J Clin Monit Comput (2013) 27:205–209
DOI 10.1007/s10877-012-9404-7

LETTER TO THE EDITOR

Automated region mask for four-chamber fetal heart biometry

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Received: 1 July 2012 / Accepted: 12 October 2012 / Published online: 21 October 2012

Abstract This letter proposes an automated region mask for the detection of cardiac chambers from ultrasonic fetal heart biometry. The fetal biometry consists of two dimensional ultrasonic cine-loop sequences of apical four chamber view of fetal heart, which are comparatively The clinical motion information of individual frame is extracted by keeping a constant frame rate of 25 frames per second (fps). The region mask is designed based on the superimposition of motion information from a set of consecutive frames that belong to one cardiac cycle followed by connected component labelling. The borders and edges of all four chambers are thus recognized leading to formation of binary region mask. Experimental study based on second trimester cine-loop sequences confirms the suitability of the proposed technique for detection of heart chambers.

Keywords Fetal heart chamber · Ultrasonic imaging · ROI · Four-chamber view · Region mask

1 Introduction

The clinical protocols that are being followed for examination of fetal heart by ultrasonic imaging include four-chamber view, identification of outflow tracts of heart [1]. Followed by this, five-chamber view, three vessel view and tracheal view are carried out. The importance of 2D ultrasonic imaging for fetal heart chamber detection is due to its simplicity in image acquisition and hence effective automated screening procedure can be introduced where computational burden will be less. On the other hand, 4D technology is widely available and currently offers a better spatial resolution for volume ultrasonography, it is not capable of performing direct volume scanning [2]. Direct volume scanning as proposed by Deng [3] describes the 4D systems that are capable of scanning a volume of interest (1) in its totality, (2) within a time in which movement is negligible (in an instant), and (3) with sufficient spatial resolution. As it makes use of mechanical transducers, the totality of the volume of interest is not scanned in an instant and hence 4D systems work based on indirect volume scanning. Further such procedure suffers from considerable implications during the examination of the moving fetus and especially, the fetal heart. This is due to the fact that the motion artefacts interfere with the quality of the images obtained when the structure of interest moves faster than the speed at which the volume data set is being acquired [3]. Computer aided diagnosis have been reported in the recent past that fastens the clinical examinations [4–8]. Lassige et al. [4] used the level set algorithm to detect the septal defects. Siqueira et al. [5] proposed self-organizing map to segment the fetal heart and obtained the heart structure. Shrimali et al. [6] carried out a cross-sectional study on fetal ultrasound images that were processed using morphological operators to obtain the shape of the femur. In [7], Zayed et al. introduced fuzzy based clustering algorithm for grouping together those pixels in the image, which had similar features in the feature space. All these previous works have been implemented based on

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user-defined methods of detection and cropping of region of interest (ROI). The most important step before any segmentation process is to localize the image to a specific ROI. If an image is processed after the localization of ROI, then image processing algorithms prove to be very effective. Yinhui Deng et al. [9] suggested a method for region detection that makes use of a search algorithm to identify the ROI, but the process requires manual selection of initial mask. This paper suggests an automated region mask for recognizing four heart chambers from the given fetal cardiac 2D ultrasound cine-loop sequence. Figure 1 shows the proposed scheme.

2 Automatic ROI detection

For this work, 13 cine-loop sequences belonging to various weeks of gestation ranging from 21st–25th week (also called second trimester) with frame rate 25 frames per second (fps) comprising of 250–500 frames are used. The ROI in a fetal cardiac image is the four chambers of the heart. The motion information in the consecutive frames is the key feature for automatic ROI detection [9]. Consecutive frames belonging to the same video sequence are superimposed to design the region mask for four heart chambers. Consider an image/frame denoted by $I_{n(i,j)}$. For a cine-loop sequence denoted by $H_{i,j}$, the superimposed image is given by $G_{i,j}$ in (Eq. 1) as

$$G_{ij} = \sum_{n=1}^{k} I_{n(i,j)} \quad \text{for all} \quad I_{n(i,j)} \in H_{i,j} \tag{1}$$

where i and j are the ith and jth components of the individual frames involved in the process of superimposition.

