

New Technique towards Operator Independent Kidney Ultrasound Scanning

Wan M. Hafizah, Nurul A. Tahir, Eko Supriyanto, Adeela Arooj, Syed M. Nooh

Abstract— Ultrasound imaging has been widely used as the primary screening of the kidney as it is non-invasive and affordable. Ultrasound can be used to measure the size and appearance of the kidneys and to detect tumors, congenital anomalies, swelling and blockage of urine flow. However, this scanning procedure is a time taking method because of the ultrasound image is full of speckle noise. Thus, the user eventually notices that it is hard to detect the boundary of the kidney in the US image, even it's done by the trained sonographers. In addition, human error might occur during the interpretation of ultrasound image by untrained sonographer, especially when taking measurement. Therefore, in order to reduce the dependability to the sonographers' expertise, some image processing can be done which can automatically detect the centroid of human kidney. The software was developed using MATLAB consist of speckle noise reduction, Gaussian filter, texture filter and morphological operators which were used for image segmentation in order to extract important features. For the result, median filter has been chosen as speckle noise reduction techniques as it is faster and detect kidney centroid better compared to wiener filter, wavelet filter and speckle noise anisotropic diffusion (SRAD) filter. This software can achieve until 96.43% of accuracy in detecting the centroid. The detected centroid can be implemented in the existing ultrasound machine that will be used as segmentation tool to reduce human errors and time.

Keywords—kidney, ultrasound, texture, morphological, Gaussian

I. INTRODUCTION

HUMAN kidneys can be evaluated by many imaging modalities such as ultrasound (US), magnetic resonance imaging (MRI), plain radiographs (x-rays), intravenous urography (IVU), computerized tomography (CT), and angiography [1-3]. These imaging techniques are important for the medical practitioners to determine the health of the kidneys and also to visualize any abnormalities present in the kidneys. IVU can be used in measuring kidney size and shape

as well as in evaluating the pelvis and ureters. IVU is the common kidney X-ray used to diagnose a wide range of problems especially if the patients have pain in the kidneys, blood in the urine, as well as suspected of obstruction, kidney stones and congenital abnormalities. However, the use of IVU may leads to serious side effects due to the use of contrast dyes.

CT scan is best used in the diagnosis of the kidneys to detect tumors or other lesions, kidney stones, congenital anomalies, fluid around the kidneys, and the location of abscesses. CT scans of the kidneys can provide more detailed information about the kidneys thus providing more information related to injuries as well as diseases of the kidneys, but highly risk due to radiation exposure. Magnetic resonance imaging (MRI), with the advantage of superior soft-tissue contrast, provides as a powerful tool in the detection and characterization of kidney lesions. Compared to CT scans which using the x-ray beam, MRI scans use radio waves and strong magnets where the energy from the radio waves is absorbed and then released in a pattern formed by the type of body tissue and by certain diseases. Then, a computer translates the pattern into a very detailed image of parts of the body.

However, the use of MRI is not as comfortable as other imaging techniques as it takes longer time for diagnosis session. Besides, it is also not as affordable as US [4]. Ultrasound (US) is one of the modality of first choice in kidney imaging. US can be used to measure the size and appearance of the kidneys and to detect tumors, congenital anomalies, swelling and blockage of urine flow. As this imaging technique is non-invasive, portable, and affordable and does not require radiation, most of the medical practitioner chosen US for primary screening of kidneys' condition.

However, US image is difficult to analyze because of its data composition which is described in terms of speckle formation [5]. Speckle noise is caused by random interference between coherent backscattered waves which may have negative effect on image interpretation and diagnostic tasks. Thus, the user eventually notices that it is hard to detect the boundary of the kidney in the US image even it is done by the trained sonographers. In addition, human error might occur during the interpretation of US image by untrained sonographer, especially when taking measurement [6]. This is the reason why the kidney US procedure needs much more time to be done. This condition also makes the patient feel uncomfortable where he/she need to change his/her position

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several times because of difficulty to detect the kidney's boundary manually [4].

