A REVIEW ON ULTRASOUND IMAGE PRE-PROCESSING, SEGMENTATION AND COMPRESSION FOR ENHANCED IMAGE STORAGE AND TRANSMISSION.

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Abstract - Imaging is one of the key medical diagnostic tools to observe internal organs and soft tissues. One such tool is ultrasound scanning, which is highly utilized in gynecology and echo cardiogram. This is due to the number of advantages of ultrasound scanning, such as being non-invasive, free of radiation, economical and real-time. However, access to ultrasound scanning facilities remain limited due to the scarcity of human and physical resources. Therefore, developing technologies to remotely perform ultrasound scans using mobile devices to extend medical imaging facilities to rural and less accessible areas is becoming an interesting research area. This requires efficient compression of ultrasound scan footage in order to facilitate real-time transmission over a mobile network. Careful selection of the Region of Interest (ROI) is essential to compress ultrasound footage efficiently. Yet, it is a challenge due to distributions of various intensities depending on the imaging conditions, boundary ambiguities and speckle noise.

This review paper highlights state-of-the-art technologies for the careful selection of ROI of ultrasound images to facilitate ultrasound image pre-processing, segmentation and compression. Furthermore, the paper proposes directions for future research to develop existing methods. It is envisaged that these technologies will pave the path to develop new technologies that would enable better patient care in the future.

Keywords: Ultrasound images, Region of interest (ROI), Image segmentation, Image compression, Speckle noise removal

I. INTRODUCTION

Medical imaging is a heavily utilized technique by medical officers to visualize internal anatomy without opening the body. Among various medical imaging techniques such as CT, PET, X-Ray, Gamma etc ultrasound is one of the key techniques used for organ and soft tissue imaging due to several reasons. Ultrasound is a non-invasive imaging technique which is free of radiation. Additionally, it provides the real-time imaging possibility. Compared with other medical imaging techniques ultrasound is a low cost technique. Transmitting and storing the ultrasound medical images is important to overcome geographical distance barriers faced by patients and to assist medical trainees/ interns. That is, reducing the travel time and cost, getting the specialists' opinions on real time, avoiding the exposure of patients to microorganisms in crowded medical centers and assisting the patients in complicated situations who cannot be transferred (Kaur & Wasson, 2015; Mofreh et al., 2016; Lee et al., 2005). Additionally, storing the medical images in Hospital Information System (HIS) helps to keep the records of patient history and they can be used as an e-learning resource for medical trainees/ interns. However, maintaining the high quality of the medical images which are large in size is important while storing and transmitting the medical images. High bandwidth is required to transmit large size images which has a negative impact on cost and the time. Moreover, transmission of the data in rural areas is difficult where the network quality can be a barrier (havada et al., 2014).

To overcome the above mentioned obstacles, new techniques for pre-processing, segmenting and compressing of the medical images have been discussed and experimented over a decade.

Medical ultrasound images are inclined to have speckle noise which affects the image quality and the diagnosis process negatively. Therefore, it is important to remove speckle noise from the image in pre-processing steps.

Usually, in a medical image, only a small area contributes for the diagnosis. Hence, maintaining the high image quality in that area is sufficient until it does not lead to any erroneous diagnosis. Accordingly, image segmentation is carried out to extract the important area which is called region of interest (ROI) from the image. Next step is compressing the image to achieve more efficient image storing and transmitting. As mentioned earlier, maintaining the high quality in ROI is sufficient to preserve the diagnostic data. Therefore, in compression process carrying out lossless compression in ROI and lossy compression in the other areas of the image is acceptable until it does not affect the diagnostic process negatively.

In this review paper, de-speckling filters which have been used in pre-processing the image is discussed in section II. In section III, introduction to Region of Interest is given. In section IV and section V, image segmentation techniques and image compression techniques have been discussed respectively. In section VI, analysis parameters which can be used to do a qualitative analysis of results have been discussed. Finally, the paper is concluded and future directions have been given.

II. PRE-PROCESSING OF THE ULTRASOUND IMAGES

Despite the fact that ultrasound images provide many advantages such as being economical, radiation free, real time etc., ultrasound images are corrupted by various types of noise which affect the visual quality negatively as these are low resolution images which are constructed by using reflection of ultrasound waves. However, speckle noise shown in Figure 1, is significant in ultrasound images and it might cause negative impact on post-processing steps such as image segmentation and image compression.

