INVESTIGATION OF EDGE DETECTION TECHNIQUES BASED ON CORONARY ANGIOGRAPHY IMAGES

BASAIER JIALADE

UNIVERSITI SAINS MALAYSIA

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INVESTIGATION OF EDGE DETECTION TECHNIQUES BASED ON CORONARY ANGIOGRAPHY IMAGES

by

BASAIER JIALADE

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LIST OF ABBREVIATIONS

AHE	Adaptive Histogram Equalization
BPDHE	Brightness Preserving Dynamic Histogram Equalization
CLAHE	Contrast Limited Adaptive Histogram Equalization
CT	Computed Tomography
FSIM	Feature Similarity Index for Image Quality Assessment
GHE	Global Histogram Equalization
HE	Histogram Equalization
IDE	Integrated Development Environment
JPEG	Joint Photographic Experts Group
L2RAT	Ratio of the Squared Norm of the Signal
LHE	Local Histogram Equalization
LoG	Laplacian of Gaussian
MAXERR	Maximum Squared Error
MRI	Magnetic Resonance Imaging
MSE	Mean Square Error
PFOM	Pratt's Figure of Merit
PNSR	Peak Signal to Noise Ratio
REPS	Ratio of Edge Pixels to Size
RMSR	Root Mean Square Error
SSIM	Structural Similarity Based Image Quality Assessment

SUSAN	Smallest Univalue Segment Assimilating Nucleus
USG	Ultrasonography

PENYIASATAN SALURAN DARAH BERDASARKAN PENGESAN PINGGIR OBJEK TERHADAP IMEJ KORONARI ANGIOGRAFI

Abstrak

Kerapkali, imej perubatan X-ray yang berkualiti rendah disebabkan jumlah rasuk unjuran yang digunakan untuk membentuk imej tersebut adalah rendah. Rasuk unjuran minima digunakan untuk mengurangkan kerosakan kepada badan pesakit. Angiografi adalah kelas penting dalam pengimejan perubatan. Imej tersebut diperolehi dengan menggunakan teknik X-ray selepas ejen perbezaan disuntik ke dalam saluran darah pesakit. Angiografi koronari adalah sejenis imej angiografi yang kritikal dan ia boleh digunakan untuk mendiagnosis penyakit serius yang berkaitan jantung dan arteri. Walau bagaimanapun, kebanyakan imej angiografi mengalami masalah pencahayaan bukan seragam dan hingar yang menyebabkan doktor sukar membuat diagnosis yang tepat. Oleh, pemprosesan angiogram adalah diperlukan untuk menghasilkan imej yang lebih jelas untuk doktor menghasilkan diagnosis yang lebih tepat dalam masa yang lebih singkat. Dalam projek ini, pertamanya, angiogram dipertingkatkan menggunakan penyamaan histogram. Kemudian, lima teknik pengesanan pinggir termasuk Roberts cross, Prewitt, Sobel, Canny dan pembaikan algoritma Sobel telah dilaksanakan. Tujuan utama adalah untuk menghasilkan imej jelas menunjukkan garisan saluran darah dan operator Sobel didapati algoritma paling sesuai untuk menganalisa imej angiografi koronari berdasarkan penilaian kuantitatif dan kualitatif.

INVESTIGATION OF EDGE DETECTION TECHNIQUES BASED ON CORONARY ANGIOGRAPHY IMAGES

Abstract

Often, low quality medical X-ray images are produced due to the least possible amount of projection used to form the images. Minimum projection beams are used to reduce damage to patients' body. Angiography is an important class of medical imaging. The image is obtained using X-ray techniques after a contrast agent is injected into the patient's blood vessels. Coronary angiography is a critical type of angiography images and it could be used to diagnose serious heart and artery diseases. However, most angiography images suffer from non-uniform illumination and noises, which makes it difficult for doctors to make accurate diagnoses. Therefore, processing of angiograms is necessary to make them more visible thus help doctors to produce more accurate diagnoses in a shorter time. In this project, the angiogram is firstly enhanced using histogram equalization. Then five edge detection techniques including Roberts cross, Prewitt, Sobel, Canny, and a modified Sobel algorithm are implemented. The main aim is to clearly delineate edges of the blood vessels, and the Sobel operator is found to be the most suitable algorithm for analyzing coronary angiography images based on the quantitative and qualitative evaluations.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Medical imaging is the technique of creating visual representations of the inner side, and functions of certain tissues and organs of a patient's body. It is used to show up the internal structures covered by the bones and skin, so that doctors can check the health condition and treat the disease of the patient. Commonly used medical imaging techniques include radiography, magnetic resonance imaging (MRI), ultrasound, thermography, computed tomography (CT) and various techniques based on nuclear emissions (Zhu, 2004). Nowadays, medical images are the basis for doctors to diagnose and identify diseases. Thus, processing of medical images has become one of the most important areas in digital image processing.

Angiography, also known as arteriography, is a medical imaging technique used to produce angiograms. It is used to visualize the inside of blood vessels, mainly focused on veins, arteries, heart chambers and other organs of the body. It is usually done by injecting a contrast agent into the blood vessel and imaging is done using X-ray based techniques. The contrast agent is very necessary since the blood vessels are not clearly visible under normal X-rays. The main objective of angiography is to find out any blockages and narrowing of the blood vessels and how blood flow through them. Angiograms can help the doctors to identify several diseases affecting blood vessels, which include atherosclerosis, peripheral arterial disease, brain aneurysm, angina, pulmonary embolism, and blockage in blood supplies to kidneys. Several different types of angiograms are available for different parts of the human body. The common ones include coronary angiography (checks the heart and nearby blood vessels), renal angiography (checks blood vessels supplying the kidneys), pulmonary angiography (blood vessels supplying lungs), and cerebral angiography (checks blood vessels within and around the brain) (NHS, 2017).

Coronary angiography is a common procedure for patients who feel chest pain or experience sudden cardiac arrest. It could be used to find out the places of blood vessel blockages which is a very important step in the diagnosis, since blockages prevent the patient's heart from getting oxygen and other essential nutrients. Based on the result of the angiography test, the doctors could find out the reasons that cause the patient suffering and to plan the proper treatment for recovery (NHLBI, 2016). Coronary angiography is an important procedure for identification and diagnosis of coronary heart disease, which is a major cause of death in the world nowadays (caused 7.4 million of deaths in the year of 2012 globally (WHO, 2016)). However, the quality of angiogram images is usually of poor quality and low contrast due to non-uniform illumination problems and noises. This increases the difficulty for the doctors to observe the images clearly and hence may lead to inaccurate or even false diagnoses. Typical coronary angiography images are shown in Figure 1.1 and Figure 1.2 with the problem of uneven illumination and blurriness.