In order to reduce the dependability to the sonographers' expertise, some image processing can be done which can simplify the ultrasound process and help in producing consistent results. In fact, in the upcoming years, if the image processing tools being thoroughly investigated and applied to US images, it might be possible for non-medical person to use ultrasound and give out accurate output images due to its user friendly and its automatic system. Image processing that can be used are image enhancement and image segmentation process. Some of the common image enhancement techniques used are median filtering, Wiener filtering, wavelet filtering, as well as Gaussian low-pass filtering. For image segmentation, there were various techniques can be used based on colour, intensity or texture of the images.

There were some previous researches done in exploring the semi-automatic and automatic ultrasound scanning especially in breast imaging. Sinha et al. developed an automated ultrasound imaging-mammography system where a digital mammography unit has been augmented with a motorized ultrasound transducer carriage above a special compression paddle [7]. Yap et al developed a novel algorithm for initial lesion detection in ultrasound breast images which automatically generate region of interest (ROI) in exchanged of manually cropped ROIs [8].

For this study, we have developed a new technique that automatically detects the kidneys' centroid in kidney US videos, which were separated into single frame images first. This study consists of the use of few filtering techniques for speckle noise reduction and image enhancement as well as texture analysis in analyzing the kidney structure in US images. The technique is helpful in recognizing the kidney in an image, which will help the sonographers in confirming the detection of the kidney as the detected kidney centroid can be an indicator for correct scanning protocol. Besides, this study also can help untrained sonographer to improve their skills in US scanning.

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

II. MATERIAL AND METHODS

In this section, we describe the procedure of image acquisition, as well as image processing methods applied to the images. For this study, we scanned some volunteers consist of staffs and students from Universiti Teknologi Malaysia. Then, we capture and save the kidney ultrasound video in .avi format by using TOSHIBA AplioMX ultrasound machine with 3.5MHz transducer. After that, the videos were copied into the laptop and separated into single frame for image processing

step. The image processing methods were applied to all single frame images. After detecting the kidney centroid, the single frame images were combined back and the output were the videos with detected kidney. Fig. 1 shows the block diagram of the whole developed system consist of ultrasound scanning, capturing and saving videos, separating the videos into single frame images, image processing for detection of kidney centroid as well as combining the single frame images back into videos.

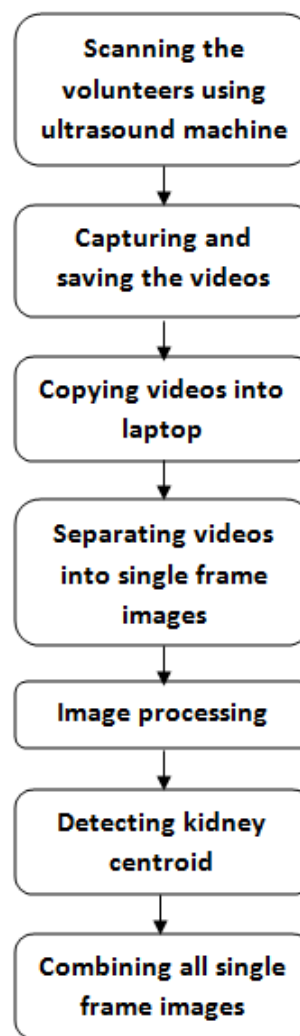


Fig 1: Block diagram of the system

In this study, we chose several MATLAB functions in the image processing toolbox to develop the image processing algorithm. For speckle reduction, several image processing methods were compared in terms of speed and accuracy. The speckle reduction techniques were Wiener filter, median filter, wavelet filter, and anisotropic diffusion filter. Then, Gaussian filter was performed as a smoothing filter.

For image segmentation, texture analysis was used to create texture image and morphological operators such as opening and closing operators was used to eliminate unwanted objects. Object properties were very important in order to select the

desired object and also to remove any unwanted objects. In this project, kidney's centroid was chosen as the desired object to be detected. Fig. 2 shows the flow chart of image processing applied to kidney US images consist of speckle noise reduction, Gaussian filter, texture analysis, morphological operation and centroid detection.

