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FETAL ULTRASOUND IMAGE SEGMENTATION USING FUZZY CONNECTEDNESS ALGORITHM

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ABSTRACT. Biometric measurements are important for fetal growth monitoring and anomaly detection. Manual measurement is time consuming and cumbersome in fetal ultrasound scans. Hence, Fuzzy Connectedness segmentation is proposed for segmenting fetal ultrasound images. The Fuzzy Connectedness Segmentation adapts to the fuzzy nature of the ultrasound images and this is a semi-automatic technique. The method could be used for specific anatomical segmentation for fetal biometric measurements with the use of seed points. The segmentation algorithm was validated on simulated ultrasound images and 300ultrasound fetal images achieving an accuracy of 90%.

1. INTRODUCTION

Ultrasound Monitoring fetal growth for the entire period of pregnancy is essential to reduce the increasing neonatal morbidity and mortality. Fetal growth are assessed using various biometric measurements such as Occipital Frontal Diameter (OFD), Biparietal diameter (BPD), Head Circumference (HC), Humer Length (HL), Femur Length (FL), Crown Rump Length (CRL) and Abdominal Circumference (AC). Fetal weight can be derived using above parameters indicating the health condition. Gestational Age (GA), and Estimated Delivery Date (EDD) are determined from the bio-metric measurements which are important parameters for risk assessment of the particular pregnancy.

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Presently, most of the obstetricians manually measure these parameters or at the least give seed points to the computer, such as indicating the end points of femur, inscribing ellipse around head and abdomen, fitting a line connecting top of head and bottom rump. Manual measurement has its own drawbacks: it takes time (decreasing the throughput in the busy schedule of the obstetricians), it is prone to errors, and operator suffers from repetitive stress injury (due to routine work for the entire period). To overcome these drawbacks, a number of automated segmentation and measurements has been developed. In this paper, fuzzy connectedness algorithm is used as a semi automatic method for fetal biometric measurements (FL, BPD, OFD, HC and AC).

The outline of the paper is as follows: In Section II, survey of current fetal segmentation methods is presented. In Section III, Fuzzy Connectedness (FC) Segmentation is dealt with. Section IV lists out the image evaluation metric used for assessing the performance of FC segmentation method for fetal ultrasound image segmentation. In Section V, results are discussed. The paper is concluded in Section IV.

2. Literature Review

There are a number of segmentation techniques for fetal ultrasound images. These techniques can be classified based on their technique or the biological structure on which the segmentation is applied. Most of the these techniques are morphological or intensity based techniques. A semi automatic segmentation technique was given by Chalana et al. [1] for segmentation of fetal head using active contour model. Hanna et al. [2] used normalized histogram analysis to form a binary image and later used 4D hough transform fit ellipse for head. K-mean clustering and morphological erosion, opening, and object recognition was performed by Lu et al. [3]. Then an iterative randomized hough transform was used for fitting ellipse. Mathews M. et al. [5] used shape based thresholds for preliminary segmentation followed by Chamfer matching and Hough transform. Thomas et al. [6] used shape based morphological operators to finally segment fetal femur structure. Shan et al. [7] used a class separable method for segmentation of fetus. Wang [8] gave entropy based segmentation and alternate edge based method for head segmentation. Jardim et al. [9] used deterministic iterative algorithm for head and femur detection. Femur is taken as 3 point spline and head as 8 point spline.

Ponomarev et al.[10] used shape and size based descriptors followed by Linear SVM to identify femur. The authors extracted texton features using a multi scale and multi oriented filter bank, specific for fetal anatomy. Few researchers used Fuzzy C means clustering to segment fetal abdomen and used an iterative randomized hough transform to final fetal abdomen. The constrained probabilistic boosting tree used for classification of fetal structures where each node is strong classifier. This algorithm has been converted as a ultrasound diagnostic tool sygno Auto OB. The extended absolute fuzzy connectedness (AFC) approach used for an affinity function using information from local phase features instead of image intensities alone.