Figure 1.1 Coronary angiography image

Figure 1.2 Coronary angiography image (Lall, 2017)

1.2 Problem Statement

Many different types of diseases could be diagnosed by analyses of angiograms, so it is important for doctors to have a clear view of the angiography images within shortest possible time. In order to achieve this goal, clear details of the blood vessels should be obtained.

There have been several previous works conducted to obtain clearer blood vessel outlines from angiography images. However, there were some drawbacks. Sun et al. (2007) presented a morphological measurement based enhancement algorithm to improve the contrast of angiogram image, but the result indicated that there is no significant improvement as compared to the original image, as it is still blur with disappearance of some thin blood vessels. Yuan et al. (2011) used generalized fuzzy operator based enhancement method to highlight blood vessels in a cerebral aortogram image. The results were much better than Sun et al. (2007) in terms of the contrast of enhanced image. However, the vessels, which appeared thin and light in the original image, still are significantly distorted on the enhanced image, which increases the difficulties for doctors to visualize and to perform correct treatments. Kumarl and Amutha (2012) employed edge detection techniques on angiogram images, and good results were obtained, even though the resultant edge maps contained large amount of noise. Even though the noise did not affect the appearance of thick main vessels, but thinner blood vessels were corrupted by the noise and became hard to observe and identify. However, the effect of edge detection is more visually appealing than the enhanced low-contrast image.

Therefore, the most suitable edge detection technique for angiography image is required to be determined, to maximumly overcome those problems mentioned above. Thus image with clearer edges could be obtained so that doctors are able to give better evaluations and provide more accurate treatments.

1.3 Objectives

The objectives of this project are:

1. To study and evaluate existed and modified edge detection techniques
2. To determine the most suitable edge detection technique for coronary angiography images

1.4 Scope of Research

Different types of medical images are available nowadays for diagnosis, however, the coronary angiography images in the JPEG format will be the interest of this research. Among many algorithms for image contrast enhancement, histogram equalization technique will be used to improve the contrast of the angiogram image. It is chosen due to its simplicity and effectiveness for improving the contrast. In addition, five different edge detection techniques will be carried out on the contrast-enhanced angiography images, namely, Roberts cross operator, Prewitt operator, Sobel operator, Canny edge detector, together with a modified Sobel operator.

1.5 Thesis Outline

This thesis consists of five chapters. Chapter 1 is a about the introduction of the project, it discusses the background of the research as well as the motivation of the project. Apart from that, the problem statement listed out certain limitations from the previous works. In addition, objectives, and scope of the research are explained. And the outline of the thesis is provided.

Chapter 2 presents the literature review of the previous related studies. It begins with reviewing some image enhancement algorithms for medical image. Then the works on edge detection operators will be covered, it consists of modifications on Sobel operator as well as comparison of edge detection algorithms. Finally, the evaluation parameters used by previous researchers to analyze edge maps were reviewed to determine the parameters to be used in this project.

Chapter 3 discusses the methodology of this project. The overall flow and the software requirement of the project is presented. The mathematical equations and theories of the techniques and evaluation parameters used in this project will be explained in detail.

Chapter 4 is about the results and discussion, where the results obtained throughout this project are presented and the quantitative as well as qualitative analyses are carried out to help understand the significance of the results. Four coronary angiography images are used for testing and the summary of the analyses are provided at the end of the chapter.

Chapter 5 concludes the whole project, and the possible future improvements for the project are suggested.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

It is known that the quality of medical images, specially angiography images are always very low (Nasr et al., 2016; Felfelian et al., 2016; Tache, 2016). The main reason is that minimum amount of projection beam is used in the process of forming the image, so that the damage to the tissues is kept low. However, this minimizes the image contrast as well. Together with addition of varieties of noises, the problems of low contrast and intensity inhomogeneity become even worse. This chapter will begin with the discussion of contrast enhancement methods for medical images and some tested methods for enhancing angiography images. Then, various works of modifications and comparisons of edge detection operators will be reviewed. Lastly, the suitable evaluation parameters for the qualitative and quantitative analyses will be determined.

2.2 Medical Image Enhancement

Image enhancement is the process of improving the contrast and sharpness of a digital image so that the resultant image is better visualized or for further processing. For instance, noise removal, image sharpening, image brightening could all be classified as digital image enhancement. Some typical enhancement methods include filtering with morphological operators, linear contrast adjustment, unsharp mask filtering, and histogram equalization (MathWorks, 2017).

One of the most popular methods of image enhancement is histogram equalization. Its aim is to make the original histogram of the image to be as flat as possible. It is normally done in 4 steps (Umbaugh, 2005): (1) determine the running sum of the histogram values, (2) normalize the values by dividing number of pixels, (3) multiply values in (2) with maximum gray level value, (4) map the gray level values to the result.

In the field of medical image processing, MRI images had been studied very frequently. And histogram based techniques had been carried out by several researchers for enhancing MRI images. MRI is an advanced medical imaging technique that could be used to check the conditions of soft tissues and brains. A wide range of dangerous diseases like epilepsy, cancer and stroke disease could all be diagnosed based on MRI images of the patient. Figure 2.1 shows a MRI image of human brain.

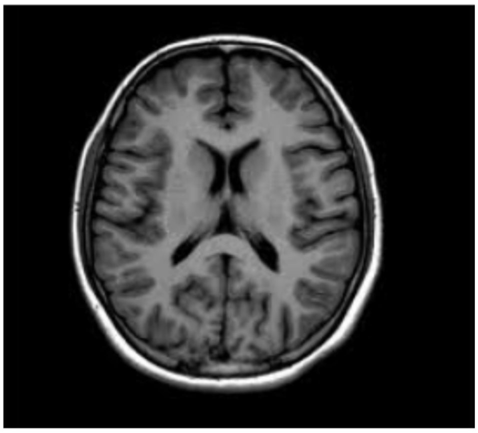


Figure 2.1 MRI brain image. (Senthilkumaran & Thimmiaraja, 2014)

Senthilkumaran and Thimmiaraja (2014) compared the performance of several image enhancement algorithms including Histogram Equalization (HE), Global Histogram Equalization (GHE), Local Histogram Equalization (LHE), Adaptive Histogram Equalization (AHE), and Brightness Preserving Dynamic Histogram Equalization (BPDHE) for MRI images. The resultant images of the study are shown in Figure 2.2.