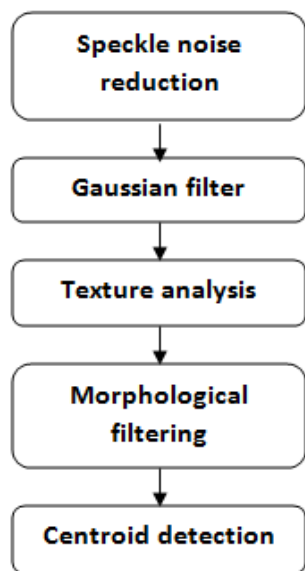


Fig. 2: Flow chart of image processing

A. Speckle Noise Reduction

Speckle noise often affects the tasks of human interpretation and diagnosis of US images. Due to the presence of speckles in ultrasound images, not only the enhancement of US image has become more difficult, but speckle also complicate further image processing, such as image segmentation and edge detection [9-11].

There were many previous researches done in finding a better speckle noise reduction technique. Thakur et al, in his research has made a comparative study of various wavelet filters with different thresholding values of US images and observed that such denoising methods are effective in the sense that they preserve the edge details besides suppressing the noise [12]. Nicolae et al in her research compared three noise reduction techniques, median, wiener and wavelet filters while Yu et al proposed that speckle reducing anisotropic diffusion excels over the traditional speckle removal filters in terms of mean preservation, variance reduction, and edge localization [13][26-29].

1. Wiener Filter

Wiener filter performs an optimal tradeoff between inverse filtering and noise smoothing where it removes the additive noise and inverts the blurring simultaneously [14]. Besides, Wiener filtering is optimal in terms of the mean square error, where it minimizes the overall mean square error in the

process of inverse filtering and noise smoothing. Wiener filtering is also a linear estimation of the original image. The Wiener filter in the frequency domain is as in equation (1):

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

where $S_{xx}(f_1, f_2), S_{\eta\eta}(f_1, f_2)$ are respectively power spectra of the original image and the additive noise, and $H(f_1, f_2)$ is the blurring filter.

2. Median Filter

Median filter, a well-used nonlinear filter is created by replacing the original gray level of a pixel to the median of the gray values of pixels in a specific neighborhood. Median filtering, also known as rank filtering helps in reducing speckle noise as well as salt and pepper noise [15- 17]. The noise-reducing effect of the median filter depends on the spatial extent of the neighborhood and the number of pixels involved in the median calculation. Fig. 3 shows an example to calculate median pixel value.

140	135	124	130	135
128	115	119	123	127
130	124	126	127	140
138	120	150	125	128
125	125	122	135	132

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

Fig. 3: Example for calculating the median value of a pixel neighborhood

3. Wavelet Filter

Wavelets are developed for the analysis of multiscale image structures [18]. Wavelet functions are different compared to other transformations such as Fourier transform, as they not only dissect signals into their component frequencies but also

vary the scale at which the component frequencies are analyzed. As a result, wavelets are suited for applications such as data compression, noise reduction, and singularity detection in signals [13].

The basic steps for denoising in wavelet based method are as below [12]:

1. Decompose the original image data into l -level of wavelet transform.
2. Threshold the resultant wavelet coefficients, for suppressing noise.
3. Thresholding, based on the convolution technique, is used to compare all the detailed coefficients.

4. Anisotropic Diffusion

Speckle reduction anisotropic diffusion (SRAD) proposed by Yu et al is based on partial differential equation (PDE). The PDE-based speckle removal approach allows the generation of an image scale space without bias due to filter window size and shape. SRAD preserves and enhances edges by inhibiting diffusion across edges and allowing diffusion on either side of the edge. Besides, SRAD also does not utilize hard thresholds to alter performance in homogeneous regions or in regions near edges and small features.

