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Automatic Segmentation of Fetal Brain from MRI of Human

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Abstract- **Fetal MRI is an essential tool for analyzing morphological changes of fetal brain structure. The automated methods developed for adult brain extraction are unsuitable for fetal brain extraction because of the differences in tissue types and tissue properties between adult and fetal brain. However, only few automated fetal brain segmentation methods are available. In this paper we propose a fully automatic method to extract fetal brain. The proposed method finds an ROI that encloses the fetal brain, using the anatomical geometry. An intensity threshold is computed using Otsu's method, from which a binary image is obtained for the ROI. Using anatomical knowledge the fetal brain is extracted. Experiments were performed on clinical in utero fetal MR volume and the results are validated against manual segmentation and quantified in terms of Dice (D) similarity coefficient, Sensitivity (S), Specificity (Sp) and Hausdorff distance (HD). The results emphasize the robustness of the method.**

Keywords- Dice Similarity Coefficient, fetal MRI, Hausdorff distance, Sensitivity, Specificity.

I. INTRODUCTION

Magnetic Resonance Imaging (MRI) of fetus is a rapidly growing field of study. Fetal MRI helps the neuroscientist and clinician to understand the evolution in the structure and size of fetal brain in utero which is the basis for adult brain structure and function. Therefore, segmentation techniques are being developed to extract fetal brain from MRI. In contrast to adult brain studies, automatic segmentation of fetal brain has limited in research. Few semi-automatic [1,2], automatic [3-6] and atlas based [7] methods have been reported for segmentation of brain from fetal MRI. The existing fetal brain segmentation algorithms have both strengths and weaknesses, also varied in different anatomic regions.

Since the fetal brain segmentation is essential for the diagnosis of normal and abnormal brain development and the study of the brain maturation, we have developed an automatic an automatic method to segment the CSF and brain based on intensity and anatomical knowledge. To evaluate the performance of the proposed method, we compute Dice coefficient, sensitivity, specificity and hausdorff distance by taking the manually segmented result as gold standard. The remaining part of the paper is organized as follows. In Section II, we present our method. The details of dataset are given in Section III, the experimental results and discussions are given in Section IV. The conclusion is given in Section V.

II. METHODS

The proposed scheme contains two major stages, image binarization and brain mask creation. The flow chart of the proposed method is shown in Fig.1.

A. Generating Binary Image

First, we use Otsu's thresholding technique [8] to estimate an intensity threshold for the MRI slice. Using T we obtain a binary image (B) from the given input image (I). Since fetal MR images have tissue intensity overlaps, Otsu's thresholding method is best suited for these types of images to produce binary images, among other thresholding methods. This method minimizes the weighted sum of within-class variances of the foreground and background pixels to find an optimum threshold. Minimization of within-class variance is equal to the maximization of between-class variance and an optimum threshold is given by [8].

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$$T_{opt} = argmax[P(T)(1 - P(T))(m_{fg}(T) - m_{bg}(T))^2] \quad (1)$$

where, P(T) is the cumulative probability from 0 to T, $m_{fg}(T)$ and $m_{bg}(T)$ are the mean value of the foreground and background pixels respectively at threshold T. The binary image (B) is obtained using T_{opt} as:

$$B(i,j) = \begin{cases} 1 & if I(i,j) \geq T_{opt} \\ 0 & otherwise \end{cases} \quad (2)$$

where i and j are the pixel coordinates in the input image I.

