Automatic Non Invasive Kidney Volume Measurement Based On Ultrasound Image

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Abstract: - Variation in kidney sizes can be associated with different kidney diseases. Ultrasound is widely used in the measurement of kidney size in diagnostic process. However, the precision and accuracy of the result is low due to the manual measurement that is highly dependent on the skill and experience of the doctor. Hence, an automatic measurement system should be developed and implemented to measure the kidney size automatically from ultrasound image. One such method has been developed here in this study. First, samples of kidney ultrasound image were collected and analysed. Then, programming algorithm in which a combination of noise filtering method such as Gabor filter, Wiener filter, and sharpening methods were used to suppress the speckle noise on the ultrasound image while preserving the fine details. The kidney was then segmented from the image using Level set method in which the zero level set was evolved to minimize the overall energy function depending on the gradient flow. Comparison of pixel value was used to determine the maximum and minimum point which was utilized to find the length, width, and thickness. At last, volume of the kidney was calculated using ellipsoid formula. Few samples have been tested and the result showed that this system is viable and able to assist in the diagnosis of early stage kidney diseases.

Key-Words: - kidney volume, kidney diseases, Gabor filter, wiener filter, sharpening methods

1 Introduction

End-stage renal disease (ESRD) is a major problem in both developing and developed countries [1,2]. In Malaysia, every year about 2500 people are diagnosed with kidney failure. Diabetes mellitus and hypertension are the common causes for chronic kidney failure [3]. Worldwide research indicates that one out of 10 adults had kidney problems and by 2015 it is estimated that about 36 premature deaths due to kidney disease will happen [3]. In general, many chronic kidney diseases have insidious onset and the early sign is usually subtle. Since kidney function impairment can be life-threatening, prompt attention is essential for early detection of any kidney disorders and diseases which could probably progress to end-stage kidney failure.

Previous research indicates that certain kidney diseases may cause some morphological changes in which the kidney size may also increase or decrease which can be portrayed by ultrasound machine that is widely used in diagnosis [4]. In clinical field, the Ultrasound is commonly used to measure the kidney length. However previous research shows that kidney volume is a more sensitive index of kidney size than kidney length for the detection of renal abnormalities [5]. Kidney length measured from ultrasound usually has deviations from the actual size which are commonly due to the inter-observer variability and also poor repeatability which also indicates that it has low accuracy. Hence, to calculate the kidney volume, the kidneys are evaluated in terms of greatest longitudinal length, width, and thickness. Currently, the kidney volume can be theoretically calculated by using ellipsoid formula [6]:

$$\text{Volume} = \text{length} \times \text{width} \times \text{thickness} \times 0.5236 \quad (1)$$

The calculated result usually will be lower than the actual size of kidney. The tendency of ultrasound to underestimate the actual kidney size could be caused by the difficulty of locating the plane of maximum bipolar length or by movement during respiration and the manual measurement is operator-dependant which highly depends on the skill and experience of the doctor [7].

Ultrasound is widely used in clinical field for various purposes but the image usually has poor quality and hard to interpret which is mainly caused by the existence of the speckle noise and other artifacts. Speckle is a characteristic phenomenon caused by the constructive and destructive coherent summation of the echoes when a coherent source and non-coherent detector used [8, 9]. It can be backscattered by the natural surface or received out of phase at the sensor [10]. Hence, noise filtering or suppression is highly required to reduce the speckle noise and smooth the image to enhance the process of computer-assisted diagnosis for kidney diseases.

There are many approaches used in speckle reduction by previous researchers. Gabor filter, Wiener filter, Median filter, and Wavelet filter are types of commonly used filtering approaches by previous research. Wiener filter which is a statistical filter specially designed to suppress additive noise has some limitations in noise filtering. Median filter is a non-linear filter that will replace the original gray level by the median of the gray values of pixels in a specific neighbourhood [11]. Wavelet filter is extensively used in noise reduction and data compression for the analysis of multi-scale structure on image.

Segmentation is widely used in image processing to partition an image into its constituent objects or regions for further image analysis. It will stop when the region of interest is obtained or isolated from the surrounding image. The goal of segmentation is to simplify a complex digital image into a segment or multiple segments which is more meaningful and to ease the analysis process. It is more typically used to locate certain object or boundary such as tumour or cancer cells detection and fingerprint recognition for further parameters measurement process in medical imaging. The accuracy of segmentation is crucial in determining the final success in any computerized analysis procedure. Hence, choose of appropriate segmentation method for an application should be given considerable care. Popular different segmentation techniques are thresholding method, region growing methods, artificial neural network (ANN) and computerized deformable model.