Given an intensity image $I_0(x,y)$ having a finite power and no zero values over the image support Ω , the output image $I(x,y;t)$ is evolved according to below PDE:

$$\begin{cases} \frac{\partial I(x,y;t)}{\partial t} = \text{div}[c(q)\nabla I(x,y;t)] \\ I(x,y;0) = I_0(x,y), (\frac{\partial I(x,y;t)}{\partial \vec{n}})|_{\partial\Omega} = 0 \end{cases} \quad (2)$$

where $\delta\Omega$ denotes the border of Ω , \vec{n} is the outer normal to the $\delta\Omega$, and

$$c(q) = \frac{1}{1 + \frac{[q^2(x,y;t) - q_0^2(t)]}{[q_0^2(t)(1 + q_0^2(t))]} \quad (3)$$

or

$$c(q) = \exp \left\{ - \frac{[q^2(x,y;t) - q_0^2(t)]}{[q_0^2(t)(1 + q_0^2(t))]} \right\} \quad (4)$$

where

$$q(x,y;t) = \frac{\sqrt{\left(\frac{1}{2}\right)\left(\frac{|\nabla I|}{I}\right)^2}}{\left[1 + \left(\frac{1}{4}\right)\left(\frac{\nabla^2 I}{I}\right)\right]^2} \quad (5)$$

and $q_0(t)$ is the speckle scale function.

B. Gaussian Filter

Gaussian filter has a similar function as median filter, but it used different kernel, which has a bell shaped distribution, as shown in Fig. 4.

The equation for Gaussian filter is:

$$g(x) = \frac{1}{\sqrt{2\pi\sigma}} e^{\frac{-x^2}{2\sigma^2}} \quad (6)$$

σ in the equation (6) is the standard deviation of the

distribution, which is also the degree of smoothing. That

means the larger the σ , the smoother the filtered image. But

larger σ needs larger convolution kernel, in order to be

accurate. Kernel is a small matrix of numbers that is used in image convolutions. It is also known as structuring element. There is some previous research which used non-linear Gaussian filter to remove speckle noise in US image as in [19, 20].

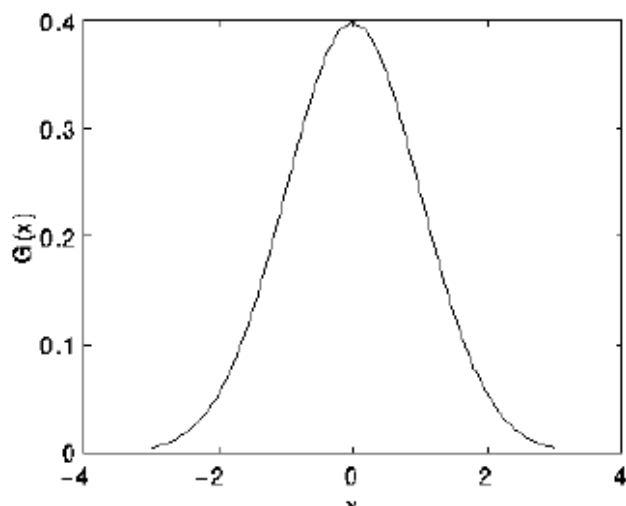


Fig. 4: The bell-shaped of Gaussian distribution

C. Texture Analysis

Texture analysis will play an important role in detecting this isolated data and reducing the error and improving the classification results [21, 22]. The toolbox in MATLAB includes three texture analysis functions that filter an image using standard statistical measures, such as range, standard deviation, and entropy. These statistics can characterize the texture of an image because they provide information about the local variability of the intensity values of pixels in an image. *rangefilt* is used to calculate the local range of the image. If the image has smooth texture, it will have small value. And if the image's texture is rough, the value will be larger. *stdfilt* is used to calculate the local standard deviation of an image while *entropyfilt* is used to calculate the local entropy of a grayscale image. It is also represents a statistical measure of randomness.