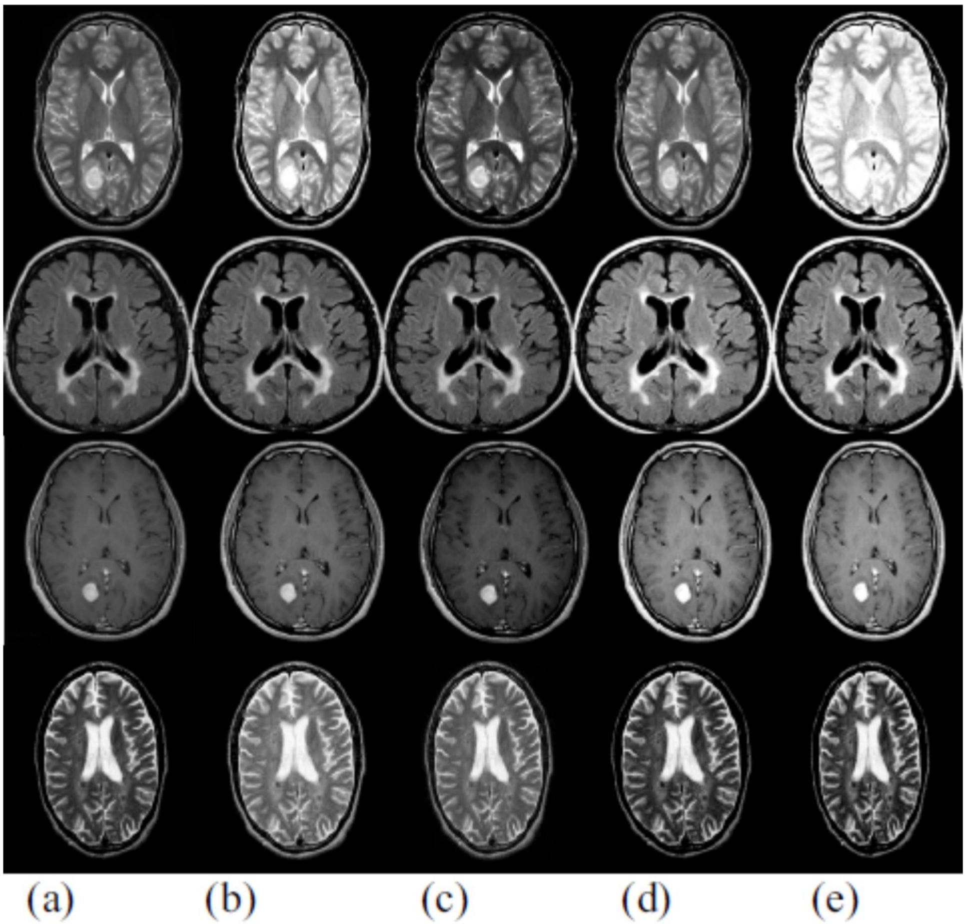


Figure 2.2 Resultant brain MRI images. (a) Original images, (b) Using GHE, (c) Using LHE, (d) Using AHE, (e) Using BPDHE. (Senthilkumaran & Thimmiaraja, 2014)

The resultant images indicated that the visual quality of all the algorithms used in this study did not make significant differences. However, the BPDHE algorithm produced best resultant image at the cost of more complicated algorithms.

Kaur and Rani (2016) included Contrast Limited Adaptive Histogram Equalization (CLAHE) into their comparisons. The results obtained is shown in Figure 2.3.

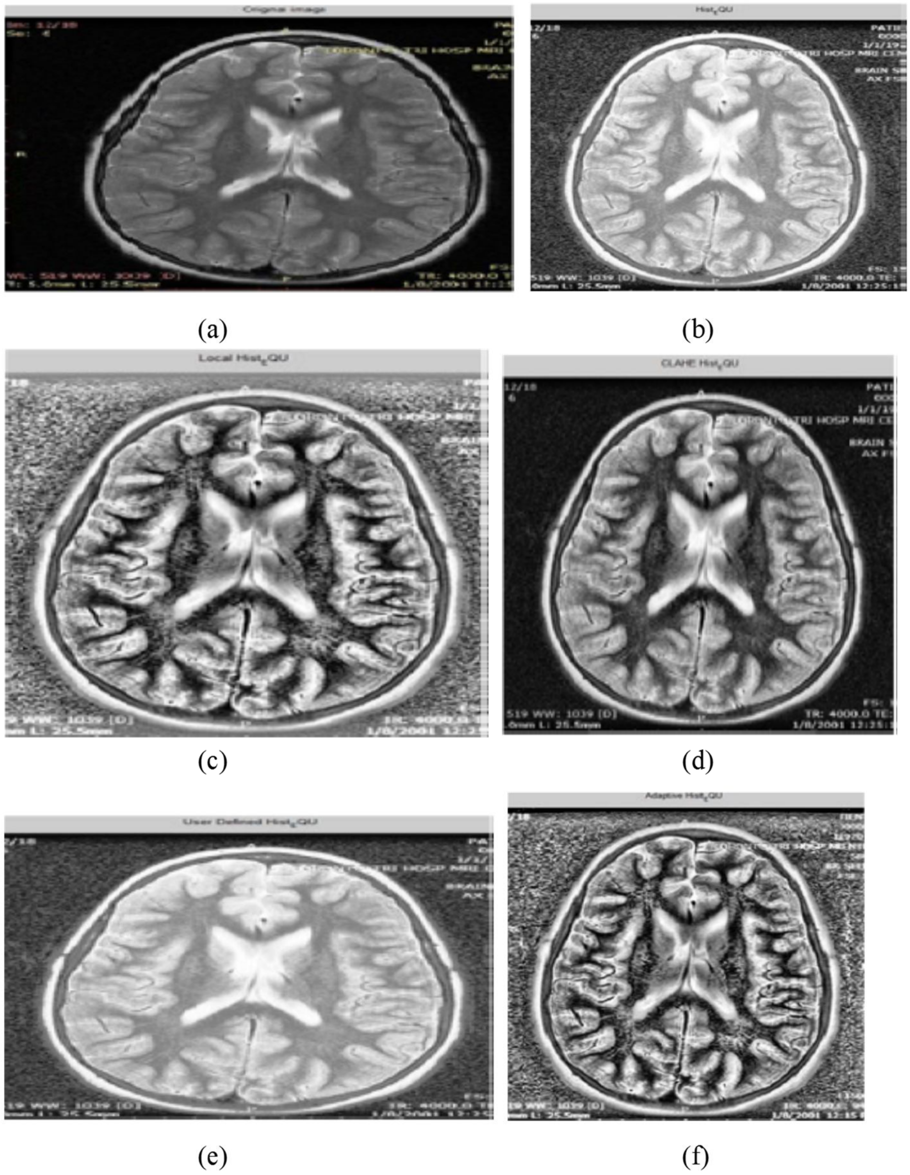
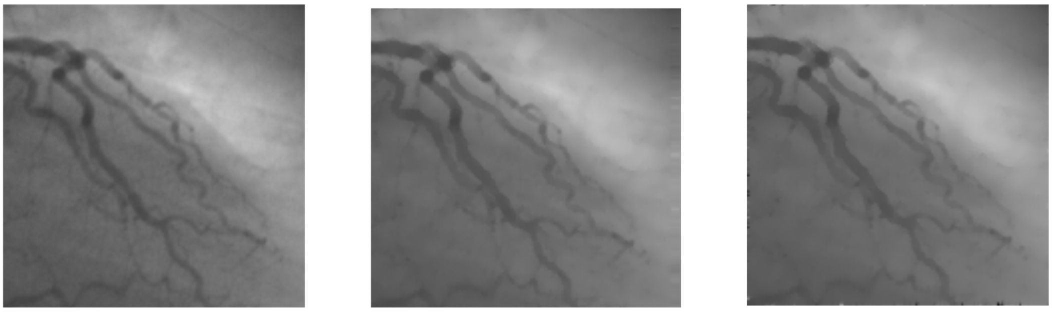