Speckle noise is a combination of additive and multiplicative noise which is statistically independent from the original image. Image with speckle noise can be given by the mathematical equation given in eq 1.

$g(m,n)=f(m,n)*u(m,n)+(m,n)$ eq 1

$g(m,n)$ – corrupted image $f(m,n)$ – original image

$u(m,n)$ – multiplicative noiseη (m,n) – additive noise

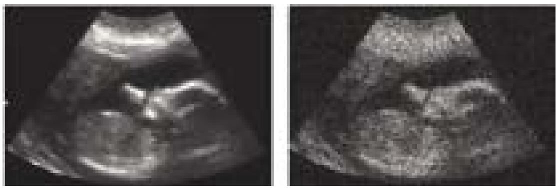

Figure 1 . Comparison between Fetal Ultrasound Image with a Fetal Ultrasound Image Degraded by Speckle Noise (Source : Latifoglu, 2013)

As speckle noise degrades the image quality and affects the diagnosis process negatively, it is important to de-noise ultrasound images, prior to diagnosis. De-speckling ultrasound images is an active research area in recent years. (Attlas, 2014; Jaybhay and Shastri, 2015)

There are various filtering techniques which have been used to remove speckle noise from medical ultrasound images namely, wiener filters, median filters, adaptive filtering techniques and transform based techniques including Fourier transform, Hilbert transform and wavelet transform.

A. Weiner Filter

Weiner filter which is known as least mean square filter in generally, has capability to minimize overall mean square error. Accordingly, this linear filter smoothen the image depending on the variance of the images. Additionally, Weiner filtering is one of the best methods to filter out both multiplicative and additive noise. (Rajesh, 2016).

B. Median Filter

Median filtering is another best known filtering techniques which have been used to remove speckle noise from an image. Median filters preserve the edges of the image while removing the noise.

C. Discrete Wavelet Transformation

In Discrete Wavelet Transformation (DWT) sampling is carried out in a discrete way as it name implies. DWT has a variable window size. Accordingly, time efficiency of DWT is high compared to Fast Fourier Transformation (FFT) as scaling can be performed.

DWT provides one more important advantage when processing medical images. It can be applied to the medical image in such a way where the transformation time duration taken for Region of Interest (discussed in latter sub topic) is greater than time duration taken for Non-Region of Interest to improve the time efficiency and preserve the important data in the area of Region of Interest.

Attlas and Guptha analyzed a de-speckling filtering model which includes median filter and Weiner filter along with DWT approach separately. Quantitative and qualitative results had proved that application of DWT along with median filter and Weiner filter improves the image quality compared with application of median filter and Weiner filter along to an image. (Attlas and Guptha, 2014)

III. REGION OF INTEREST

Each and every area of a medical image does not contribute to the clinical diagnosis equally but a very small area in the image is sufficient enough to make the diagnosis in most of the cases. Accordingly, medical image can be divided into three different areas namely, region of interest (ROI), Non-ROI and the background as shown in Figure 2. Extracting Region of Interest from a medical image is the process of image segmentation. Moreover, it is important to carry out an efficient image compression.

Region of interest is the smallest area in the medical image. Yet, it is the most important and considerable area as it contains the most critical information in the medical image (Kaur & Wasson, 2015).

Determination of ROI by manual, automatic or semi-automatic techniques is an active research area at present (Janaki and Tamilarasi, 2012; Norouzi et al., 2014).

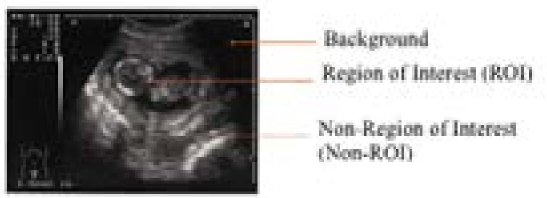

Figure 2 . Different Regions in a Medical Image (Source: http://www.nova-medical.com/ultrasound-3d.htm)

IV. ULTRASOUND IMAGE SEGMENTATION

As mentioned earlier, segmentation is the procedure of extracting region of interest from the image. It is one of the important steps in medical image analyzing process. It helps to improve the time efficiency and cost efficiency in the coming steps of the analysis process.

There are several image segmenting techniques. Most of these techniques depend on the region or edge properties of an image. Under region based methods, thresholding based methods and region-growing based methods are the relatively popular as they are simple and efficient.

