Performance Observation of Gabor Filter for Wall Thickness Measurement of Human Colon Based on Ultrasound Image

C. Pahl, J. Lam, H. N. Abduljabbar, E. Supriyanto, and Y. M. Myint

***Abstract*—Ultrasound-based imaging technique becomes a promising way to acquire normal or abnormal condition of most human organ since it provides several advantages compared to other imaging modalities. This study used ultrasound imaging modality to acquire colon images and determine the wall-thickness of the colon. Wall thickness is important parameters for evaluating the condition of colon, especially for the people with irritable bowel condition. Three different parts of colon were scanned during this study; ascending part, transverse part and descending part. Manual measurement of cross-sectional area and wall-thickness of colon was done by the radiologist during image acquisition process. In order to obtain clear image and ensure measurement accuracy, several steps of image processing; pre-processing, filtering, cropping, and textural segmenting were done. The results showed that the result from the measurement after image processing relatively closed to that of the manual, with the value of standard deviation of 0.02. The output from this study can be used for further study in assessment of various colon diseases that based on the cross-sectional area and the wall thickness of the colon like inflammatory bowel disease (IBD).**

***Index Terms*—Colon, irritable bowel disease, non-invasive, wall-thickness and cross-sectional area, ultrasound image processing.**

I. Introduction

Ultrasound imaging machine is a non-invasive, non-ionizing, and less expensive medical diagnostic tool that can be used to produce images of internal organs or tissues. It uses echoes concept where the transducer transmits the high frequency sound wave and receives it back as a signal [1]. Measurement of colon cross-sectional area and wall thickness can be done using ultrasound imaging technique. Analysis on the colon cross-sectional area and wall-thickness is able to detect the abnormalities of the colon especially for the bowel irritation. Based on previous studies, normal colon wall thickness and its diameter are in the range less than 4mm and 6cm respectively, Colon that exceeds the normal ranges will be diagnosed as abnormal and can be further classified as colon-related diseases [2].

The colon also known as the large intestine which has length of 1.5m to 1.8m as shown in Fig. 1. The colon structures are divided into four parts; the ascending colon that travels up to the right side of the abdomen, the transverse colon that runs across the abdomen, the descending colon that travels down the left abdomen and the sigmoid colon that is a short curving just before the rectum [3]. The colon wall can be divided into five distinct layers which are mucosa, submucosa, muscle, subserosa and serosa.

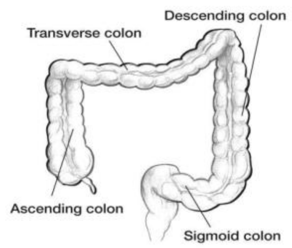


Fig. 1. Anatomical view of the colon.

Major abnormality that occurs in the colon is the inflammatory bowel disease (IBD). IBD is a chronic inflammatory of the intestinal tract which commonly affects the children. Two major phenotypes of IBD are Crohn's disease (CD) and Ulcerative colitis (UC). These diseases can be easily mistaken because both have similar symptoms and treatments [4]-[7]. Crohn's disease is an inflammation of any part of gastrointestinal (GI) tract, where the end part of small intestine is the most affected, whereas ulcerative colitis (UC) is the inflammation and ulcer in the lining of the colon [8]. Abdominal pain, diarrhea, fever, weight loss, vomiting and dehydration may indicate the symptom of Crohn's disease and also ulcerative colitis [9]-[10].

Colon wall thickness measurement has important roles in determining the IBD. Table I shows the value of colon wall thickness in normal range for ascending colon, transverse colon and descending colon wall [11]. The main differences ultrasound features of Crohn's disease and Ulcerative colitis are shown in Table II [12].