Figure 2.3 Resultant enhancement images. (a) Original image, (b) Using HE, (c) Using LHE, (d) Using CLAHE, (e) Using User Defined AHE, (f) Using AHE (Kaur & Rani, 2016)

The results show that CLAHE managed to produce clearer image than other methods but the running time and complexity are the major drawbacks.

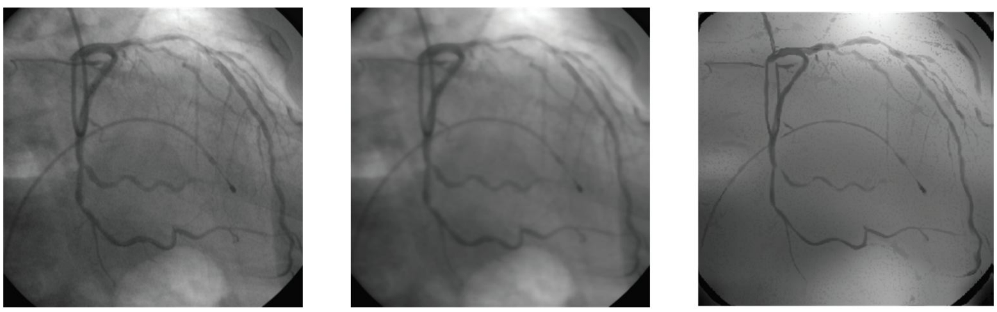
Several other enhancement techniques had been implemented based on angiography images. Sun et al. (2007) employed a nonlinear diffusion enhancement algorithm based on morphological measures. The results obtained are presented in Figure 2.4. It showed that some of the fine details were unclear or lost.



(a) (b) (c)

Figure 2.4 Results of nonlinear diffusion enhancement algorithm (a) Original image, (b) Result of proposed method after 5 iterations, (c) Result of proposed method after 10 iterations (Sun et al., 2007)

Chen et al. (2015) proposed an improved image enhancement method based on bilateral filter. The bilateral filter is a nonlinear filter based on Gaussian filtering algorithm. The classical bilateral filter is basically a low-pass Gaussian filter modified by spatial filter and intensity filter. The results in Figure 2.5 show that the improved bilateral filter produce better image with less distortion than the original bilateral filter. However, some of the thin blood vessels could not be seen clearly or disappeared.



(a) (b) (c)

Figure 2.5 Results of original and improved bilateral filter (a) Original image, (b) enhancement by original bilateral filter, (c) enhancement by improved bilateral filter (Chen et al., 2015)

After comparing several existing algorithms for image enhancement, Histogram Equalization is the technique chosen for this project due to its satisfactory ability of enhancing the image while keeping the running time short, and its simplicity for implementation.

2.3 Edge Detection

Edge detection is the most frequently used technique for segmenting the image based on changes in image continuity. Generally, there are three types of edges: step edge, ramp edge and roof edge. A step edge involves a transition between two intensity levels over a distance of 1 pixel in an ideal case. A ramp edge normally occurs in real images where blurring and noise are always seen. In this situation, the edge is no longer a thin path, but a connection of set of edge points contained in the ramp. While the roof edges are models of lines through a region. Roof edges normally occur in digitization of line drawings and satellite images (Gonzalez & Woods, 2002).

2.3.1 Modifications on Sobel operator

Traditional Sobel operator detects two types of edges: horizontal edges, and vertical edges. Edges are calculated by using the difference between corresponding pixel intensities in an image. 2 sets of 3×3 matrix masks are used to detect edges (Gonzalez & Woods, 2002). However, the original Sobel kernels could only detect the edges in horizontal and vertical directions, making it not very efficient in finding the edges of more complicated images. Therefore, many improved or modified versions of Sobel masks were introduced by the researchers to improve the resultant edge maps.