Based on above problem, a method has been proposed to accurately measure the kidney size after image processing and segmentation to get the clear boundaries of the kidneys. From this an algorithm and software can be created for auto-detection of kidney border and later on kidney volume.

The rest of this paper is organized as follows. In section 2, we describe on the materials and the procedure of image acquisition of the kidney images. The results of present method are shown in Section 3, and finally we draw some conclusions in Section 4.

2 Materials and Methods

Firstly, the samples of ultrasound kidney image were collected from students and staff from Universiti Teknologi Malaysia (UTM). Then, MATLAB was used to develop an automatic detection and measurement programming language after completing design of algorithms for auto-measurement of kidney size.

Fig 1: The original ultrasound kidney image

Fig. 1 shows the example of the original ultrasound kidney image. Since the original ultrasound image full of noise which affects the effectiveness of the software implementation, pre-processing approaches were used to reduce the noise and enhance the boundary of the image to improve the accuracy of the system.

Segmentation method was used to auto-detect the kidney border from the samples image collected before. Segmentation method such as level set algorithm was used to auto-detect the kidney border. If the detection of the kidney shape is incorrect, run again the segmentation method to get the correct shape of kidney. The resulting segmented kidney part was transformed into binary image to simplify the calculation process. Length and width were obtained automatically from the ventral part of kidney while thickness will be measured from the cross section image.

At last, volume was calculated from the three parameters obtained. Since the kidney volume is related to the body height and weight, the kidney volume obtained could be used in graphical analysis to determine any abnormality which may be associated to any kind of kidney diseases. Fig. 2 shows the flow chart of the algorithm for auto-detection of kidney border and auto-measurement of kidney volume.

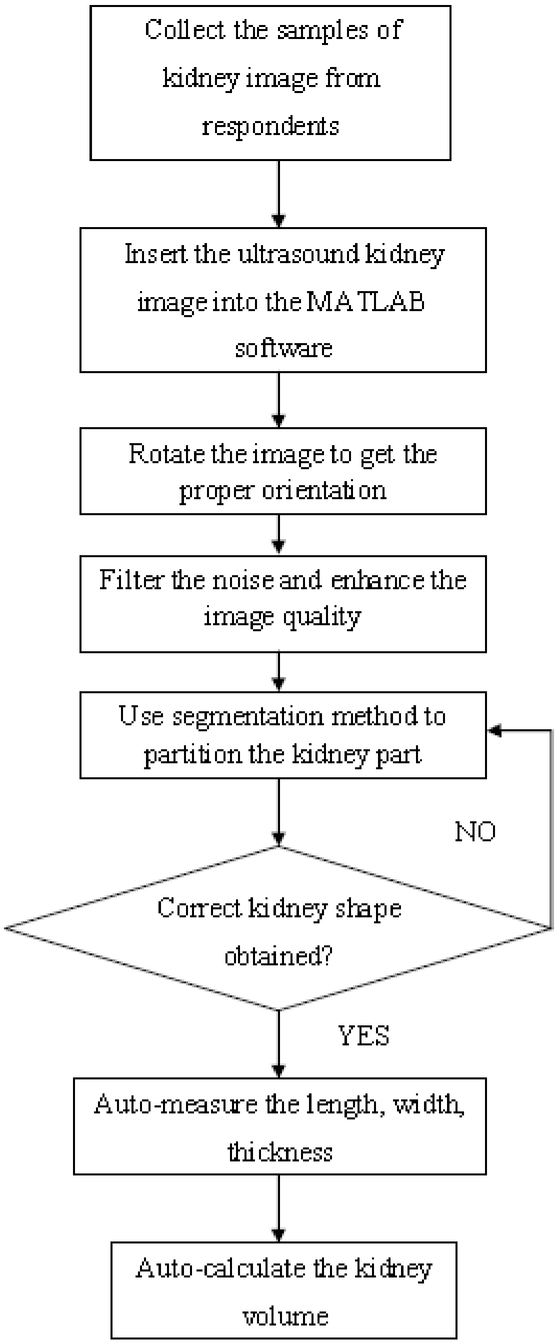

Fig. 2: Algorithm for auto-detection of kidney border and auto-measurement of kidney volume

2.1 Image Enhancement

There are many approaches used in speckle reduction by previous research. An effective speckle noise filter should be able to increase the signal to noise ratio while maintaining the edges in the image. Gabor filter, Wiener filter, Median filter, and Wavelet filter are types of commonly used filtering approaches by previous research. Wiener filter which is a statistical filter specially designed to suppress additive noise has some limitations in noise filtering. Median filter is a non-linear filter that will replace the original gray level by the median of the gray values of pixels in a specific neighborhood [12]. Wavelet filter is extensively used in noise reduction and data compression for the analysis of multi-scale structure on image.