D. Morphological Filter

All morphological filters are based on two main operations, dilation and erosion [23]. A small pattern called structuring element is translated over the image to extract useful information in images [24]. Spiros et al used morphological closing and opening to segment the nuclei of breast tissue [25]. The dilation equation is as follows:

$$A \otimes B = \{z | (\hat{B})_z \cap A \neq \emptyset\} \quad (7)$$

where \emptyset is the empty set and \hat{B} is the reflection of the structuring element B. The erosion equation is defined as:

$$A \ominus B = \{z | (B)_z \cap A^c \neq \emptyset\} \quad (8)$$

where A^c is the complement of A.

There are several operators in MATLAB Image Processing Toolbox such as *bwareaopen*, *imopen*, *imclose*, and *imfill*. *bwareaopen* is morphologically open a binary image and remove small object. It is usually used to remove background. *imopen* is function to erodes an image then it will dilate the eroded image using the same SE (structuring element). SE is also known as kernel, which is a small matrix of numbers that is used in image convolutions. While *imclose* is used to dilate an image and then erodes the dilated image using the same SE. *imfill* is used to fill any holes in the image. For binary image, it changes any connected background pixels to the foreground pixels.

E. Centroid Detection

After image segmentation was done, we can select certain object in the binary image by using some of MATLAB command. For example *regionprops*, which is used measures properties of objects in an image. The properties that can be measures by this function are objects' area, objects' centroid, pixel values, and may more. Another important function is *bwconncomp*. It finds connected components in binary image. By using this function, we can calculate the total objects in an image and we also can find any desired object by implementing that function.

III. RESULTS AND ANALYSIS

Fig. 5 shows the original image of the kidney US, which was taken from a video that has been separated into single frame.



Fig. 5: Original kidney US image

Firstly, speckle noise reduction techniques were applied to all the single frame images. The techniques include wiener filter, median filter, wavelet filter, and SRAD. Fig. 6 shows the

result of the speckle reduction techniques where (a) is the result after Wiener filtering, (b) after median filtering, (c) after wavelet filtering, and (d) after SRAD.

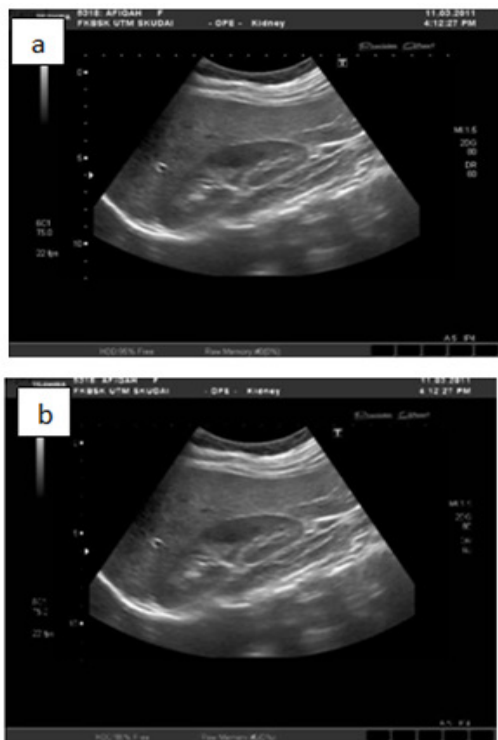


Fig. 6: Speckle reduction techniques using (a) wiener filter, (b) median filter, (c) wavelet filter, (d) SRAD

