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FETAL CARDIAC STRUCTURE DETECTION FROM ULTRASOUND SEQUENCES

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Abstract- Fetal heart abnormalities are the most common congenital anomalies and are also the leading cause of infant mortality related to birth defects. More than one-third of all malformations found after delivery are congenital heart defects. The prenatal detection of fetal cardiac structure is difficult because of its small size and rapid movements but is important for the early and effective diagnosis of congenital cardiac defects. A novel method is proposed for the detection of fetal cardiac structure from ultrasound sequences. An initial pre-processing is done to remove noise and enhance the images. An effective K means clustering algorithm is applied to the images to segment the region of interest. Finally an active appearance model is proposed to detect the structure of fetal heart.

Keywords- *Congenital heart defects, Fetal heart, K means clustering, Median filtering, Ultrasound images.*

I. INTRODUCTION

Fetal cardiac defects are the most common congenital abnormality found at birth and are the primary reason for the death of the new-born. Fetal heart anomalies are found to affect 1% of all live births [1]. More than one-third of all malformations found after delivery are congenital heart defects (CHD). Only 4-7% of malformations detected before delivery are cardiovascular defects. Despite the widespread use of ultrasound during pregnancy, the vast majority (80-90%) of fetal heart abnormalities are thus not suspected prior to the birth of the baby. Prenatal diagnosis of CHD can be difficult, but is valuable because outcome for certain abnormalities can be dramatically improved by accurate diagnosis and adequate preparation.

International and national prospective studies of prenatal screening for heart defects show that, up to now, only 10%-30% of all cardiac defects or 20%-50% of discoverable cardiac lesions are actually diagnosed prenatally [2]. 50% of all infant deaths can be attributed to congenital heart disease or cardiovascular malformations. About half of these cardiovascular malformations are severe and usually require one or more surgical procedures in the neonatal period or during childhood. In only about 10%-30% of fetuses with cardiac lesions, there are case-history related or (molecular) genetic risks (family history, teratogens in early pregnancy, maternal disease, etc). Since a risk factor can currently not be elicited either from the history or with conventional genetic or molecular genetic methods in 70%-90% of congenital heart defects, sonographic "abnormalities" on obstetric ultrasound screening during prenatal care point the way to effective use of the expertise available in pre- and perinatal centers. If a heart defect has already been diagnosed prenatally, the infant with heart disease can usually be born spontaneously in the relevant perinatal or cardiac pediatric center and be treated and cared for without delay in the affiliated departments, thus avoiding a potentially hazardous postnatal transport. In many cases early interventional and/or surgical treatment is important for improving the prognosis of the neonate with heart disease besides using intensive care and medication.

The fetal heart anomaly diagnosis depends on the expertise of the doctor and is also time-consuming [2].Thus, several computerized methods are proposed to help the diagnosis of fetal heart. The level set algorithm was used by Lassige et al to detect the septal defects used [3].Later Siqueira et al applied the self-organizing map to segment the fetal heart and obtain the heart structure [4]. A more improved level set algorithm was proposed by Dindoyal et al by introducing the shape prior to segment four chambers of fetal heart [5].This more efficient multi chamber level set model used region growing technique. The region component arrives at a segmentation based on local deviations from the interior and exterior regions. The level set was started from a small sphere placed in the centre of each chamber to fit the endocardium boundaries.The snake evolution was updated using a first order iterative scheme because of its low computational complexity

$$\varphi_{n+1} = \varphi_n + \Delta S \varphi_n \qquad (1)$$

where φ_n is the level set function, n is the iteration number and ΔS is a small time step.

These methods are effective to some extent but are still more or less semi-automated. However, these computerized methods are mainly based on the information of edge or region, which is not reliable for the ultrasound data of fetal heart. This makes them not suitable for the early detection of fetal cardiac structure [1, 7-8].

The first automated fetal cardiac structure detection was done by Deng et al using ultrasound image sequences.