2.1.1 Gabor Filter

Gabor Filter originally introduced and named after Dennis Gabor [13]. Gabor filter is used to obtain the optimal resolution in both spatial and frequency domains by acting as a band-pass filter for the local spatial frequency distribution. It is widely used as convolution operator to smooth images and to remove noise which is almost similar to the mean filter. Additionally, it is efficiently used for edge detection and also for segmentation of texture features especially in the fingerprint recognition. By varying the standard deviation of the Gaussian function, the degree of smoothing can be adjusted. The equation for the 2D isotropic Gaussian function is as follow:

$$g_e(x,y) = \frac{1}{2\pi\sigma_x\sigma_y} e^{-\frac{1}{2}\left(\frac{x^2}{\sigma_x}+\frac{y^2}{\sigma_y}\right)} e^{cos(2\pi\omega_{x_0}x+2\pi\omega_{y_0}y)} \quad (2)$$

$$g_0(x,y) = \frac{1}{2\pi\sigma_x\sigma_y} e^{-\frac{1}{2}\left(\frac{x^2}{\sigma_x}+\frac{y^2}{\sigma_y}\right)} e^{sin(2\pi\omega_{x_0}x+2\pi\omega_{y_0}y)} \quad (3)$$

where ω_0 defines the centre frequency and σ the spread of the Gaussian window.

2.1.2 Wiener Filter

Wiener filter is first proposed by Norbert Wiener during 1949. It is designed with the purpose to reduce the noise present in a signal which may cause corruption of the information. It is a linear low pass filter based on statistical approach which is effective in reducing the additive noise (Gaussian white noise) in image.

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2.1.3 Sharpening Filter

The image after applying the noise filtering method is normally become not clear and blurred because of the variation in the intensity value. Hence, image enhancement technique is needed to sharpen or enhance the visibility of the image for further analysis. Contrast enhancement is one of the common ways to improve the visibility. Unsharp masks which are generally a high pass filter where the high frequency components such as edges in an image will be enhanced thus reduces the dullness in the image.

2.3 Image Segmentation

For image segmentation process, level sets methods has been chosen. Level set segmentation method was first proposed by Osher and Sethian in 1988 to capture the moving front [14]. It involves the computation of the geodesics or minimal distance curves [15]. It uses the approach where the curve is embedded as a zero level set which is defined in a higher dimension. The surface will be evolved to minimize a metric which is defined by the curvature and the image gradient [16]. It is used for automatic topology adaptation and provides the basis for a numerical scheme. Level set method is partial differential equation based and its main idea is to evolve the curve towards the lowest potential for tracking the interfaces and shapes.

A new variational formulation of level set without re-initialization method has been proposed by Li et al. [17]. Generally they have proposed the following numerical integral:

$$\mathcal{P}(\emptyset) = \int_{\Omega} \frac{1}{2}(|\nabla\emptyset| - 1)^2\, dxdy \tag{4}$$

Then, based on defined functional $\mathcal{P}(\emptyset)$, following variational formulation has develop:

$$\mathcal{E}(\emptyset) = \mu\mathcal{P}(\emptyset) + \mathcal{E}_m(\emptyset) \tag{5}$$

Where $\mu > 0 = \textit{parameter control}$

$\mathcal{E}_m(\emptyset) =$ energy to drive the motion of zero level curve

Basically, there are few advantages by using this new proposed method. This method gives a fast curve evolution and it can be simply implemented via simple finite difference. The level set function can also be initialized with general functions that are more effective and efficient to construct thus make it easier to practically use compared to commonly use signed distance function [17].

2.4 Auto-measurement of kidney length, width, and thickness

By comparing the pixel value of the binary image, the maximum and minimum point can be obtained. The four points obtained are the maximum and minimum points for pixel of the kidney binary image. The length and the width are calculated from the points using Euclidean distance. The values are then converted to distance in centimetre. Then, volume of the kidney was calculated by using Equation (1).