The inherent similarity property of frames is exploited here for determining the value of k. To start with, the similarity between the first and rest of the frames in the sequences is determined by image subtraction and whichever frame yields a value equal or close to zero, the corresponding frame number is fixed as $k + 1$. Interestingly the selection of k frame also clinically confirms one cardiac cycle. Figure 2 shows the variations observed in 2D ultrasonic cine loop sequence (frame) during a typical cardiac cycle. Figure 2a, b show the frame, $n = 1$ and $n = k + 1$ belonging to first and second cardiac cycles respectively. Figure 2c indicate the 5th frame of the second cardiac cycle, i.e. $n = k + 5$. Figure 2d shows the effect of subtraction of first frame belonging to first and second cardiac cycles where minute difference in the background is only observed. The effect of subtraction between frames belonging to $n = 1$ and $n = k + 5$ as well as $n = 1$ and $n = k + 10$ is depicted in Fig. 2e, f respectively.

It can be observed from Fig. 2e, f that the dissimilarity between the frames (the frames of the different phases in a cardiac cycle, where the position of the chamber keeps changing due to their contraction and relaxation) are indicated by a comparatively greater amount of distribution of residual gray shades of the chamber region as highlighted inside the red circle in Fig. 2f as compared to Fig. 2d.

The term $G_{i,j}$ in (Eq. 1) denotes the superimposition of frames belonging to a single cardiac cycle. Consecutive frames are extracted from the video sequence using a multimedia reader. An illustration of binary mask formation is shown in Fig. 3. Two consecutive frames of a cine-loop sequence (say from cycle 1) are illustrated in Fig. 3a, b respectively. The superimposition of various frames gives the summed up motion image as in Fig. 3c. The superimposition operations performed on the other consecutive cycles have also yielded similar results as in Fig. 3c indicating that the ROI can be detected from any one of the complete cardiac cycles within that cine-loop sequence. This process ensures that the mask produced for ROI identification detects the exact region for any shape and position of the heart at different phases of a cardiac cycle. Once the superimposed image is converted into