A. Thresholding based techniques

Simply, thresholding is the process of division of the pixels in the image into two as foreground and background depending on the threshold value selected according to the need. Pixels which are having greater or equal intensity to threshold value, are the foreground pixels. Pixels which are having less intensity than threshold value are the background pixels.

i. Global Thresholding

This is the one of the simplest methods of image segmentation. In global thresholding, foreground of the image is extracted from the image easily by assigning a threshold value. Yet it fails when the image background is not a constant and object is having different intensities in its pixels. In such cases, global thresholding might work for some regions in the image but fails in other regions.

ii. Variable Thresholding

Variablel thresholding provides different threshold values to different regions in the image. Initially, image is divided into sub-images statistically based on the mean, standard deviation, mean along with standard deviation etc. Then, thresholding is applied separately to each sub-image. Finally, they are merged to obtain the result. Variable thresholding can be categorized into two as adaptive and local thresholding. In adaptive thresholding, threshold value is a function of neighborhood X and Y. In local thresholding, threshold value is not a function of neighborhood X and Y but depends on them. This method is suitable for the images which are having varying backgrounds. However, this process takes time than global thresholding.

iii. Otsu's Thresholding

One of the critical disadvantages of thresholding is the manual selection of threshold value based on visual impact which is a subjective selection. To overcome this issue, methods such as Otsu's thresholding have been introduced where threshold value will be selected by an automatic process.

Thresholding provides the advantages such as being the simplest and less complicated method. However, thresholding is highly dependent on peaks. In addition, spatial details of the pixels are not considered when segmenting the image.

B. Region Growing Based Techniques

In the region growing based techniques, segmentation starts at a seed point and region grows depending on the intensity value of the neighboring pixels. The main disadvantage of region growing based techniques is the difficulty of selection of seed point. Manual selection of the seed point depends on the person's ability and it might leads to erroneous results. Selection of seed point by automatic or semi-automatic processes are active research areas recently (Norouzi, 2014; Kaur and Kaur, 2014)

Region growing techniques work best when the intensities of the objected to be detected is uniform and different from the background. This method is more immune to noise. But this is less time efficient and cost the memory too.

C. Edge Detection Techniques

Boundary properties dependent or edge detection based methods are another type of commonly used segmentation method. These methods depend on the rapid intensity changes in the image. There are different edge detection based methods which can be used to extract the region of interest from an image such as Canny edge detection method, Sobel-Feldman operator, Laplacian edge detection, Robert cross operator etc. In these methods, first the edges are detected and then they are joined together to form the object. The main disadvantage of this technique is that, it cannot be used where multiple edges are presented.

D. Partial Differential Equation Based Segmentation Methods

As these methods are relatively fast, they can be used in time critical applications. There are two main purposes of using PDE. Non-linear isotropic diffusion filter is used to enhance the edges and convex non-quadratic variation restoration is used to remove noise. Main disadvantage of this method is computational complexity.

E. Artificial Neural Network Based Segmentation Methods

These methods are based on the working principal of human brain. Neural networks are constructed of large number of nodes which are having particular weight in each. ANN based segmentation methods do not require complex computational programs. However, they are time in-efficient as they take time to train. (Yogamangalam and karthikeyan, 2013; Kaur and Kaur, 2014)

Recently, ultrasound image segmentation got much attention in the research field and novel advanced approaches have been introduced to segment the images.

Schmidt-Richberg et al. has proposed a new technique which integrates the information of the image with voxel probability maps generated by a fovFCN (Fovea Fully Convolutional Network) architecture based on deformable shape models. It is applied to 3D fetal ultrasound images to measure fetal abdominal circumference. The results of the experiment had shown that combination of fovFCN and deformable shape models performs better with mean-error of 2.24mm (Schmidt-Richberget al., 2017).

V. ULTRASOUND IMAGE COMPRESSION

Image compression is based either on irrelevancy reduction or redundancy methods. Frequently, both of the methods are used alongside with each other to improve the efficiency. There are two types of image compressions namely, lossless image compression and lossy image compression. Lossless image compression is used where critical data exists as in such cases, loss of information is not acceptable. Though the lossy compression is efficient in terms of time, memory requirement and cost in image storing and image transmission, it causes the data loss of the original image. The information of the original image may or may not be preserved. However, this is acceptable where the data of the original image is not critical. Lossless image compression is highly utilized in medical image compression as the data of a medical image is very critical. (Mofreh et al., 2016 & Anastassopoulos et al., 2002) Nevertheless, in some medical applications lossy compression of the full image or part of it is accepted until it doesn't lead to any erroneous diagnosis (Amri et al.,2017).