The methodology involved automatic selection of region of interest based on the motion summation image, despeckling using Rayleigh anisotropic filter [12] and finally the structure detection using active appearance model [15].The ROI was automatically selected based on motion which is the characteristic feature of the heart. The ROI in a fetal cardiac ultrasound sequence has relatively large motion compared to other regions. The motion information was obtained using Hierarchical block matching algorithm (HBM) [9]. The sum of all results of the motion estimation is done to obtain a motion summation image that could denote ROI distinctly. Then a rectangle mask is used to search the region having the most of motion information. A threshold process is applied to obtain the primary motion region which is followed by filtering it using the successive morphological opening and closing operations. After the automated selection of ROI, a despeckling method is proposed which consists of two major components: the Rayleigh-trimmed filter and the anisotropic diffusion. The former is used to suppress the primary noise based on the characteristic of the Rayleigh distribution of speckle [12]. The latter is performed in the three dimensional space to retain regions with anisotropic gradients and preserve the motion information between different images. After despeckling, the active appearance model [15] is applied to achieve the structure of fetal heart. The active appearance model combines the shape model with a texture model. During training, the images are annotated with labelled points which denote key features to represent the object. The shape model is built up by aligning these labelled points and calculating the statistical characteristics. The "shape-free" patches obtained by matching the labelled points in training data to the corresponding mean positions are analyzed by eigen decomposition.

The texture model is established based on eigen analysis. The active appearance model is obtained by learning the correlations of the shape and texture model. This model was used to obtain the fetal cardiac structure. Thus the detection of fetal heart structure from ultrasound images is mainly limited by the small size of the fetal heart and the low signal to-noise (SNR) ratio of the ultrasound imaging [7]. These limitations make the detection of fetal cardiac structure hard even for human visual system and are thus nowadays mainly carried out by the manual operations of experienced doctors [1-2, 6-7].

II. MATERIALS AND METHODS

A novel method is proposed for the detection of fetal cardiac structure from ultrasound images. An initial pre-processing is done to remove noise and enhance the images using median filtering. An effective K means clustering algorithm is then applied to the segment the region of interest. Finally an active appearance model is proposed detect the structure of the heart.

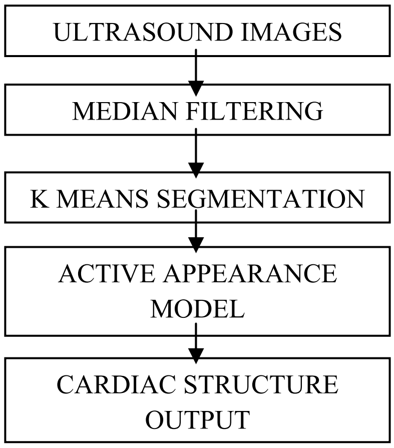

Figure 1. Proposed methodology

A. *Pre-processing*

The ultrasound images have high inherent noise which should be eliminated to acquire information. A study on the performance of various filters that can be used for pre-processing was done based on the work of Loizou et al [10]. A comparative evaluation of despeckle filtering based on texture analysis, image quality evaluation metrics, and visual evaluation by medical experts in the assessment of ultrasound images of the carotid artery bifurcation. A total of 10 despeckle filters were evaluated based on local statistics, median filtering, pixel homogeneity, geometric filtering, homomorphic filtering, anisotropic diffusion, nonlinear coherence diffusion, and wavelet filtering. The results of the study showed that simple filters based on local statistics and geometric filtering could be used successfully for the processing of these images.

The study further emphasized that proper selection of a despeckle filter is very important in the enhancement of ultrasonic imaging.

(i) Conversion to Gray Scale:

Before pre-processing the input images are converted into gray scale images to enable the application of filter. The true colour ultrasound image in RGB is converted to gray scale intensity image by eliminating the hue and saturation information while retaining the luminance.

(ii) Median Filtering:
The median filter is an effective method that can suppress isolated noise without blurring sharp edges[11]. Specifically, the median filter replaces a pixel by the median of all pixels in the neighbourhood:

$$y[m,n]=\text{median}\{x[i,j],\ (i,j)\in w\} \qquad (2)$$

where w represents a neighbourhood centred around location (m,n)in the image.

2D median filter:
The window of a 2D median filter can be of any central symmetric shape, a round disc, a square, a rectangle, or a cross. The pixel at the centre will be replaced by the median of all pixel values inside the window. A square window of 5x5 neighbourhoods was used for noise suppression.

B. Segmentation
A simple and effective K means clustering was used to segment region of interest in the ultrasound images. Different methods of segmentation were used earlier. But desirable efficiency was not achieved except for the method proposed by Deng et al which involve automatically locating the region of interest (ROI) using hierarchical block matching algorithm (HBM) [9]. In this method the ROI was located based on motion information. This was based on the characteristic that fast movements of the fetal heart will result in large motion 'energy' in the cardiac region compared to other regions. This novel and efficient method is however very much computation intensive.