Deng et al. (2011) introduced an edge detection approach using image fusion based on improved Sobel operator, where two different kernels were used for morphological filtering before application of Sobel operator. The two kernels used had a size of 3×3 and 5×5 respectively as shown in Figure 2.6. It was suggested that kernel *S1* has a small structure, making it weak in denoising but preserves the details of the image. The larger diamond shaped kernel *S2* would have stronger ability of denoising while many useful details could be smoothed out. So the combination would produce a good trade-off between denoising as well as keeping the details of the image.

$$S1 = \begin{pmatrix} 0 & 1 & 0 \\ 1 & 1 & 1 \\ 0 & 1 & 0 \end{pmatrix} \quad S2 = \begin{pmatrix} 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{pmatrix}$$

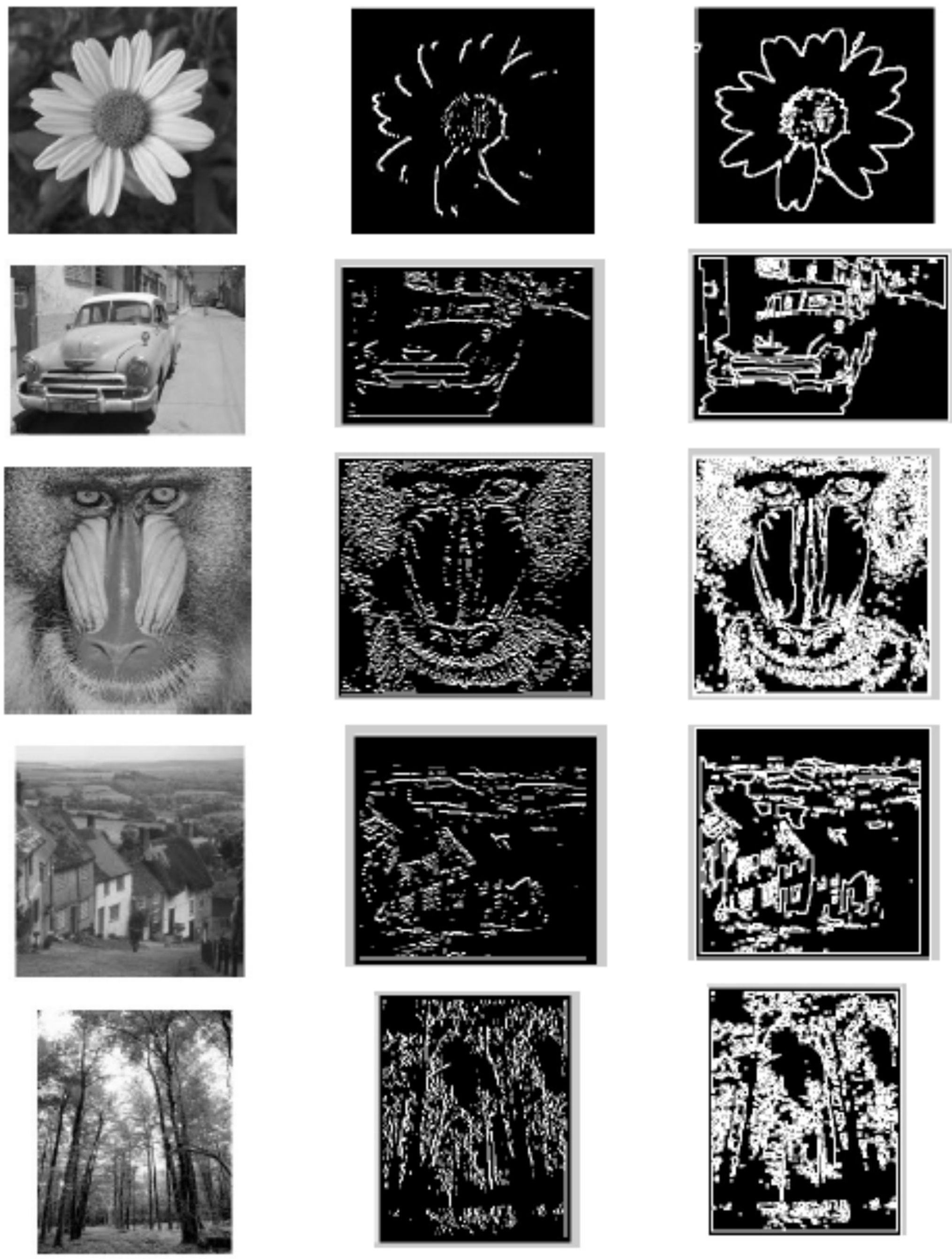
Figure 2.6 Open and close morphological filter used by Deng et al. (Deng et al., 2011)

Gupta and Mazumdar (2013) demonstrated the modified Sobel kernels made up of 2 sets of 5×5 masks. The suggested masks are shown in Figure 2.7. The results provided in Figure 2.8 indicated that this modified Sobel operator produced edge maps with more details as compared to the original Sobel operator, although it is visually noticeable that this modified operator produced more noise as well.

-5	-4	0	4	5
-8	-10	0	10	8
-10	-20	0	20	10
-8	-10	0	10	8
-5	-4	0	4	5

5	8	10	8	5
4	10	20	10	4
0	0	0	0	0
-4	-10	-20	-10	-4
-5	-8	-10	-8	-5

Figure 2.7 Modified Sobel masks suggested by Gupta & Mazumdar (Gupta & Mazumdar, 2011)



(a) **(b)** **(c)**

Figure 2.8 Results obtained by Gupta. (a) Original images, (b) Edge maps by original Sobel operator, (c) Edge maps by modified Sobel operator (Gupta & Mazumdar, 2011)

While back in 2009, Zhang proposed a new edge detection method. The method is based on the improved Sobel operator and genetic algorithms. In order to make the edge points more accurately describe the image and to reduce noise level, 5×5 masks in four directions were used (x-direction, y-direction, 45 degrees, and 135 degrees). The masks used for the improved Sobel operator is shown in Figure 2.9.

$$T_x = \begin{bmatrix} 2 & 3 & 0 & -3 & -2 \\ 3 & 4 & 0 & -4 & -3 \\ 6 & 6 & 0 & -6 & -6 \\ 3 & 4 & 0 & -4 & -3 \\ 2 & 3 & 0 & -3 & -2 \end{bmatrix} \quad T_y = \begin{bmatrix} 2 & 3 & 6 & 3 & 2 \\ 3 & 4 & 6 & 4 & 3 \\ 0 & 0 & 0 & 0 & 0 \\ -3 & -4 & -6 & -4 & -3 \\ -2 & -3 & -6 & -3 & -2 \end{bmatrix}$$