Most of the time, maintaining high image quality only in the ROI is sufficient (Gokturk et al., 2001). Accordingly, high compression ratio is acquired while maintaining high image quality by utilizing ROI-based compression where both lossy and lossless image compressions are performed. Initially, medical image is segmented into two as ROI and non-ROI. Then lossless compression is performed on ROI region and lossy compression is performed on non-ROI region (Janaki and Tamilarasi, 2012).

Hence, available bit budget can be non-uniformly distributed among ROI and non-ROI regions to enhance the efficiency of image compression. Comprehensively, bits of the ROI region are placed in higher bit-planes than the bits of rest of the image (Anastassopoulos et al., 2002).

VI. ANALYSIS PARAMETERS

Quality assessment of the pre-processed, segmented or compressed images is performed through analyzing various image parameters. There include,

1. Maximum Absolute Error (MAE)
2. Mean Square Error (MSE)
3. Root Mean Square Error (RMSE)
4. Signal-to-noise Ratio (SNR)
5. Peak Signal-to-noise Ratio (PSNR)
6. Compression Ratio (CR)

Maximum Absolute Error (MAE) is one of the most common objective performance measurements. It can be calculated by using eq 2 where F(I,j) is the original image and f(I,j) is the reconstructed image.

$$MAE = max(\left| F(i,j) - f(i,j) \right|)$$

Mean Square Error (MSE) is the second moment of the error function between the reconstructed and original image. To calculate MSE, eq 3 should be applied. M x N is the image size.

$$MSE = \frac{1}{M \times N} \sum_{i=0}^{N-1} \sum_{j=0}^{M-1} [\{F(i,j) - f(i,j)\}^2]$$

Root Mean Square Error (RMSE) is the square root of MSE as given in eq 4.

$$RMSE = \sqrt{MSE}$$

Signal-to-noise Ratio (SNR) can be calculated using the following formular given in eq 5

$$SNR = 10log\left[\frac{\sum_{i=0}^{N-1}\sum_{j=0}^{M-1}\left\{F(i,j)^2\right\}}{\sum_{i=0}^{N-1}\sum_{j=0}^{M-1}\left\{\left|F(i,j) - f(i,j)\right|^2\right\}}\right]$$

The ratio of the highest signal power to the undesirable noise power is the Peak Signal-to-noise Ratio (PSNR). To enhance the performance, higher PSNR should be assigned. PSNR can be calculated using the equation given in eq 6.

$$PSNR = \frac{20log_{10}(maximumpixelvalue)}{\sqrt{MSE}}$$

Compression Ratio (CR) is simply the ratio between the numbers of bits in original image and the compressed image. CR can be calculated using eq 7.

$$CR = \frac{Numberofbits(size)oftheoriginalimage}{Numberofbits(size)oftheoriginalimage}$$

(Mofreh et al., 2016; Anandan&Sabeenian, 2016; Attlas, 2014; Jaybhay&Shastri, 2015)

VII. CONCLUSION AND FUTURE WORKS

Ultrasound is one of the key imaging techniques used due to it's non-invasive nature, being free of radiation, real-time viewing possibility, being economical etc. Remotely performing ultrasound provides accessibility in consulting medical experts to patients in remote and less accessible places. Selection of Region of Interest (ROI) of the ultrasound image (Image segmentation) and image compression are two most important steps in the above mentioned process. However, automatic selection of the ROI is still a challenge due to speckle noise presents in ultrasound images which affects the image quality negatively. Therefore, it is important to pre-process the ultrasound images prior to image segmentation and image compression.

Ultrasound diagnosis is not based on only one picture but on sequences of images or a video. Therefore, it is important to carry out researches to identify active region in the ultrasound image sequence or in the video which we need to pre-process, segment and compress. Moreover, real time image transferring is another active research area where we can pay attention. Time efficiency and cost efficiency of the process is required for a better patient management.

This review paper analyzes the methods which can be used to pre-process, segment and compress ultrasound images. This analysis will be useful in implementing better pre-processing, segmentation and compression in medical ultrasound images to facilitate better patient management.

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