TABLE I: Normal Range Value for Ascending Colon, Transverse Colon, and Descending Colon's Wall within 20-29 Years Old

Parameter	Ascending part	Transverse part	Descending part
Thickness	0.9 ±0.1	1.4 ±0.2	1.5 ±0.3
Length	0.9-2.0	1.0-1.8	0.8-2.0
Diameter	1.0 ±0.5	2.0 ±0.5	3.0 ±0.5

TABLE II: Ultrasound Difference Features of Crohn's Diseases and Ulcerative Colitis

Features	Crohn's disease	Ulcerative colitis
Bowel wall thickening	5-14mm	5-7mm
Location and extension	Ileum (70%) Colon (60%)	Recto sigmoid tract and colon

Manuscript received October 20, 2013; revised December 20, 2013.
The authors are with Diagnostics Research Group, Universiti Teknologi Malaysia, 81310 Skudai Johor and Ilmenau University of Technology in Germany (e-mail: pahl.christina@gmail.com, jostinah.lam@gmail.com, heamn_jabbari@yahoo.com, eko@utm.my).

DOI: 10.7763/IJIEE.2014.V4.429

In order to reach the main theme of wall thickness measurement, we study texture that applied to Ultrasound colon images. The time-frequency transformed based method of texture discrimination, which is in turn based on Gabor filter is done. In Gabor transform, a signal can be represented in terms of sinusoids that are modulated by translated Gaussian windows. The resulting time frequency decomposition is a suite of local Fourier transforms which displays any non-stationary spectral trends.

Medical ultrasound images are poor in contrast along with strong speckle noise. Hence, traditional image segmentation methods fail to segment the ultrasound images satisfactory. So, this paper addresses to obtain the proper Gabor filter to segment the colon wall from ultrasound image.

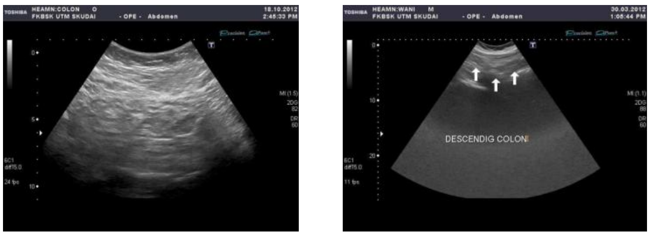
II. Methology

The overall processes involved in this study were data collection, image processing, region based segmentation, colon wall thickness measurement, and data analysis.

A. Data Collection

Ultrasounds scanning of 8 subjects (22 – 23 years old) were obtained using Ultrasound Machine (TOSHIBA Aplio MX). Two transabdominal transducers with h frequency 3.5

MHz and 7MHz were used to scan the subject. All data are recorded by registered diagnostic medical sonographer. Ultrasound images of colon were scanned into three different parts; ascending, transverse, and descending parts. The wall thickness from the colon was measured directly using ultrasound. The comparison of image quality scanned with two types of transducers can be observed in Fig. 2. According to this illustration in Fig. 2, it can be determined that colon is clearer in the ultrasound image using higher frequency probe shown in Fig. 2 (b), although it is noisy with textural features when compared to Fig. 2 (a) where the colon is barely recognized.



(a) (b)

Fig. 2. (a) Ultrasound image of colon wall using 7MHz transducer. (b) Ultrasound image of colon wall using, 3.5MHz transducer.