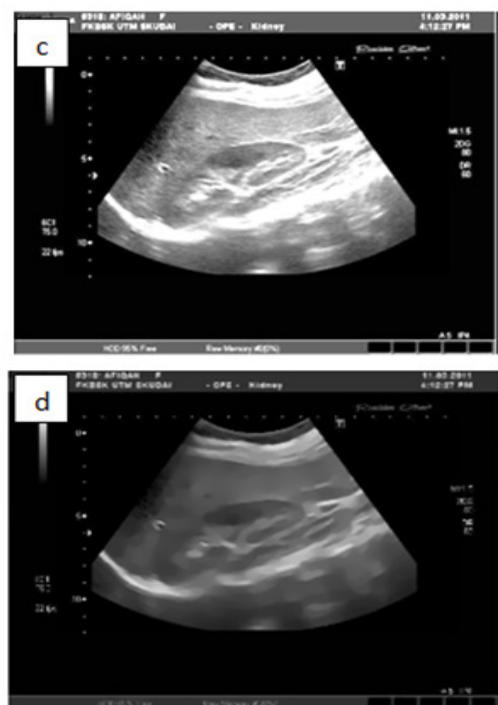


Fig. 6: Speckle reduction techniques using (a) wiener filter, (b) median filter, (c) wavelet filter, (d) SRAD

Next, we applied Gaussian filtering to the output images of speckle noise reduction techniques as a smoothing filter. Fig. 7 shows the result of the images before and after being filtered using Gaussian filter where (a) is the result for Wiener filter, (b) median filter, (c) wavelet filter, and (d) SRAD.

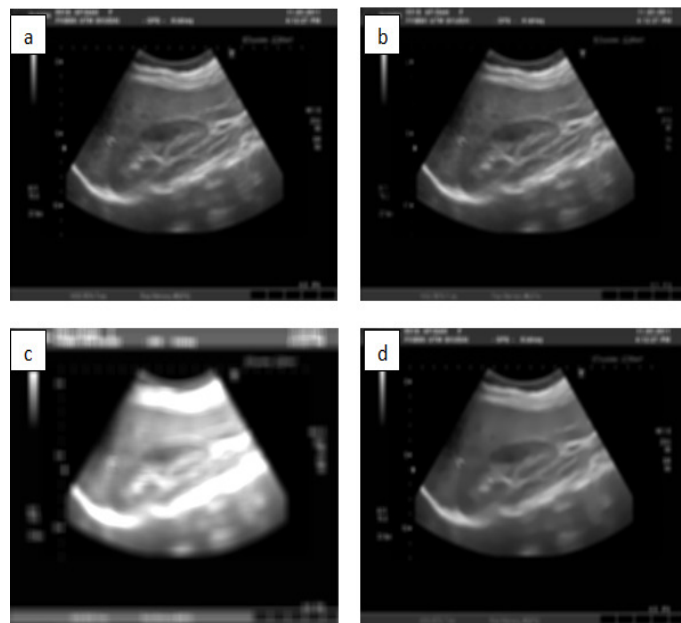


Fig. 7: Images (a) wiener filter, (b) median filter, (c) wavelet filter, (d) SRAD filtered by Gaussian filter.

Next, the filtered image will be filtered again using texture filter to create filter image. In this project, *entropyfilt* was chosen and after that, the filtered image was converted into binary image using *im2bw* function. The images can be seen in Fig. 8.

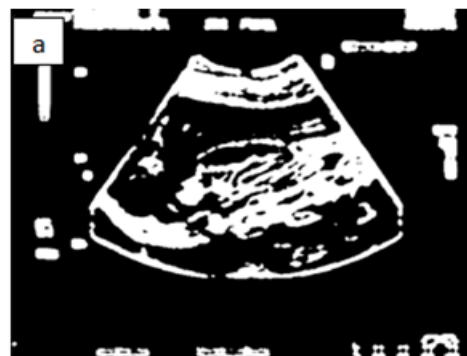




Fig. 8: Binary image after texture filter for (a) wiener filter, (b) median filter, (c) wavelet filter, (d) SRAD

Then, morphological operations were done several times in order to segment the desired part, which is the centroid. *bwareaopen* with 3000 of filter kernel's size was used to extract the background with object while *imopen* and *imclosed* were used to eliminated the unwanted part in the image. *imfill* was used to fill in any holes in the object.



Fig. 9: Morphological operation for (a) wiener filter, (b) median filter, (c) wavelet filter, (d) SRAD

The result can be seen in Fig. 9. As can be seen in Fig. 9, only two speckle noise reduction techniques successfully detect the kidney sinus which was Wiener filter and median filter. Wavelet filtering caused all the regions in the output image connected to each other thus fail to detect kidney sinus. SRAD technique removes the kidney sinus from the image and therefore fails to detect any kidney sinus.