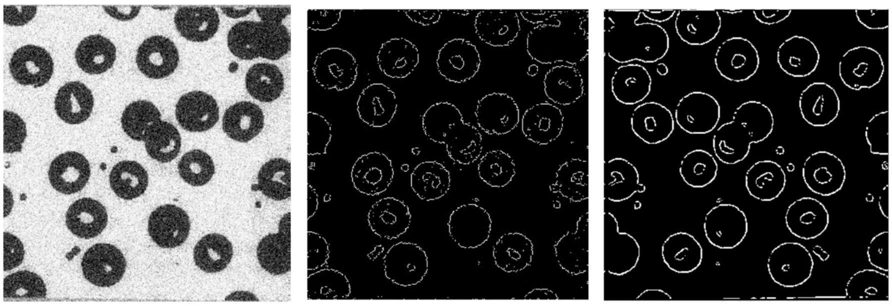
$$T_{45} = \begin{bmatrix} 0 & -2 & -3 & -2 & -6 \\ 2 & 0 & -4 & -6 & -2 \\ 3 & 4 & 0 & -4 & -3 \\ 2 & 6 & 4 & 0 & -2 \\ 6 & 2 & 3 & 2 & 0 \end{bmatrix} \quad T_{135} = \begin{bmatrix} -6 & -2 & -3 & -2 & 0 \\ -2 & -6 & -4 & 0 & 2 \\ -3 & -4 & 0 & 4 & 2 \\ -2 & 0 & 4 & 6 & 2 \\ 0 & 2 & 3 & 2 & 6 \end{bmatrix}$$

Figure 2.9 Improved Sobel operator used by Zhang et al. (Zhang et al., 2009)

After edge points were obtained, a genetic algorithm was used to further process the edge maps. The results shown in Figure 2.10 and Figure 2.11 indicated that this method produce better edge images than the original Sobel operator.

(a) (b) (c)

Figure 2.10 Result of rice image. (a) Original image, (b) Sobel detection, (c) New detection (Zhang et al., 2009)



(a) (b) (c)

Figure 2.11 Result of cell image. (a) Original image, (b) Sobel detection, (c) New detection. (Zhang et al., 2009)

Chawlal and Jain (2015) proposed a set of new diamond-structured 5×5 Sobel masks. The proposed masks are shown in Figure 2.12. G_x and G_y is the proposed horizontal and vertical mask respectively. And the overall improved Sobel mask is made by addition of the two masks (G_x+G_y). It was mentioned that the improved mask has fewer values than the original Sobel operator, which would result in shorter computational time and less power consumption at architectural level.

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

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

Figure 2.12 Proposed improved Sobel mask by Chawlal (Chawlal & Jain, 2015)

As a result, three parameters were used to evaluate the proposed method, which are PSNR (Peak Signal to Noise Ratio), SSIM (Structural-Similarity-Based Image Quality

Assessment), and FSIM (Feature Similarity Index for Image Quality Assessment). The author claimed that this improved Sobel operator show better performance as compared to the original Sobel operator.

Since only two directions of templates are used in the Sobel operator, it can only detect edges of two (horizontal and vertical) directions, which makes it not suitable to detect edges of more complicated images as mentioned previously. Hence, addition of two more 3×3 masks in the direction of 45 degrees and 135 degrees were done by Zhang and Fang (2016). The kernels used are shown in Figure 2.13.

$$\begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix} \qquad \begin{bmatrix} -2 & -1 & 0 \\ -1 & 0 & 1 \\ 0 & 1 & 2 \end{bmatrix}$$

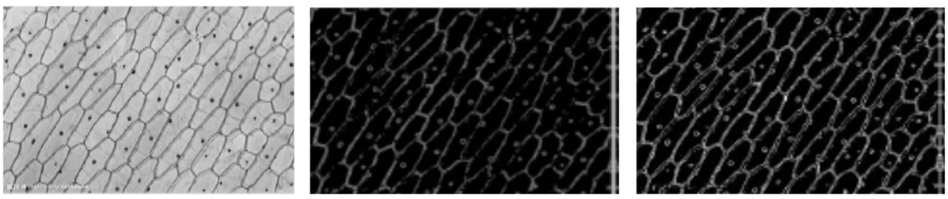
horizontal direction   45 degree direction

$$\begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \qquad \begin{bmatrix} 0 & 1 & 2 \\ -1 & 0 & 1 \\ -2 & -1 & 0 \end{bmatrix}$$

vertical direction   135 degree direction

Figure 2.13 Improved Sobel kernels used by Zhang and Fang (2016)

And this improved operator is then able to detect edges from 4 directions, which yielded better result than traditional Sobel operator and extracted more edge information without significantly increasing the computational time. The results obtained are shown in Figure 2.14 and Figure 2.15.



(a) (b) (c)

Figure 2.14 Result of cell image. (a) Original image, (b) Original Sobel operator, (c) Improved Sobel operator (Zhang & Fang, 2016)

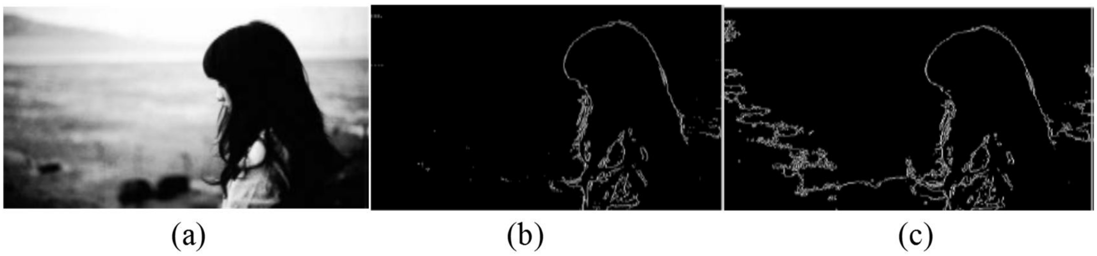


Figure 2.15 Result of person image. (a) Original image, (b) Original Sobel operator, (c) Improved Sobel operator (Zhang & Fang, 2016)

2.3.2 Comparisons of edge detection operators

Commonly used edge detection techniques include Prewitt, Roberts, Sobel, Canny and Laplacian operators. Several previous works on comparing and analyzing these techniques will be reviewed in this section.

Juneja and Sandhu (2009) presented a comparative study on various image edge detection techniques. Quantitative and qualitative analyses were carried out base on Prewitt, Roberts, Sobel, Canny and Laplacian of Gaussian operators. According to the results shown in Figure 2.16, it was concluded that Prewitt, Roberts and Sobel produce low-quality edge maps, while Canny operator had the best performance.