B. Proposed Method

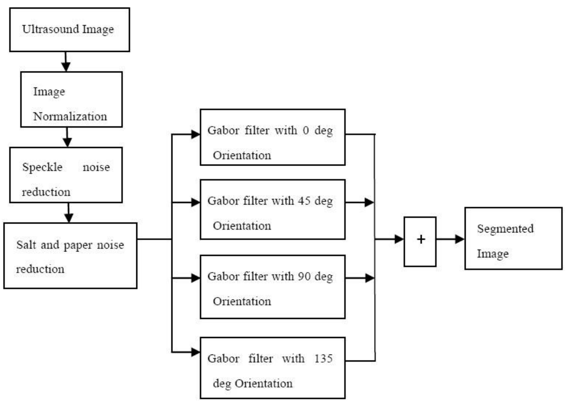
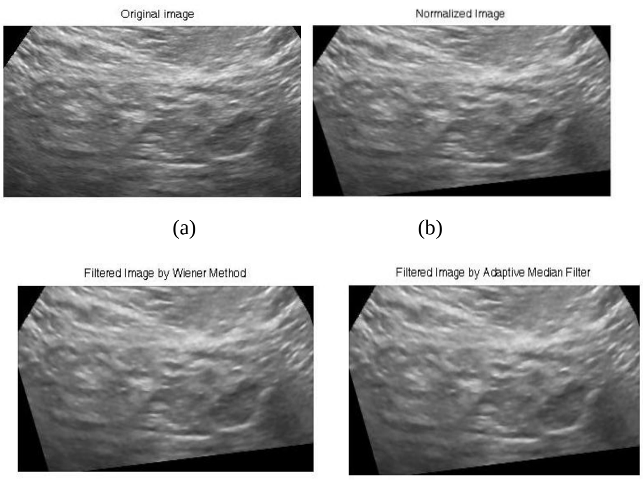


Fig. 3. The proposed algorithm to process the colon ultrasound image.

This paper addresses on exploitation the concept of texture segmentation to define the boundary of colon wall in ultrasound images in order to analyze the colon wall thickness. Gabor filtering method is proposed to extract the colon wall. Fig. 3 shows the proposed algorithm to process the colon ultrasound image.

Because of the low contrast and speckle noise affects, the images are needed to be pre-processed to improve the image quality. Wiener filter is proposed to eliminate the speckle noise and median filter is also used for noise removal. Then the enhanced image is filtered by four Gabor filters. Outputs from each Gabor filter are finally combined to get the segmented colon image. Then the measuring process is conducted.

C. Image Enhancement



(c) (d)

Fig. 4. (a) Original image. (b) Normalized image (c). Image after speckle noise reduction by wiener filter. (d).Output image from adaptive median filter.

The colon ultrasound original images shown in Fig. 4 (a) have strong speckle noise and the complicated textural structure. The first step for pre- processing the image is normalization and the normalized image is shown in Fig. 4 (b). 2D adaptive noise removal and median filtering are used to remove the noise existing in colon images. 2D adaptive noise removal is a lowpass filter applied on gray scale images. The pixel wise adaptive wiener method with a local neighborhood of size 3 by 3 for each pixel is used in our approach. The enhanced image after speckle noise removal is shown in Fig. 4(c). To remove salt and pepper noise, the adaptive median filter is used. Median filter is a nonlinear operator which effectively eliminates the noise and keeps edges. Each output pixel contains the median value of p by q neighborhood around the corresponding pixel of the input image. Here, we use 9 by 9 neighborhood kernel for median filter. Fig. 4 (d) illustrates removal of salt and pepper noise.

D. Wiener Filter

It executes an optimal trade-off between inverse filtering and noise smoothing. The inverse filtering is a restoration technique for deconvolution. When the image is blurred by a known lowpass filter, recover the image by inverse filtering or generalized inverse filtering. This filter removes the additive noise and inverts the blurring simultaneously. The Wiener filter minimizes the overall mean square error in the process of inverse filtering and noise smoothing. The Wiener filter can be expressed as in (1).

$$W(f_1, f_2) = \frac{H^*(f_1 f_2) S_{xx}(f_1 f_2)}{|H(f_1 f_2)|^2 S_{xx}(f_1 f_2) + S_{yy}(f_1 f_2)} \quad (1)$$

H(f_1, f_2) represents the blurring filter and $S_{xx}(f_1, f_2)$ and $S_{yy}(f_1, f_2)$ are power spectra of the original image and the additive noise.