3. FUZZY CONNECTEDNESS SEGMENTATION

There is an inherent fuzziness present in the ultrasound images. This approach is a region based segmentation technique. Fuzzy connectedness defines the strength of adjacencies of pixels within an image along with their spatial adjacency and intensity adjacency within a specific region. There are two components in Fuzzy connectedness algorithm:

- Local adjacency (affinity)
- Global adjacency (connectedness)

The local adjacency is defined by local fuzzy relation called affinity between any two adjacent pixel x and y. The hard adjacency, μ_α of between two pixels is given by Eq. 3.1

$$\mu_\alpha(x,y) = \begin{cases} 1; \text{ if x and y are identical or different} \\ \text{in one coordinate by 1} \\ 0; \text{ otherwise} \end{cases} \tag{3.1}$$

The affinity function depends on the region homogeneity and intensity difference values of the pixels compared to intensity value of the region of interest. The affinity function between pair of pixels, x and y is given by Eq. 3.2.

$$\mu_k(x,y) = \mu_\alpha(x,y)(w_1 G_1(f(x) - f(y))) + w_2 G_2(x-y), \tag{3.2}$$

where $G_j(x)$ function of pixel value. $f(x)$ and $f(y)$ are pixel intensities x and y respectively and x and y are the positions of the pixels. Global adjacency called fuzzy connectedness is determined using the above affinities. The largest of the strength of all paths between the pixels x and y gives the strength of connectedness between two pixels, x and y is given by as given in Eq. 3.3.

$$\mu_c(x,y) = max_{p_{xy}\in P_{xy}}\mu_k(P_{xy}), \tag{3.3}$$

where P_{xy} is set containing all possible paths p_{xy} from x to y. Every path between x and y, is a sequence of adjacent pixels from x and y. The minimum affinity between any pair of pixels gives the strength of the path along the path given by Eq. 3.4.

$$\mu_N(P_{xy}) = min_{j=0,1,2,\ldots,m-1}\mu_k(x,y_{j+1}). \tag{3.4}$$

When this local and global adjacency functions are applied, connectivity map is obtained. Thresholding this map gives the region of interest.

4. Quantitative and Qualitative Metrics

The following are the evaluation metrics used for validating the performance of the segmentation technique. Most of the existing segmentation researches utilize these indexes to compare the performance of various techniques in image segmentation, for this reason these measures are selected to evaluate our proposed algorithm. Let A be the ground truth of the segmentation (manual delineation by the radiologist) of the input image I, B be the segmentation result obtained using the proposed method.

- Jaccard Index (JI), $JI(B,A) = \frac{|A\cap B|}{|B|+|A|-|B\cup A|}$.
- Dice Coefficient (DC), $DC(B,A) = \frac{2\times|A\cap B|}{|B|+|A|}$.
- Variation of Information (VoI) - VoI gives shared information between ground truth, A and segmentation result, B by calculating information lost when changing from one to another. Lower the VoI better the segmentation.
- Probability Rand Index (PRI) - The probabilistic Rand index (PRI) calculates the consistency of labelling between the computed and the ground truth segmentations. A higher PRI indicates better performance.
- Global Consistency Error (GCE) - GCE measures the refinement of one segmentation as another method. Lesser GCE indicates better segmentation performance.

5. Results and Discussion

The fetal anatomical structures are segmented from ultrasound images using fuzzy connectedness technique implemented in MATLAB 9.2 (R2017a) and validated with synthetic image and clinical fetal ultrasound images. The synthetic image used in the evaluation of the fuzzy connectedness algorithm technique for segmenting fetal ultrasound image is shown in Fig. 1(a). Speckle noise of varying density such as 1%, 3%, 5%, 7% and 9% are added to the synthetic image and segmented using k means, EM (Expectation Maximization), FCM (Fuzzy C Means), FCM_S1, FGFCM, FLICM, EM, techniques in addition to the fuzzy connectedness algorithm. The qualitative analysis of the segmentation techniques on the speckled synthetic image is shown in Fig. 1.