After the morphological operations, the smallest object in the image, which is the kidney's sinus, was chosen. *regionprops* was used to measure the properties of objects in the image. The specific properties that important in this object were the area and also the centroid of the object. As can be seen in most output images which successfully detect the sinus, they showed that the sinus has the smallest area compared to all other regions. Therefore, this smallest region was selected and it was tagged with red marks as the centroid of the kidney.

Table 1 shows the speed of the software and Fig. 10 shows the result of the detected centroid for each of speckle noise

reduction techniques applied in this study. In Table 1, Wiener filter and median filter has the fastest speed which is 4seconds, follow by wavelet filter which is about 5 seconds. SRAD however has the slowest speed which is more than 150 seconds.

Table 1: The software speed for kidney centroid detection

Speckle Noise Reduction Techniques	Speed(sec)
Wiener Filter	4 sec
Median Filter	4 sec
Wavelet Filter	5 sec
SRAD	>150 sec



Fig. 10: The detected centroid for (a) wiener filter, (b) median filter, (c) wavelet filter, (d) SRAD

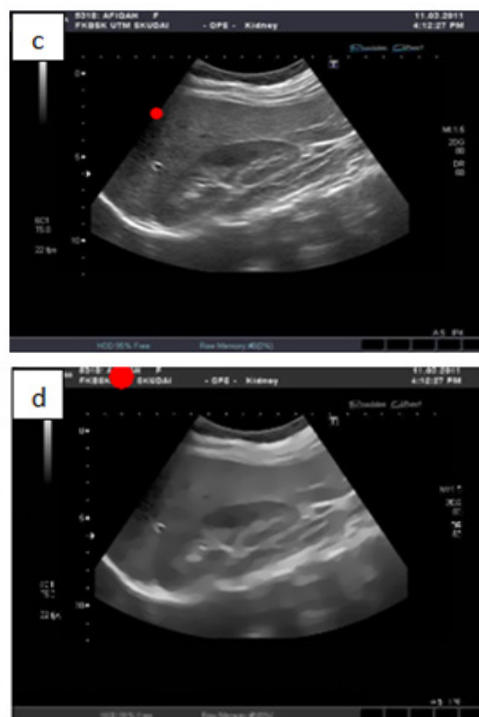
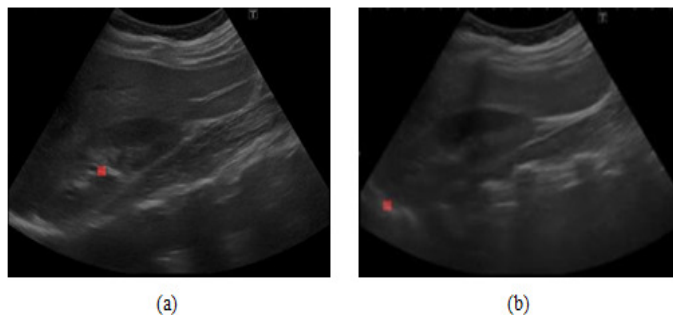


Fig. 10: The detected centroid for (a) wiener filter, (b) median filter, (c) wavelet filter, (d) SRAD

Based on the result in Fig. 10, it shows that the kidney was successfully detected by using wiener filter and median filter as speckle noise reduction technique as the red tag is inside the kidney boundary. By using wavelet filter and SRAD, the area detected is not the kidney as the red tag is outside the kidney boundary. Median filter however shows a more accurate result as the red tag is more to the center of the kidney image. Therefore, in this study, median filter was chosen as the method for speckle noise reduction.

The software was tested with three different videos and each video with different total images. Fig. 11 shows the sample images with detected centroid and also images with undetected centroid. The results for all images from the three tested videos were summarized in Table 2. As explained before, the video uploaded into the software will be cut into single frames for image processing. Total images produced were depending on the length and frame rate of the video. For example, one second video with 26 fps (frame per second) will created 26 images.