E. Adaptive Median Filter

These kinds of filters smooth the data while keeping the small and sharp details. Median filtering is very effective at removing various kinds of noise. It is especially effective for removing impulse noise which is characterized by bright and/or dark high-frequency features appearing randomly over the image. Statistically, impulse noise falls well outside the peak of the distribution of any given pixel neighborhood, so the median is well suited to learn where impulse noise is not present, and hence to remove it by exclusion. The median of a distribution is the value for which larger and smaller values are equally probable. To calculate the median of a list of sample values, we sort them in a descending or ascending order, and then select the central value. An example of applying a median filter is a kind of nonlinear filter and a subset of so-called order statistics filter. Example calculation of median value is depicted as follows:

123	125	126	130	140
122	124	126	127	135
118	120	150	125	134
119	115	119	123	133
111	116	110	120	130

Neighbourhood Values : 124, 126, 127, 125, 123, 119, 115, 120, 124, 150
Median Value : 124

F. Adaptive Median Filter

Gabor filter is used for edge detection and extraction of texture features. An application of Gabor filters is in local time-frequency analysis of signals, specifically, a fixed windowed Fourier transform, referred to as the Gabor transform. A difficulty with the Gabor transform is that it is linearly independent but highly nonorthogonal and as such cannot be easily inverted. Gabor filtering implements one or multiple convolutions of an input image with a two-dimensional Gabor function in (2).

$$G\lambda, \emptyset, \varphi, \sigma, \gamma(x, y) = \exp\left(-\frac{x^2 + \gamma^2 y^2}{2\sigma^2}\right) cos(2\pi \frac{x'}{\lambda} + \varphi)$$

$$x' = x \cos\theta + y \sin\theta$$

$$y' = -x \sin\theta + y \cos\theta \quad (2)$$

The Gabor function for the specified values of the parameters wavelength (λ), orientation (θ), phase offset (φ), aspect ratio (γ), and bandwidth (b) can be calculated from (3).

$$b = log_e \frac{\frac{\sigma}{\lambda} + \sqrt{\frac{ln2}{2}}}{\frac{\sigma}{\lambda}\pi - \sqrt{\frac{ln2'}{2}}}$$

$$\frac{\sigma}{\lambda} = \frac{1}{\pi}\sqrt{\frac{ln2}{2}}\frac{2^b + 1}{2^b - 1} \quad (3)$$

where $\sigma = 0.56\lambda$

As shown in Fig. 2 quality of ultrasound colon images are not adequate for automated segmentation and measurement. And automatic segmentation of medical images becomes a challenging to biomedical engineers.

On the purpose to overcome this condition, this paper addresses to observe the performance of Gabor filter. The colon images, here, are tested with four Gabor filters with different orientations. Gabor filter parameters are set to the values of $\gamma = 0.6$, $\lambda = 10$ *and* $\varphi = 0$. Gabor filtering applies through different orientation of 0°, 45°, 90° and 135°. The images of Gabor filter kernal with the orientations of 0°, 45°, 90° and 135° can be seen respectively in Fig. 5 (a), Fig. 5 (b), Fig. 5 (c) and Fig. 5 (d). θ is the parameter that specifies the orientation of the normal to the parallel stripes of a Gabor function.

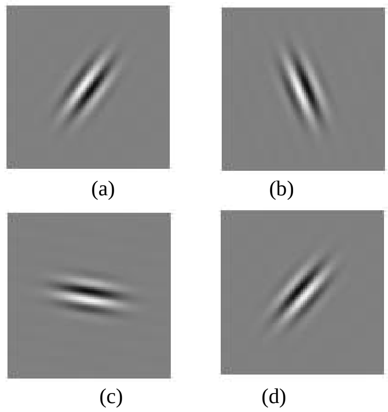


Fig. 5. Gabour filter kernel images with orientation (a).0 deg, (b) 45 deg, (c) 90 deg and (d) 135 deg.

