculated and a vector value ( $V_D$ ) is obtained. The vector value  $V_D$  and vector value  $V_0$  sorted to obtain the maximum difference and the value is registered to the  $V_0$  processed pixel. The steps are repeated until all the pixel values are organized in the noise added image.

The images with various level of noise were filtered and the PSNR values and MSE values were obtained. The adaptive noise added images that were filtered with median filter had good PSNR values with lower noise images. However, the median filter is not so efficient with images on high noise density. The modified median filter has provided good filtering and good edge preservation even for images that were highly noised.

### **2.4.2 Contrast Enhancement Techniques**

Image contrast refers to difference of level of grayscale various elements in the digital image. Contrast in medical images is important because the internal structures of body such as bone, tissue and tumour tissue need to be clearly differentiated for diagnosis and treatment of disease. Hence, superior image contrast is important in the medical images (Sprawls, 2014). There are several methods to improve the image contrast in a digital image.

Contrast enhancement methods could be applied to images either in spatial domain or frequency domain. The spatial domain contrast enhancement process precisely manipulate the pixel values and in frequency domain, the pixels converted to frequency before contrast enhancement techniques applied to images (Roomi and Ganesan, 2015). MATLAB imaging software has a processing code for contrast adjustment. This approach upgrade the contrast value of image by adjusting the intensity of the pixel value and saturate the high and low pixel values to form an image with better contrast (Mittal, 2012).

The histogram equalization flattens and stretches the pixel values and provide uniform pixel distribution. This will provide image with improved contrast and structures in dark region will become more visible in the output image (Adam et al., 2015; Agarwal and Mahajan, 2018). Histogram equalization is a principal step in processing of image to enhance the contrast of the images. The histogram equalization is the simplest procedure to enhance the contrast of an image without altering the geometry of the image in the digital image processing using image processing software (Chen and Ramli, 2003).

Histogram equalization can be done in two ways. One is global histogram equalization (GHE) and the other is adaptive histogram equalization (AHE). Adaptive

method is histogram equalization conducted only on a selected region in an image. The main objective of this technique is to enhance contrast in specific region of the image without disrupting high contrasted area in the digital image. In the adaptive histogram equalization, each pixel is sorted to the intensity of the pixels in the surrounding area and these pixels are grouped together according to the assigned pixel intensity values. On the other hand, global histogram equalization conducts complete equalization in the digital images (Abdullah-Al-Wadud et al., 2007; Zhu and Huang, 2012).

Both equalization techniques are good to enhance image contrast. Global histogram equalization technique is superior compared to AHE due to shorter processing time. (Zhu and Huang, 2012). However, AHE technique is preferred histogram equalization method due to effective results in contrast enhancement. From previous studies, GHE method proven to over enhance images and also unnecessary brightness added to the output image (Agarwal et al., 2014).

Even though AHE method provide an image with enhanced contrast, this method too has a drawback. The AHE method has shown increase of noise in the output image in addition to degradation of the crucial image information (Agarwal et al., 2014). Many modified version of AHE method was researched and implemented to the digital images to enhance image contrast without additional noise in the output image. The conventional histogram equalization methods also compromise the light luminance of the output image. The brightness preserving bi-histogram equalization (BBHE) technique (Subramani and Veluchamy, 2018), has an advantage of brightness preservation in the output image. This method categorize the grayscale image into two different histograms. One part of image represents the intensity value lesser than the mean value, and the other sub image represents the intensity values more than the mean value. The BBHE is applied to both sub histograms to equalize both the sub histograms



independently. This will produce an output image with enhanced contrast, preserved image brightness and with no added noise (Tang and Isa, 2017). Histogram equalization techniques that has been researched in previous studies are given in Table 2.1.

Table 2.1: The various histogram equalization methods studied in previous studies.

Author Name and Year	Method	Theory and analysis	Remarks
Senthilku maran and Jayaraman (2014)	Brightness preserving Dynamic Histogram equalization (BPDHE)	Histogram of the image is first smoothed to the mean intensity of the image. Then, the BPDHE technique separates the histogram based on local maximum of the smoothed image.	Advantage: output image preserves the mean intensity of the input image, improves the contrast and has good brightness preservation compared to GHE, AHE and LHE
Yang et al. (2007)	Mean weighted Local Bi-Histogram Equalization	An algorithm for easy implementation of the local bi-histogram equalization (LBHE) is introduced. The size of mapping range is modified using the bilinear mapping instead of cumulative distribution function (CDF).	Advantage: Simpler algorithm and prevents over enhancement of output image as compared to the LBHE method.