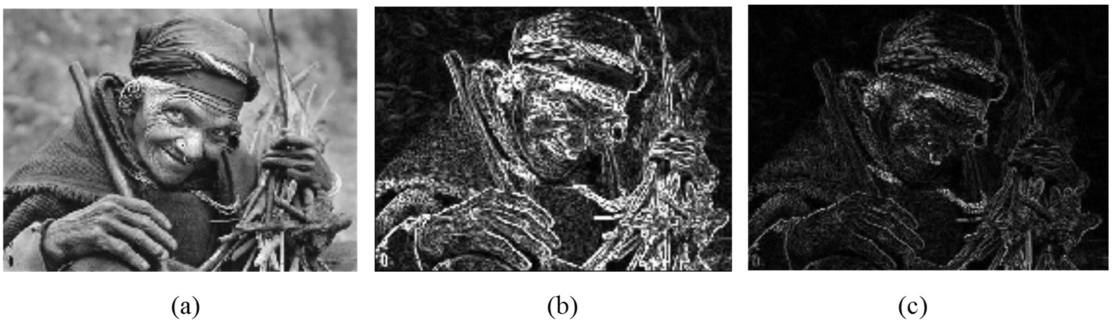
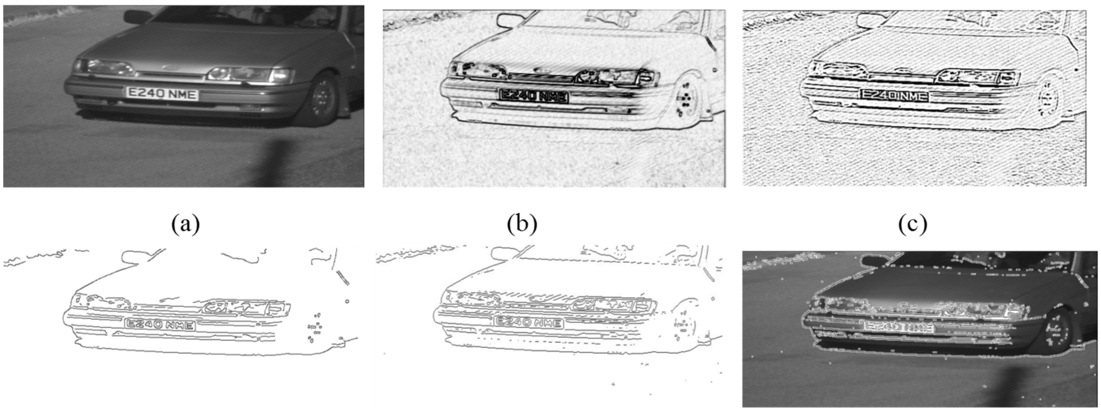


Figure 2.16 Comparison of edge detection operators by Juneja & Sandhu. (a) Original image, (b)Prewitt operator, (c) Roberts operator, (d) Sobel operator, (e) Laplacian of Gaussian operator, (f) Canny operator (Juneja & Sandhu, 2009)

(d) (e) (f)

Figure 2.16 Continued

Musoromy et al. (2010) compared the effects of Canny, Kirsch, Rothwell, Sobel, Laplace and SUSAN edge detection operators based on car plate images. The results obtained indicated that Canny produced the most accurate results among all tested algorithms, but it took longer time as compared to other methods which made it not very suitable for real-time applications. The edge maps are shown in Figure 2.17.

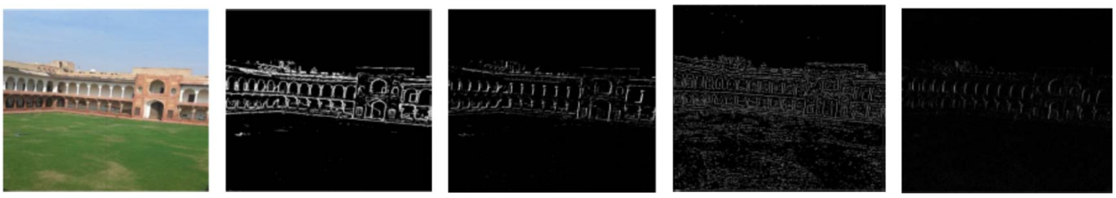


(a) (b) (c)

(d) (e) (f)

Figure 2.17 Comparison of edge detection operators by Musoromy. (a) Original image, (b) Sobel edge, (c) Laplace edge, (d) Canny edge, (e) Rothwell edge, (f) SUSAN edge (Musoromy et al., 2010)

Jose et al. (2014) did a performance study of edge detection operators including Prewitt, Roberts, Sobel and Canny operators. Apart from visual observations, the quantitative parameters like PSNR, MSE, MAXERR, L2RAT were included for analysis. The authors claimed that the conditions of the image would affect the performance of respective operators, but Canny gave the most satisfactory result based on the experiments performed. The results are demonstrated in Figure 2.18 and Table 2.1.



(a) (b) (c) (d) (e)

Figure 2.18 Comparison of edge detection operators by Jose on a building. (a) Original image, (b) Sobel, (c) Prewitt, (d) Canny, (e) Roberts (Jose et al., 2014)

Table 2.1 Quantitative parameters for the building image (Jose et al., 2014)

Edge Detection Operators	PSNR(dB)	MSE	MAXERR	L2RAT	Processing time (ms)
Sobel	6.2890	1.527×10^4	255	4.5729	265
Prewitt	4.8980	2.105×10^4	255	0.0443	215
Canny	4.9068	2.100×10^4	255	6.9625×10^{-6}	730
Roberts	5.0634	2.026×10^4	255	0.0090	182

Öztürk and Akdemir (2015) compared various edge detection techniques for texture analysis on glass production. This study involved five different algorithms including Prewitt, Roberts, Sobel, Laplacian of Gaussian and Canny operators respectively. The object being studied were glass images, they were first preprocessed to remove the salt and pepper noise. It was determined that the Laplacian of Gaussian (LoG) algorithm produced the best result among all operators. The results obtained in the study are shown in Figure 2.19.