G. Colon Wall Thickness Measurement

The colon wall thickness measurement was obtained from two different methods. The first measurement was taken during data collection step. The measurement was taken five times at particular colon wall segment. The overall data was divided into three main colon parts. Secondly, the measurement was obtained using MATLAB application.

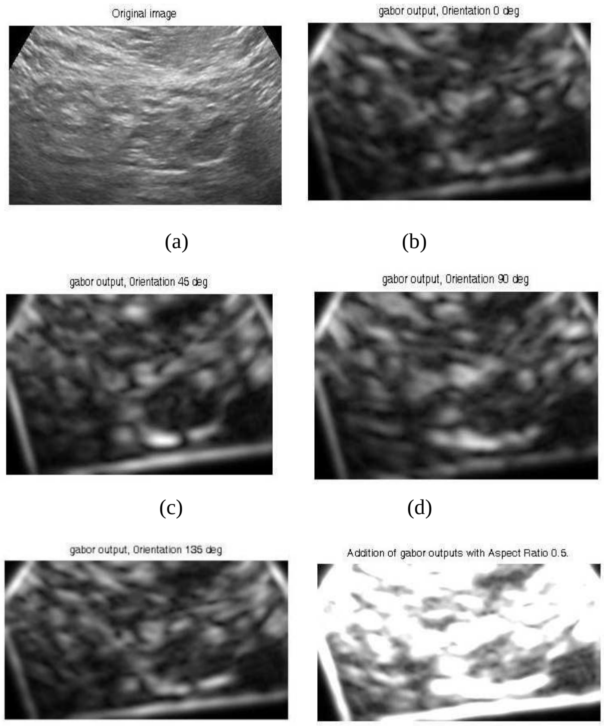
H. Data Analysis

The data analysis was performed using SPSS analysis tool software. The mean and standard deviation of each set data were calculated. Pearson correlation coefficients (r) were computed in order to compare the measurement data before and after the image processing.

The positive output obtained indicated that there was a positive relationship between the variables, whereas the negative output indicated no relationship or inverse association between variables.

III. Results and Discussions

The measurement data will be compared based on mean and standard deviation values. The measurement differences of colon wall thickness before and after processing will be discussed.



(a) (b)

(c) (d)

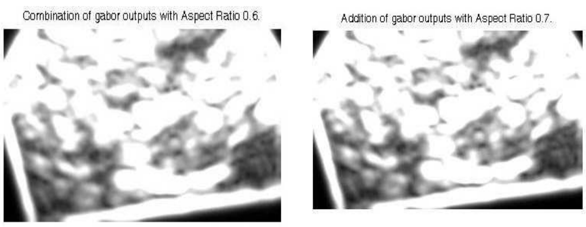
(e) (f)

Fig. 6. (a) Original Image. Magnitude filtered image with (b) 0deg Orientation, (c) 45deg Orientation, (d) with 90deg Orientation (e) 135deg Orientation (f) Combined Image of all Gabor filter outputs.

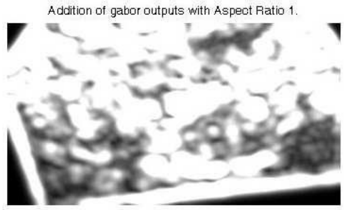
A Gabor filtering function used in this paper is a complex sinusoid modulated by a rotated Gaussian. It segments the input image with the 2D Gabor filter described in G by the parameters λ, θ, γ, φ, and BW to create the output filtered image.

The original image is shown in Fig. 6 (a). The enhanced image is filtered by the Gabor filter. The magnitude output images of each filter with the orientations of 0 °,45 °, 90 °and 135 °respectively are shown in Fig. 6 (b), Fig. 6 (c), Fig. 6 (d) and Fig. 6 (e). The linear combination of the Gabor filtered images, i.e. the sum of images in Fig. 6 (b) through Fig. 6 (e) is the final processed image. That is expressed in Fig. 6 (f).