Table 2.1 continued			
Author Name and Year	Method	Theory and analysis	Remarks
Agarwal et al. (2014)	Modified Histogram Based Contrast Enhancement Homomorphic Filtering (MH-FIL)	Two steps image contrast enhancement. It's the histogram modification. The second step is the homomorphic filtering.	Advantage: Provide good contrast improvement, preserves brightness and reduce unnecessary added noise to the output medical images.
Abdullah -Al- Wadud et al. (2007)	Dynamic Histogram Equalization (DHE)	Original histogram into few parts of histograms. Then a gray value is set to parts histogram equalized individually.	Advantage: good contrast enhancement with no brightness and noise added to the output image.
Chen and Ramli (2003)	Minimum Mean Brightness Error Bi-Histogram Equalization (MMBEBHE)	This is alike to the BBHE method but the separation of histograms are based on threshold value.	Advantage: Maximum level of brightness preservation and over enhancement on the image contrast.

### 2.4.3 Morphological Operation

Another image processing step in image enhancement is the morphological image processing. Morphological operations are useful in image enhancement properties such as image sharpening, noise reduction, edge detection and feature extraction. This operation is also known as non-linear filters. The morphological image processing operates as two sets of input image. One is the image need to be analyzed and another is the image element known as structuring element (strel) which will

conduct the morphological operation on the image. The structuring element shape is chosen from different geometrical shapes that is provided by image processing software. The shapes are square, circle, diamond cross and line (Rani et al., 2017)

Morphological image processing is conducted most commonly on binary images but it can also be operated with grayscale image. The most popular morphological operations in image processing can be categorized into four types. They are the dilation, erosion, opening and closing operations. Dilation process is the expansion of the size of object in image but reduces the diameter of holes in the image. Erosion operator on the other hand, erode the size of object in image and increase the diameter of holes in an image. Opening and closing morphological operations arises from the basic concept of erosion and dilation. Opening operation is the technique of applying erosion then applying the dilation process of the structuring element in the image. The closing operation is the inverse of the opening operation where, dilation operation then followed by erosion process (Fang et al., 2012; Kamil, 2015; Hassanpour et al., 2015)

In a research conducted by Kimori (2011), the author introduces a new image enhancement technique formulated on morphological operation that enhances the appearances of masses, lesions, tumours and different abnormalities usually exists in medical images. This method is a two steps method. The extraction of the target object in the medical image using morphology operation and the enhancement of the extracted object using two contrast enhancement method. The modified morphology operation used in this study is known as Rotational Morphological Processing (RMP). This method enables the image to rotate in respect to structuring element which is not possible in the classical morphological operation provided by image processing software. This method has proven to be able to enhance the target tissue without

disrupting the image quality of background tissue. This method also able to change the size and the shape of structuring element.

In another study by Mahmoud and Marshall (2008) morphological operations are used to sharpen the medical images. In the study, the morphological operations are applied to images after the gradient based edge detections and image thresholding are done on the images. By applying this edge detection techniques and morphological operation filters, the visibility of image is improved and thus provide better image sharpening and improve image contrast in the output image. This edge detected morphological filter has proven to provide images with improved sharpness and contrast compared to other image processing filters.

In a research conducted by Firoz et al. (2016), Bottom-Hat and Top-Hat morphological techniques were applied on several medical images using MATLAB software to improve the image contrast. The top-hat morphological operations function mainly to detect and enhance the contrast of objects or lesions from non-uniform background tissue. The Top-Hat operation is acquired by removing the opening of the input image from the same input image and Bottom-Hat transform is acquired by removing the input image from its closing. Various sizes of structuring element used in this study to achieve the superior contrast values in the medical images. The contrast of the medical images have improved using this top-hat morphological operations.

#### **2.4.4 Image Segmentation**

Segmentation is a principal segment in the processing of image stage. Segmentation is the technique of separation into various areas with non-overlapping of regions and the partitions are based on the pixel characteristics. Pixel intensities with similar characteristics are grouped together in segmentation process. The partition in segmentation process can be based on many criteria. But the basic of image

segmentation is based on pixel similarity and pixel discontinuity. All the segmentation types in image processing are based in these two types. The partition based on pixel similarity is where the pixel intensities with similar values are grouped together. The partition based on pixel discontinuity is where partition depending on sudden changes in pixel intensity between two regions such as at the edge of image (Manoharan, 2020).

Medical image segmentation can be classified based on the involvement of computer and human interaction in the analysis of the segmented images. These classifications are manual segmentation, semiautomatic segmentation, and fully automatic segmentation.

In manual segmentation, the region of interest (ROI) or the tumour volume is drawn or labelled manually by physicist or medical imaging technologists. The anatomical and diagnosis knowledge of the physicians are important in segmenting the medical images manually. This manual method is time consuming and have high chances of error while segmenting the images. The semiautomatic segmentation process has the involvement of both human and computer manipulation. The human observation and knowledge are used to evaluate the results of the image segmented using computer software. This method is the most preferred segmentation method in medical image analysis. The segmentation and analysis are all done by the computer system (Gordillo et al., 2013; Salman, 2009; Wadhwa et al., 2019). Other classifications of image segmentation approach are such as region based, boundary based, threshold, edge detection, modal based and pixel value based (Chaibou et al., 2017; Gordillo et al., 2013; Wadhwa et al., 2019). Most popular image segmentation techniques used in medical image processing are given in Figure 2.4. The segmentation techniques are thresholding method, watershed based techniques, edge detection