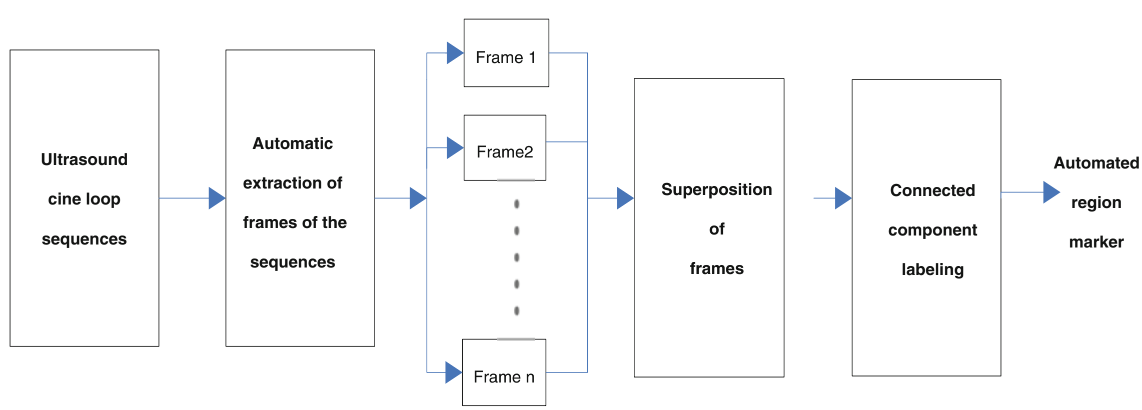

Fig. 1 Proposed scheme for obtaining automated region mask

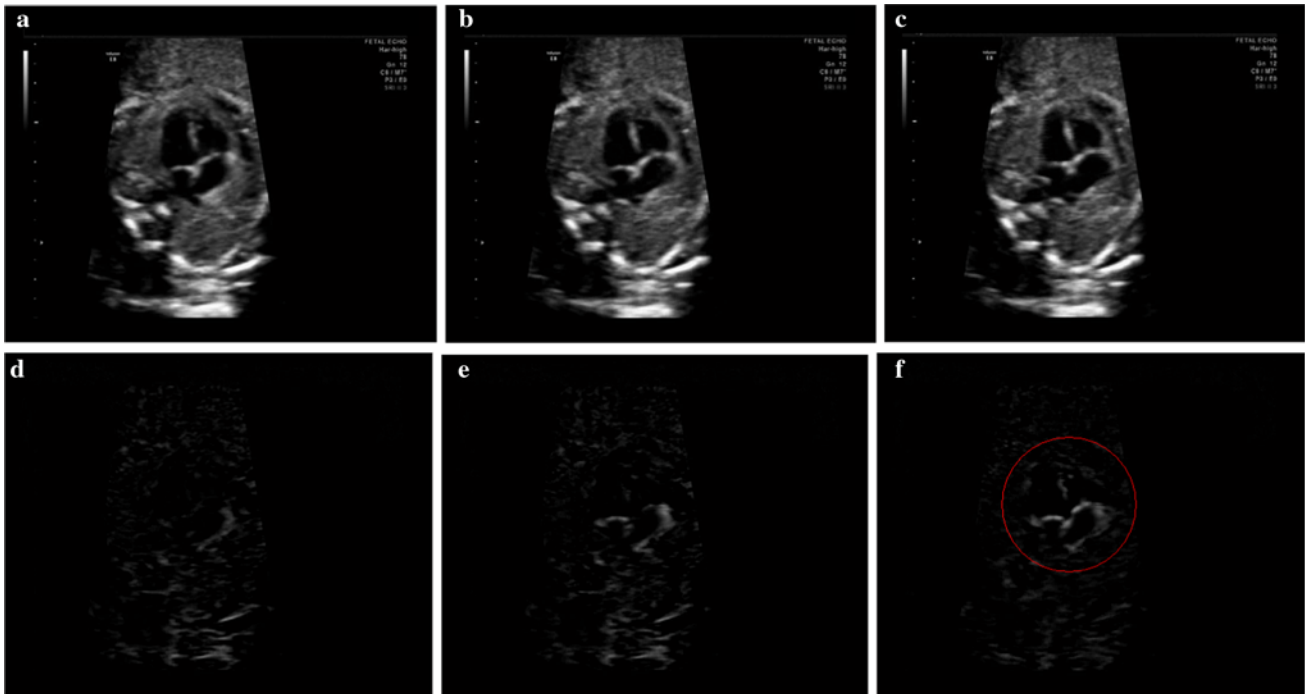

Fig. 2 Variation occurred in an ultrasound cine-loop sequence (frame). **a** The first frame (n = 1)under first cardiac cycle, **b** first frame under the second cardiac cycle (n = k + 1, where, k = 22), **c** frame (n = k + 5) belonging to second cardiac cycle, **d** difference image between frame n = 1 and n = k + 1, **e** Resultant frame after subtraction between frame n = 1 and n = k + 5, **f** resultant frame after subtraction between frame n = 1 and n = k + 10 (*gray colour* region that is still remaining after subtraction, due to dissimilarity between the two frames n = 1 and n = k + 10—indicated inside the *red circle*)

binary image (Fig. 3d), connected component labelling is performed. Connected component labelling provides the information of various individual connected objects in an image [10]. Connected components in a binary image are white pixels that are connected together. In our work, the heart chambers are the largest connected component as seen in Fig. 3e. Using this information, the top, bottom, left and right edges of the chamber region is identified. A binary mask is created as shown in Fig. 3f, which depicts the position information (pixels) of the four corners that form the ROI in all the frames of the same cine-loop sequence. This is mainly achieved due to the inherent similarity in the position of chambers in all frames of a single cine-loop sequence.

It is important to note that the information in the superimposed image is very efficient in detecting the ROI due to the inherent similarity in shape of the heart chambers region in the consecutive frames belonging to the same video sequence.

3 Performance evaluation

The performance of the automatic method of ROI detection is analyzed by evaluating the algorithm on cine-loop sequences of various weeks belonging to the second trimester. Figures 4, 5 and 6 show the region mask for gestation week of 24, 22 and 21 respectively. The robustness of the automated binary mask in ROI detection can be observed from Figs. 4, 5 and 6.

4 Discussion

The major need for the automated detection of ROI is due to the fact that most of the works carried out in fetal ultrasound technique so far, is based on manual cropping/defining of ROI [5–7]. In an automated system where the heart chambers and their structural and geometrical abnormalities are of great emphasis, the process of defining or detecting the ROI should also be made automated, rather than introducing a constraint of user intervention for the process of cropping or defining region specificity alone. Keeping such perspective in mind, this work automates the region detection process as well.