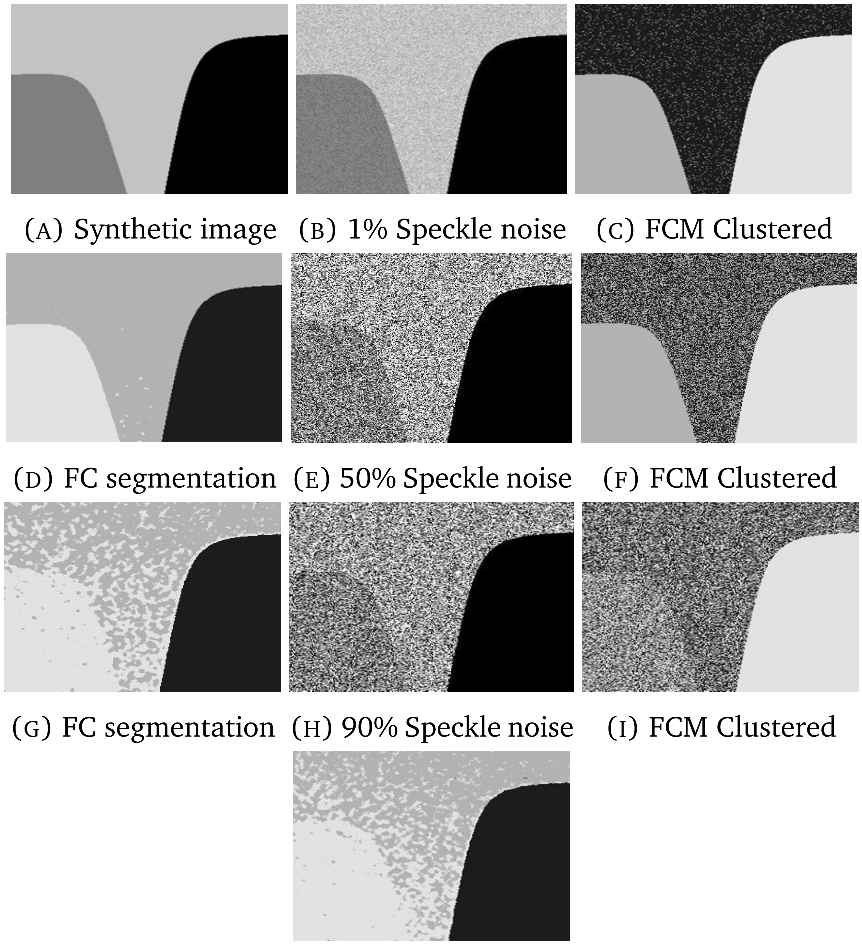
TABLE 1. Quantitative evaluation for various object of interest

Object of Interest	JI	DC	RI	GCE	VoI
Head	0.6853	0.8133	0.9184	0.0186	1.1229
Femur	0.7953	0.9023	0.9465	0.0236	0.8208
Abdomen	0.5861	0.7390	0.8604	0.0256	1.7488

The quantitative evaluation of the segmentation techniques is given in Fig. 2. It can be seen that the Fuzzy connectedness technique (FC) has higher segmentation quality in comparison with the other existing techniques.

Further, in terms of the evaluation metrics, the FC gives good results and performs consistently for all noise levels. The technique has been applied on 300 ultrasound images (100 fetal femur images, 100 cranial images and 100 abdominal images). The header and patient information are cropped and images of size 780 x 615 are selected for evaluation. The qualitative evaluation of the proposed technique in comparison with the existing techniques for abdomen, femur and head are given in Fig. 3-5, respectively.

The average evaluation metrics for head femur and abdomen segmentation in comparison with expert delineation are given in Table 1. It can be seen that the proposed method gives good results for head and femur segmentation since bony structures appear with high intensities. Abdomen segmentation using proposed method gives slightly less accurate results compared to manual segmentation due to varying appearance of these structures in ultrasound images.



(A) Synthetic image (B) 1% Speckle noise (C) FCM Clustered

(D) FC segmentation (E) 50% Speckle noise (F) FCM Clustered

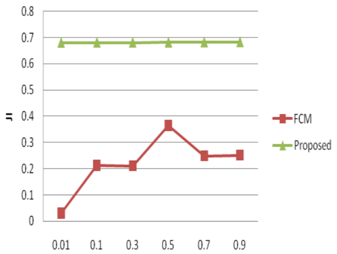
(G) FC segmentation (H) 90% Speckle noise (I) FCM Clustered

(J) FC segmentation

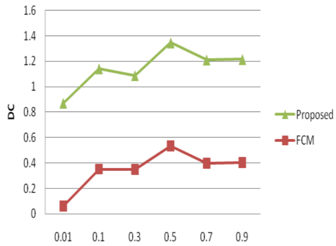
FIGURE 1. Qualitative analysis of the segmentation techniques