Although the Gabor filter can extract some textural structure, it needs significant improvements on the output image. There are still individual pixels and still lack of the exact boundary. So some morphological operations are needed to use to eliminate the isolated pixel. And pixel lightening and darkening procedures should be added to the existing process to approach the fully automatic segmentation.



(a) (b)



(c)

Fig. 7. Combined outputs at aspect ratio at (a) 0.6, (b) 0.7 and (c) 1 respectively.

The performance of Gabor filter highly depends on the parameters value considered. Fig. 7 (a), Fig. 7 (b), and Fig. 7 (c) depict the output performance of Gabor filter according to the aspect ratio at 0.6, 0.7 and 1 respectively. This parameter, called more precisely the spatial aspect ratio, specifies the ellipticity of the support of the Gabor function.

According to these results, we can observe that the Gabor filer specified in this work needs to be enhanced to get the clear boundary of colon wall. Mophorlogical operations are needed to eliminate the undesired pixels and GLCM (Gray Level Co-occurance Matrix) analysis and active contour methods should be considered. Since there are geses and fluids inside the colon, the image itself is complicated to easily extract the features.

A. *Colon Wall Thickness Measurement*

The aim of this study is to observe the colon abnormalities based on the colon wall thickness. Table III shows the measurement data for colon wall thickness obtained from both methods based on three parts of the colon; ascending, transverse and descending colons.

Based on the colon wall thickness measured, the average value for the subject in this study lay between 1.5 mm to 3.1mm. The data indicates that there is no presence of abnormalities in the colon based on the colon wall thickness analysis. The data obtained from the processed image provide two significant figures which provide better results. These data are presented in Table III.

TABLE III: The Colon Wall Thickness Values for Ultrasound Measurement and Processed Image Measurement Based on Ascending Colon, Transverse Colon and Descending Colon. The Result Was the Mean Data with Standard Deviation *N*=5

Colon part	Colon wall thickness (mm)	
	Ultrasound measurement	Image processed measurement
Ascending	3.1±0.2	2.97±0.2
	1.9±0.2	1.84±0.1
	2.9±0.2	2.78±0.2
	2.2±0.2	2.15±0.1
	2.0±0.2	1.98±0.1
Transverse	2.3±0.2	2.27±0.2
	2.5±0.2	2.46±0.2
	1.9±0.2	1.86±0.2
	2.7±0.2	2.71±0.2
	2.5±0.2	2.44±0.2
Descending	2.0±0.2	2.02±0.1
	1.6±0.2	1.51±0.2
	1.9±0.2	1.88±0.1
	1.9±0.2	1.92±0.2
	1.4±0.2	1.37±0.2

TABLE IV: THE PEARSON CORRELATION COEFFICIENTS VALUE FOR ASCENDING, TRANSVERSE, AND DESCENDING

Colon part	Pearson correlation coefficients, *r*
Ascending	0.999374
Transverse	0.997176
Descending	0.992746

Pearson correlation coefficients (r) are computed in order to compare the measurement data before and after the image processing. The results are presented in Table IV. The result shows a positive correlation between the two measurement which indicates that both measurements are significantly true. Hence, both measurement methods can be implemented during analysis study on the colon abnormalities based on colon wall thickness.

ACKNOWLEDGMENT

This work is fully support by Ministry of Science, Technology and Innovation (MOSTI) Malaysia under grant of Science Fund Vot No. Q.J130000.2536.02H96. The authors would like to thank Research Management Centre (RMC), Biotechnology Research Alliance (RA), and Faculty of Biosciences and Medical Engineering, Universiti Teknologi Malaysia (UTM) for their support.

REFERENCES

[1] General ultrasound information. [Online]. Available: http://www.radiologyinfo.org/en/info.cfm?pg=genus

[2] J. K. Fisher. (Nov. 1982). Normal colon wall thickness on CT, RSNA Raciology. [Online]. *145(2)*. Available: http://pubs.rsna.org/doi/abs/10.1148/radiology.145.2.7134445.