The automated method that made use of superimposition of frames and followed by connected component labelling. The proposed automated region mask found to be more reliable as the chambers form the major connected components in any frame in a given sequence and hence during

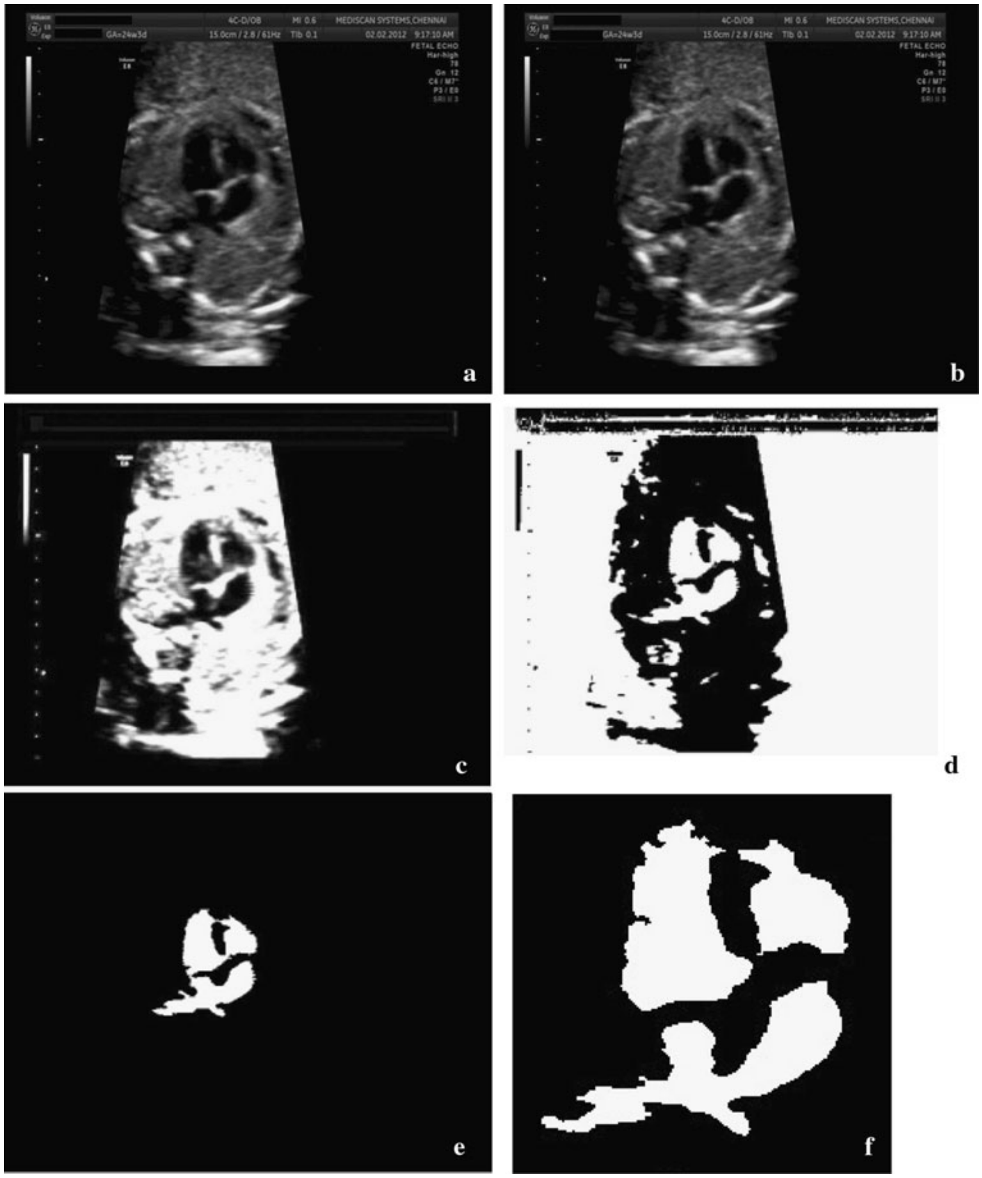

Fig. 3 Illustration of binary mask formation. **a** A frame from an ultrasound cine-loop sequence in apical four chamber view (say, n = 1), **b** next frame from the same sequence (say, n = 2), **c** superimposed image, **d** superimposed image converted to binary, **e** connected component extracted from labelled image, **f** binary mask containing the position information to detect ROI in frames

clinical procedure, the chamber region is accurately detected automatically, irrespective of the position of the fetal heart chambers (anywhere in the field of view).

Even though the advancement in ultrasonic fetal cardiac imaging using 4D matrix array imaging exists [11], the proposed screening tool make use of 2D ultrasound technique due to the simpler nature of 2D cine clips. They are comparatively easier to acquire than 4D ultrasound cine-loops and the computational complexity is less compared to 4D procedure [12]. The volume information in 4D ultrasound though provides the depth information, is preferred by sonographers and doctors only in case of serious conditions of abnormalities [2] and not at the early detection stage for diagnosing the presence or absence of a congenital heart abnormalities [9] or any structural abnormalities related to the chamber geometry such as atrioventricular septal defects.