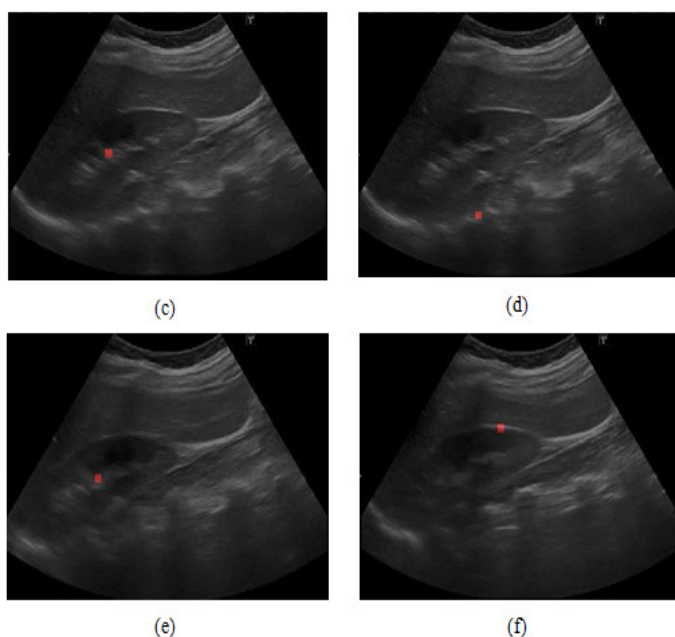


Fig. 11: Sample images with detected centroid (a, c, e) and also images with undetected centroid (b, d, f).

Table 2: The results after software tested with three different videos

Video	Total Image	No. of Centroid Detected	No. of Centroid Not Detected	Percentage of Centroid detection
A	28	27	1	96.43%
B	26	22	4	84.62%
C	26	19	7	73.08%

From the result, we can see that the first video gives higher percentage of centroid detection with 96.43%. That means only one of the 28 images was failed to detect the kidney's centroid. For video B, 84.62% of the total images were detected while other four images were failed to detect the kidney's centroid. And for video C, 73.08% which is represents 19 images of 26 images were successfully detected kidney's centroid.

The undetected centroid in certain images was caused by noise in kidney US image, and it maybe caused by wrong probe position during scanning. Thus, the algorithm for image processing was failed to detect the centroid. The comparison between detected centroid and undetected centroid images can

be seen in the previous Fig 8. We can clearly see that the image with detected centroid (a, c, e) was clearer and sharper compare to image with undetected centroid (b, d, f). That is why the algorithm failed to detect the centroid. It is also maybe due to the present of inefficient filters and some unnecessary image processing techniques in the algorithms.

IV. CONCLUSION

Kidney ultrasound (US) is performed for assessment of kidney's shape, size and location. It is important to detect any appearance of abnormalities in the kidney such as cysts and tumors. But, existing scanning procedure is a time taking method because of the US image is full of noise. The sonographer with less experience in handling US machine also had greatly contributes to the problem.

Therefore, the system has been developed to automatically detect the centroid of human kidney in the US videos. The software consists of speckle noise reduction, Gaussian filter, texture analysis, and morphological operation for image segmentation in order to extract important features. For speckle noise reduction, four techniques have been applied and compared in term of accuracy and speed. Based on the result, it shows that median filter is the best speckle noise reduction technique as it is not only faster, but also able to detect the kidney centroid better compared to other techniques.

From the results also, it was proved that the software can be used to detect the kidney's centroid automatically by giving great accuracy up to 96.43%. Compared to other researches, this software only produces one initial point, which is the kidney's centroid. The detected centroid can be used for further research to detect the kidney's contour automatically. The time taken to process the whole video was only one minute for each video. Thus, it had reduced the time for clinicians to interpret the kidney. For further research, improvement can be made by selecting another better filter, as well as by investigation the morphological operation in finding the optimum values for detecting a more accurate kidney centroid.

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