6. CONCLUSION

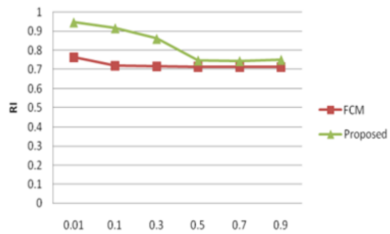
Fuzzy connectedness technique has been implemented for fetal ultrasound image segmentation. The clustering techniques such as K-means, EM, FCM, modified FCM and FC technique are validated using synthetic, and clinical ultrasound images. The performance of FC algorithms is measured using segmentation parameters such as SA, JI, PRI, VoI, and GCE. The computational results shows that the K-means image segmentation consumes less time but it provide poor result. From the computational results, it can be concluded that the FC



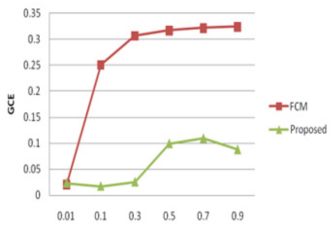
(A) Speckle Noise vs JI



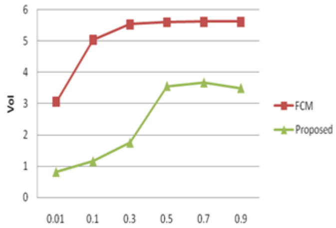
(B) Speckle Noise vs DC



(C) Speckle Noise vs RI



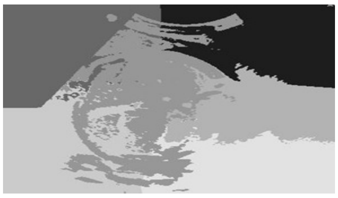
(D) Speckle Noise vs GCE



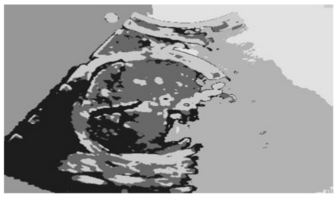
(E) Speckle Noise vs VoI

FIGURE 2. Quantitative analysis of evaluation metrics of FC Segmentation with conventional FCM for noisy Synthetic image

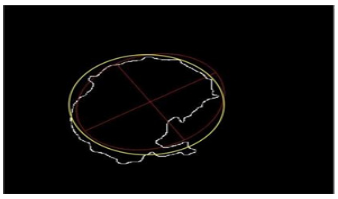
(A) Fetal abdomen image



(B) FCM Clustering



(C) FC Segmentation

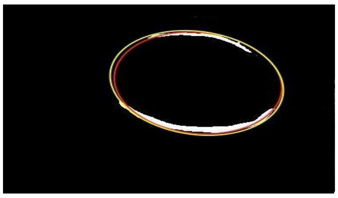


(D) FCS with manual

FIGURE 3. Qualitative analysis of Fetal abdomen UIS

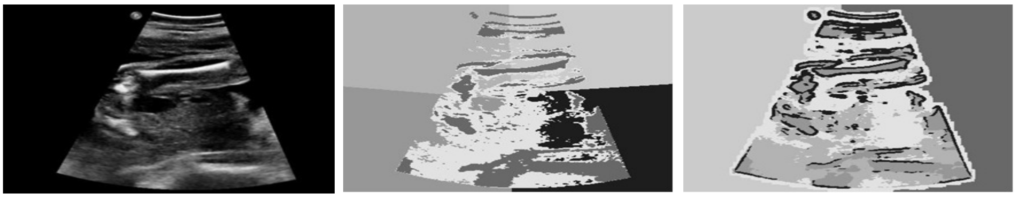
segmentation technique performed better than others in terms of performance accuracy for fetal ultrasound images.

(A) Fetal abdomen image (B) FCM Clustering (C) FC Segmentation



(D) FCS with manual

FIGURE 4. Qualitative analysis of Head femur UIS



(A) Fetal abdomen image (B) FCM Clustering (C) FC Segmentation

(D) FCS with manual

FIGURE 5. Qualitative analysis of Fetal femur UIS

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