For avoiding motion artefacts, due to the movement of fetus, the 4D matrix array imaging though uses simultaneous acquisition of the heart's movement in a cine-loop by making use of an array of transducer probes [11], it is not being investigated for this proposed study. This is mainly by taking into consideration that the movement of the fetus does not play an important role here and the proposed screening involves in extracting out the individual frame from the cine-loop sequences. The 4D matrix

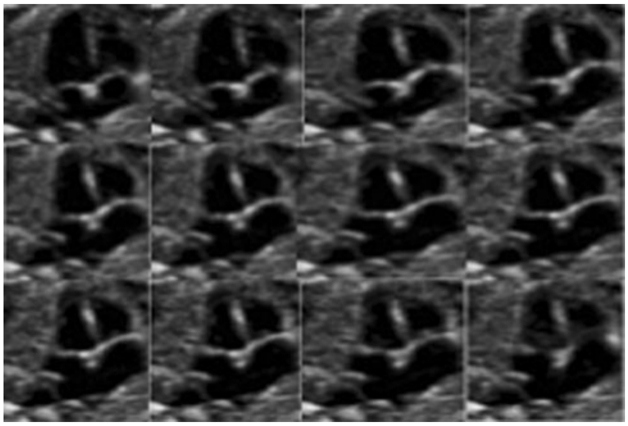

Fig. 4 Illustration of automatically detected ROI from 12 consecutive frames of a cine-loop sequence at different phase of a cardiac cycle of all fetal heart chambers (gestational age = 24th week)

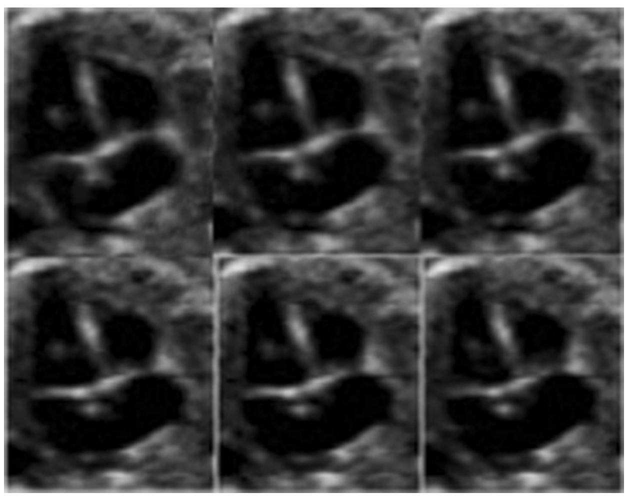

Fig. 5 Illustration of automatically detected ROI from six consecutive frames of a cine-loop sequence at different phase of a cardiac cycle of all fetal heart chambers (gestational age = 22nd week)

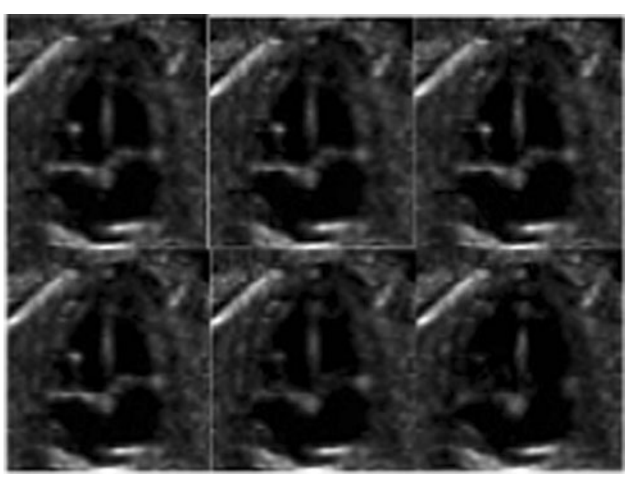

Fig. 6 Illustration of automatically detected ROI from six consecutive frames of a cine-loop sequence at different phase of a cardiac cycle of all fetal heart chambers (gestational age = 21st week)

array imaging make use of entire video sequences for the quantitative analysis.

5 Conclusions

It can be concluded that the proposed automated region mask scheme confirms the appropriate region recognition for the fetal heart chambers. Various frames belonging to the cine-loop sequences of different gestational age have been effectively detected for the ROI in spite of their different sizes and orientation. A suitable segmentation scheme shall be introduced to further enhance the chamber region.

Acknowledgments This work was supported by Mediscan Systems, Chennai, India.

Conflict of interest The authors declare that they have no conflict of interest.

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