3 Result and Analysis

3.1 The comparison of pre-processing approach

To verify the efficiency of the different noise filtering methods, MSE(mean square error) and PSNR(peak signal to noise ratio) are used to evaluate the effectiveness of the noise filtering method in removing the speckle noise on ultrasound image by comparing the noise filtered image with the original image as reference. There is inverse relation between the value of MSE and PSNR where the higher the value of PSNR will result in a lower value of MSE. PSNR is normally expressed in logarithmic and the pixels are defined using eight bits per sample with value of 255. It is actually to measure the peak error and the result is considered good if the ratio is higher which also means less noise compared to the signal (original image). The formulas used are shown as follow:

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j) - K(i,j)]^2 \tag{6}$$

$$PSNR = 10.\log_{10}\left(\frac{MAX^2}{MSE}\right) \tag{7}$$

The MAX is the maximum possible value of pixel where in this case we use 255. The size of the image is m*n. The I is the resulting image while the K is the reference image. In this project, the speckle noise is added to the original ultrasound image at first and the different noise filters or combination of filters will be used to reduce the noise. The noise filtered image will then be compared to the original image and the MSE and PSNR formulas will be used to evaluate the effectiveness of the filter in smoothing the image.

From the table below, it can be noticed that the PSNR values are high for all the three types of noise filters when they are used alone. The noise can be well reduced by three types of filters: Gabor, Wiener, and Median filter. However, from the resulting images, it can be observed that the images become blur as many of the fine details have been lost. Since the kidney boundary is crucial when applying Level set method for segmentation, sharpening method needs to be applied after using the noise filter in order to enhance the boundary of the image. Different combinations of filter with sharpening method are implemented on the image to evaluate the effect. The table shows that the combination of Gabor, Wiener, and sharpening method is the best way in reducing the noise while preserving the fine details of the image as it has the highest value for PSNR and lowest value for MSE from all the combinations.

Table 1: The MSE and PSNR for various combinations of pre-processing methods

Types of filtering	**Mean Square Error (MSE)**	**Peak Signal-to-noise ratio PSNR (dB)**
Gabor filter	339.3988	22.8577
Wiener filter	54.9085	30.7684
Median filter	221.8167	24.7049
Gabor, sharpened	270.5629	23.8421
Wiener, sharpened	462.7882	21.5110
Median, sharpened	453.0424	21.6034
Gabor, wiener, sharpened	262.5290	**23.9730**

3.2 Kidney segmentation with level set method

The level set curve evolution is highly dependent on the continuity of the border. For the ultrasound image with extremely poor resolution and contrast, this accuracy of the boundary detection is low since the evolution of the level set curve depends on the intensity gradient and the strength of the edge.

In this system, we set the number of iterations to 130 so that the contour can definitely fit the boundary in order to get an accurate result. The initial contour must be set as near as possible to the boundary so that the evolution of the curve is less affected by the image noise.

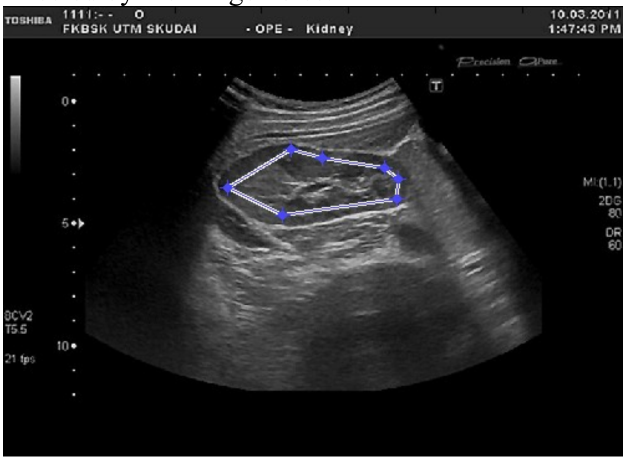

Fig. 3: The initial contour set obtained

Fig. 4: The final contour obtained

3.2 Kidney volume measurement

The volumes of the kidney were compared between the use of manual measurement using the ultrasound machine itself and also the automatic measurement using this developed system. Table 2 and Table 3 show the result of the kidney measurement. Based on the result, it shows that the result of the measurement between two methods were slightly different. Compared to manually measured, which highly depends on operator, this system consider the calculation of the pixel of the image which is much easier.