[3] Drawing of the colon. (2011). [Online]. Available: http://www.catalog.niddk.nih.gov/imagelibrary/.

[4] C. D. Zois, K. H. Katsanos, M. Kosmidou, and E. V. Tsianos, "Neurologic manifestations in inflammatory bowel diseases: Current knowledge and novel insights," *Journal of Crohn's and Colitis*, vol. 4, no. 2, pp. 115-124, ISSN 1873-9946, Jun 2010.

[5] M. Cornaggiaa, M. Leutner, C. Mescolic, G. C. Sturniolo, and R. Gullotta, "Chronic idiopathic inflammatory bowel diseases: The histology report, digestive and liver disease," vol. 43, no. 4, pp. S293-S303, ISSN 1590-8658, March 2011.

[6] V. Andersena, A. Olsenc, F. Carbonneld, A. Tjønnelandc, and U. Vogele, "Diet and risk of inflammatory bowel disease," vol. 44, no. 3, pp. 185-194, ISSN 1590-8658, March 2012.

[7] D. Strobel, R. S. Goertz, T. Bernatik, "Diagnostics in inflammatory bowel disease: Ultrasound," *World J. Gastroenterol*, vol. 17, no. 27, pp. 3192–3197, July 2011.

[8] Umich. [Online]. Available: http://www.med.umich.edu/ibd/info.htm

[9] J. J. Murray, "7 Controversies in Crohn's disease," *Baillière's Clinical Gastroenterology*, vol. 12, no. 1, pp. 133-155, ISSN 0950-3528, March 1998.

[10] H. P. Haber, A. Busch, R. Ziebach, and M. Stern, "Bowel wall thickness measured by ultrasound as a marker of Crohn's disease activity in children," *The Lancet*, vol. 355, no. 9211, pp. 1239-1240, ISSN 0140-6736, 8 April 2000.

[11] H. P. Haber and M. Stern, "Intestinal ultrasonography in children and young adults: Bowel wall thickness is age dependent," *J. Ultrasound Med*, vol. 19, no. 5, pp. 315-21, 2000 May.

[12] G. Maconi, E. Radice, S. Greco, and G. B. Porro, "Bowel ultrasound in Crohn's disease," *Gastroenterol Hepatol (N Y)*, vol. 7, no. 2, pp. 107–109, February 2011.

Heamn Noori Abduljabbar is a medical sonographer of IJN-UTM Cardiovascular Engineering Centre. He has 8 years of experience in medical ultrasound scanning. He obtained his bachelor of Radiology from Baghdad University Iraq. He has a Master in Biomedical Engineering from UTM. He has more than 7 international publications. His research interests are fetal echocardiography, general ultrasound, and biomedical imaging.

E. Supriyanto was born in Demak, Indonesia. He graduated from Bandung Institute of Technology in Biomedical Engineering. He obtained his PhD from University of Federal Armed Forces Hamburg Germany. He is currently a full professor and director of IJN- UTM Cardiovascular Engineering Centre. He has more than 130 publications and 30 international awards. His research interests are medical imaging, medical informatics, electronics, biomaterials and biotechnology.

Yin Mon Myint was born in Myanmar in 1972. She received the B.E degree in Electronic Engineering in 1996 from Mandala Technological University (MTU), Myanmar and M.E in Electronic Engineering in 2002 from the same university. Since from 1996 after achieving her Bachelor degree, she started working in her mother university as an Assistant Lecturer. In 2002, she continued her study for Ph.D in Yangon Technological University, Myanmar. After Ph.D study, she joined back to MTU again. Throughout her studies and working life in MTU, she did in the areas of Digital Signal Processing and autonomous guided robot. Since 2011, she has been working in Faculty of Bioscience and Medical Engineering, UTM, as a Senior Lecturer. Her current research interests are image guided autonomous robotic systems and medical image processing.