K-means is one of the simplest unsupervised learning algorithms that solve the well known clustering problem. The procedure follows a simple and easy way to classify a given data set through a certain number of clusters (assume k clusters) fixed a priori. The main idea is to define k centroids, one for each cluster. The K means algorithm is for partitioning (or clustering) N data points into K disjoint subsets Sj containing Nj data points so as to minimize the objective function, the squared error function:

$$J = \sum_{j=1}^{K} \sum_{n\in S_j} \left|x_n - \mu_j\right|^2 \qquad (3)$$

where x_n is a vector representing the n the data point and μ_j is the geometric centroid of the data points in Sj.

For n sample feature vectors x1, x2, ..., xn all from the same class and falling into k compact clusters, k < n, let mi be the mean of the vectors in cluster i. If the clusters are well separated, a minimum-distance classifier can be used to separate them. Thus, x is in cluster i if || x - mi || is the minimum of all the k distances. This suggests the following procedure for finding the k means:

Make initial guesses for the means m1, m2, ..., mk.
Until there are no changes in any mean,
(i)Use the estimated means to classify the samples into clusters
(ii) For i from 1 to k, replace **m**i with the mean of all of the samples for cluster.

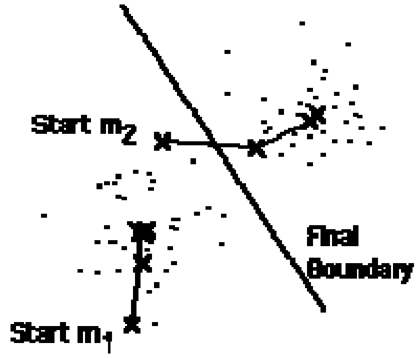

Figure 2. Cluster formation by movement of the means m_1 and m_2 into the centres of two clusters.

C. Active Appearance model
In the field of medical image processing, there arises a need to fit the shape of an object to a new image. Models for such matching are not necessary if the object is rigid. However when the object is non-rigid such as a heart or human face, active appearance models can be used to match a user defined set of points to images using their texture information as the matching criteria.

Active appearance models are widely used for matching and tracking faces and objects in medical image interpretation and computer vision. It is built during training phase of the project. It is implemented in order to estimate a better guess towards what the real shape in the image is, when some initial estimate for the shape of the object in an image is available.

A model is created using the error between the current estimate of appearance and target image. This difference drives an optimization process to create a new better fitting shape. In order to build such a model, a set of training images and shapes is used. The training for the detection of fetal heart structure is done by labelling the boundary of the whole heart and the atrioventricular septa. The statistical characteristics are calculated by aligning these labelled points and the shape model is thus built. Then "shape free patches" are obtained by comparing the labelled points in the training data to the corresponding mean positions. These are analyzed by eigen decomposition. The texture model is built by eigen analysis. Since there is a correlation between shape and texture models, both models can be controlled using only one parameter. Thus we concatenate the shape and texture model parameters into one vector to give the combined appearance model.

III. RESULTS AND DISCUSSION

The image sequences for the experiment were obtained using Philips HD 15 Ultrasound System with a convex 3.5 MHz probe. Three ultrasound sequences were used to train and validate the experiment.

First the images are converted to gray scale for further pre-processing. The images after conversion to gray scale is filtered for reducing the speckle noise which is a characteristic of ultrasound images. An efficient median filter with a window size 5x5 is applied. The resultant images are found to have less noise without much blurring to their edges. The filtered images are then segmented using K means clustering to obtain the region of interest.