Table 2: The measurement using the ultrasound machine

Sample	Length	Width	Thickness	Volume
1	8.98	3.58	3.00	50.50
2	9.52	3.50	3.04	53.04
3	8.96	3.60	3.51	59.22
4	9.4	3.54	3.55	61.85
5	10.62	3.27	3.05	55.46
6	9.60	3.40	3.10	52.98

Table 3: The automatic measurement using the system developed

Sample	Length	Width	Thickness	Volume
1	8.89	3.19	2.77	41.13
2	9.39	3.23	2.81	44.62
3	9.20	3.23	3.15	49.01
4	9.76	3.27	3.19	53.31
5	10.57	3.08	2.79	47.56
6	9.73	3.23	2.83	46.57

4 Conclusion

A system has been developed to improve the quality of kidney ultrasound image by reducing the speckle noise and enhancing the boundary. It was followed by the implementation of automatic segmentation method using the level set method to partition the kidney from the ultrasound image. Pixel comparison was then used to auto-measure the parameters such as length, width, and thickness in the kidney image to calculate the kidney volume. Testing and optimizing process were done continuously to ensure the robustness of the algorithm until the satisfied result is obtained. In future, a better segmentation method can be used to partition the kidney without the need of a very clear image from ultrasound machine. Furthermore, the kidney should be located using the probe in a proper orientation to get the full size so that the volume calculated can be more accurate.

References:

[1] Mealey, B. L., Ocampo, G. L., Diabetes mellitus and periodontal disease, *Periodontology 2000*, Vol. 44, 2007, pp. 127–153.

[2] Barsoum, R., End-stage renal disease in North Africa. *Kidney Int* 2003 63(Suppl 83):S111–S114.

[3] Chugh, K.S., Jha, V., Differences in the care of ESRD patients worldwide: Required resources and future outlook, *Kidney Int*, 1995, 50(Suppl):S7–S13.

[4] Jennyhow, Life Health Screening Health Tourism. 17 March 2009MJ.

[5] Dinkel, E., Dittrich, M., Peters, H., Berres, M., Schulte-Wissermann, H., Kidney size in childhood sonographical growth charts for kidney length and volume, 1985 15:38-43.

[6] Shin, H.S., Chung, B. H., Lee, S.E., Kim, W.J., Ha, H.I., Yang, C.W., Measurement of Kidney Volume with Multi-Detector Computed Tomography Scanning in Young Korea, v.50(2); Apr 30, 2009.

[7] Sampaio, F.J.B., Theoretical kidney volume versus real kidney volume: comparative evaluation in fetuses. 1995, 17:71-75.

[8] Kang, K.Y., Lee, Y.J., A comparative study of methods of estimating kidney length in kidney transplantation donors. 2007, 22(8):2322-2327.

[9] Tamilselvi, P.R., Thangaraj, P., Noise Suppression and Improved Edge Texture Analysis in Kidney Ultrasound Images.

[10] Adam, D., Beilin-Nissan, S., Friedman, Z., Behar, V., The combined effect of spatial compounding and nonlinear filtering on the speckle reduction in ultrasound images, *Ultrasonics 44* ,2006,166–18.

[11] Gagnon, L., Jouan, A., Speckle filtering of SAR images: A comparative study between complex-wavelet based and standard filters, In *SPIE Proc*., 3169, 1997, pp. 80–91.

[12] Mariana Carmen Nicolae, Luminita Moraru, Laura Onose: Comparative approach for speckle reduction in medical ultrasound images, Romanian j. biophys., Vol. 20, No. 1, P. 13–21, Bucharest, 2010.

[13] Gabor, D., Theory of communication, *Journal of the Institute of Electrical Engineers*, 1946, 93, 429–457.

[14] Osher, S., Sethian, J. A., Fronts propagating with curvaturedependent speed: algorithms based on Hamilton-Jacobi formulations, *J. Comp. Phys.*, 1988, vol. 79, pp. 12-49.

[15] Caselles, V., Kimmel, R., Sapiro, G., Geodesic active contours. *Int'l J. Comp. Vision*, 1997 22(1):61–79.

[16] Michael E. Leventon, Olivier Faugeras, Level set based segmentation with intensity and curvature priors,

[17] Li, C., Xu, C., Gui, C., Fox, D.M., Level set evolution without re-initialization: a new variational formulation, in *IEEE Computer Soceity Conference on Computer Vision and Pattern Recognition(CVPR),* 2005.

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