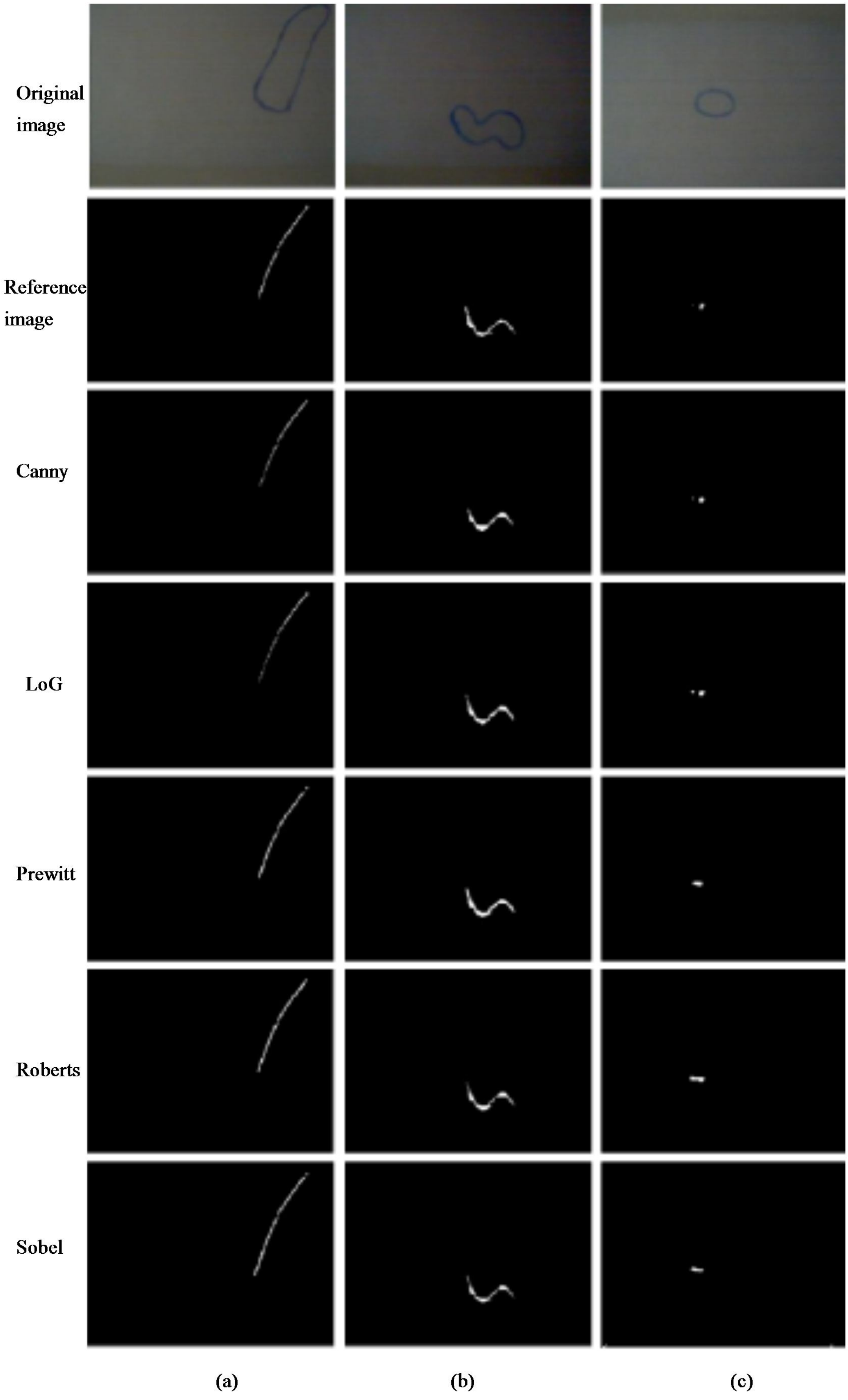
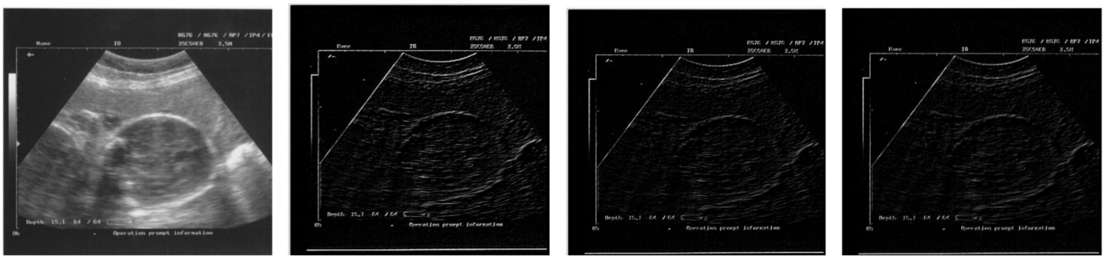


Figure 2.19 Results from Öztürk based on three glass images (Öztürk & Akdemir, 2016)

Khairudin and Irmawati (2016) did a study on comparing Prewitt, Sobel and Canny edge detection operators on ultrasonography (USG) images. MSE and PSNR are the parameters being used for quantitative analyses. As a result, the Sobel algorithm managed to produce the best edge maps with more details displayed. The results are shown in Figure 2.20.



(a) (b) (c) (d)

Figure 2.20 Comparison of edge detection operators by Khairudin & Irmawati. (a) Original image, (b) Sobel operator, (c) Prewitt operator, (d) Canny operator (Khairudin & Irmawati, 2016)

It could be seen from the previous works that different operators were suitable for images of different conditions and types. And medical images were not the objects to be tested until the very recent work of Khairudin and Irmawati (2016). So more woks could be done based on medical images.

2.4 Evaluation Parameters

A widely-used parameter for evaluating edge map is Pratt's figure of merit (PFOM). To apply this evaluation procedure, the reference edge map, or ground truth edge map is required. The two edge maps (obtained edge map and ground truth) will be compared, and the value of PFOM equals to one if the two maps are identical (Hameed & Wang, 2011). However, the ground truth images are never available for medical images, so subjective evaluation by medical doctors and experts are very common. But human errors and biases could not be completely eliminated, and the cost in terms of time and resources would be high (Panetta et al., 2014).

Hence, five parameters will be used for evaluating the quality of the resultant edge map. Four quantitative parameters include: (1) Mean square error (MSE), which is a very important parameter in statistics to measure the average of the square of the errors, it is used to calculate the difference between edge detection operators in this project. (2) Root mean square error (RMSE), which is used to measure the differences between values. (3) Peak signal to noise ratio (PNSR), it is a ratio between the signal power and the noise power, the higher the value of the PNSR, the better the quality of the image. (4) the computational time, which measures the time taken to run the software program. While the qualitative aspect is the visual effect of the resulting images.

2.5 Summary

In this chapter, several image enhancement methods based on medical images (MRI, angiograms) were presented in order to determine the method to be used for this project. Then, previous works on modifying and improving the original Sobel edge operator were reviewed. It was found that the modified Sobel operator could potentially produce better edge maps than the original Sobel operator. Furthermore, several previous works on comparing existed edge detection algorithms were looked at. Operators like Prewitt, Roberts, Sobel and Canny were extensively used to determine the edges for different types of images and different results were achieved. Lastly, the evaluation parameters to be used to analyze the results for this project were determined based on the experience of previous researches.