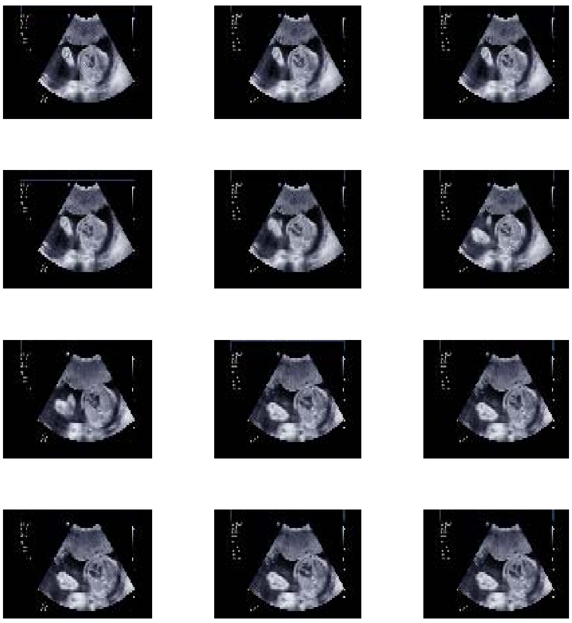

Figure 3. Sequence of input images

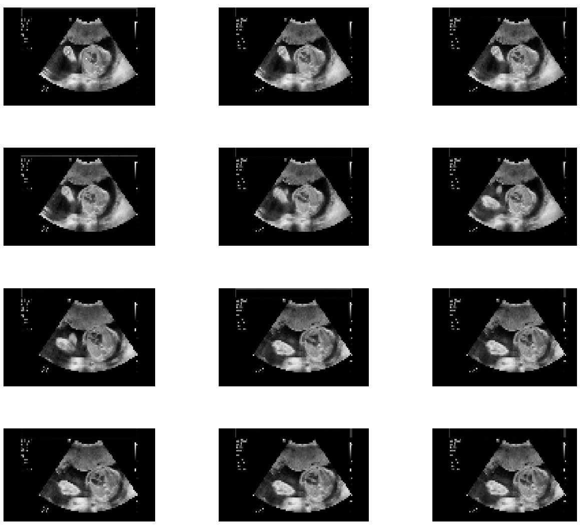

Figure 4. Sequence of gray scale images

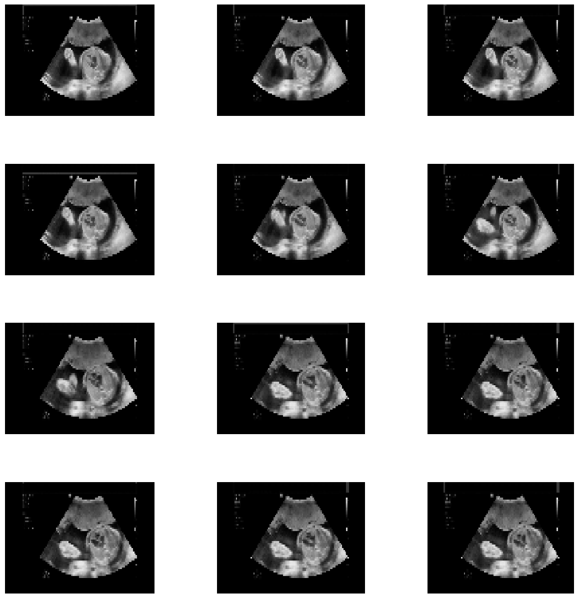

Figure 5. Sequence of filtered images

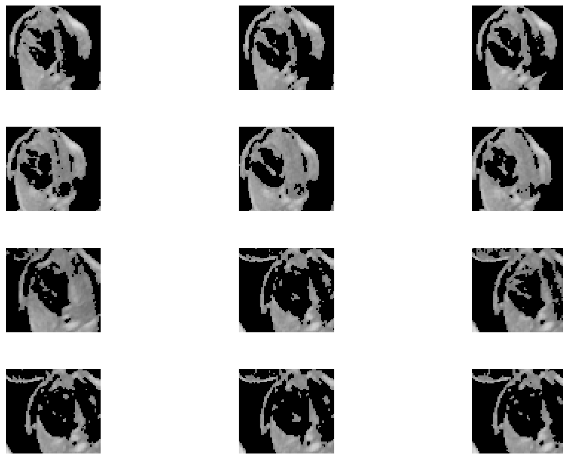

Figure 6. Segmented heart region

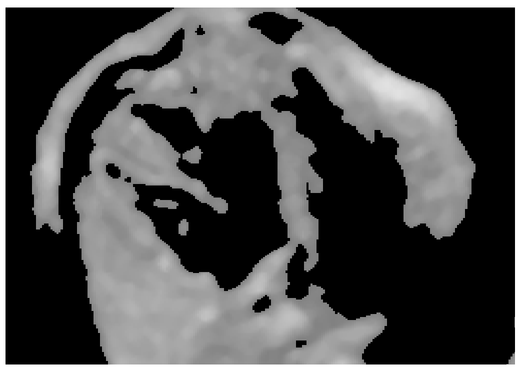

Figure 7. Segmented ROI

IV. CONCLUSION AND FUTURE WORK

A novel and efficient method for automated detection of fetal cardiac structure has been proposed in this paper. After the initial pre-processing, the region of interest has been successfully segmented. The final fetal cardiac structure detection is being implemented by active appearance model.

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