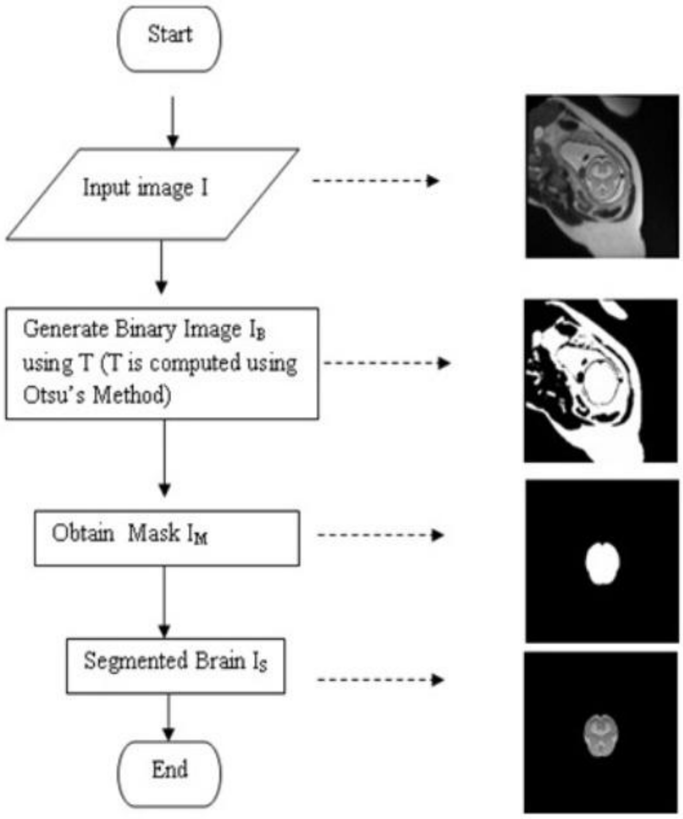

Figure 1. Flowchart of the proposed method

B. Mask Creation

Using the binary image B, we create a mask for the brain portion. The brain extraction completely depends on the anatomy of T2 scans. Medical experts opine that all the volumes which we collected for this work, contains fetal brain in the middle of the scan. Using this expert knowledge we start the process from the midpoint of the binary image B, with a value 1, and proceed in all the directions until a change from 1 to 0 occurs. If the process reads 0 then the position is marked as a boundary of ROI for all rows and columns. The brain mask is obtained as:

$$M(i,j) = \begin{cases} 1 & if B(i,j) = 1 \\ 0 & otherwise \end{cases} \quad (3)$$

C. ROI segmentation using Mask

The brain and CSF are extracted from the original image I using the mask M as:

$$Br(i,j) = \begin{cases} I(i,j) & if M(i,j) = 1 \\ 0 & otherwise \end{cases} \quad (4)$$

III. MATERIAL

We used six volumes (around 20 slices per volume) of retrospective fetal T2- w MR images which are acquired from 1.5T MRI (Wipro GE Medical Systems – SignaHDxt). The dimension of each slice is 256×256 pixels and number of excitations = 1. The slice thickness is 3.5mm with 3.7mm inter slice gap. The field of view = 300mm, flip angle =90^{o}, echo time (TE) = 89ms and relaxation time (TR) = 1308.74ms. Out of 20 slices in the volume, 8-10 slices contain fetal brain and these slices were used for our experiment. The remaining slices contain maternal, uterine and other fetal structures. Each slice, for all input volumes, has manually segmented of fetal brain, carried out by a medical expert of University of Washington Medical Center, Seattle, Washington.

IV. RESULTS AND DISCUSSION

We carried out experiments by applying our method on six volumes of axial and sagittal datasets, which containing the brain region. The extracted brain portions are shown in Figure 2.The hand segmented results are also provided in Figure 2 for comparison. Qualitatively, a visual insight of the segmentation (Figure 2) shows the accuracy of the method, even though a slight over-segmentation can be observed in lower slices. Column 2 shows the original MRI slices, 3 shows the hand segmented brain portion (gold standard) and 4 shows the brain portion extracted by the proposed method.

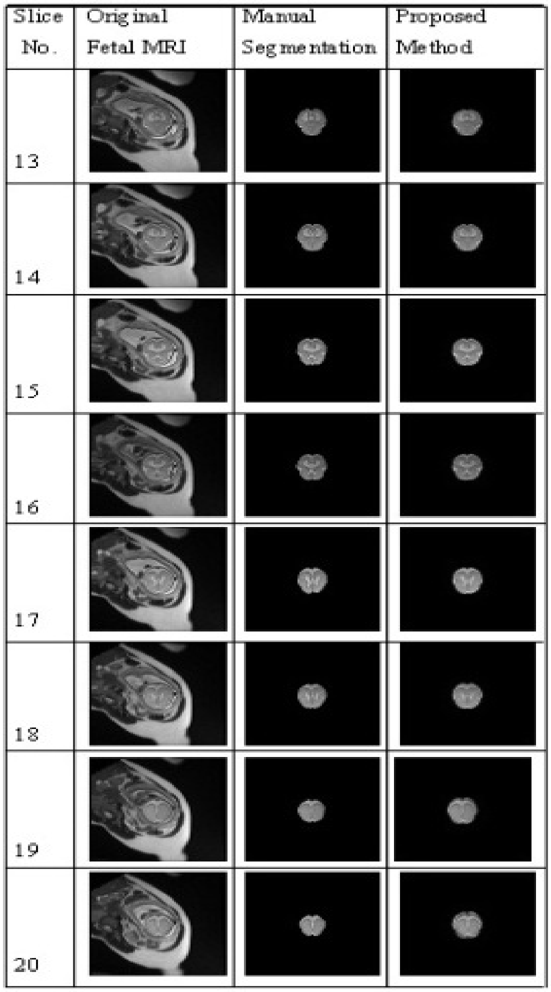

Figure 2. Sampe Fetal brain extracted. Column 1 shows the slice number, 2 the original MRI slices, 3, the hand segmented fetal brain and 4, the brain extracted by the proposed method.

For quantitative evaluation of the performance of the method, we computed the spatial overlap measures , the Dice (D)[9] coefficient, Sensitivity(S)[10] and Specificity (Sp)[10] between the gold standard (A) and our automated segmentation method (B). The D is given by:

$$D(A,B) = \frac{2\,|A\cap B|}{|A| + |B|} \quad (5)$$

The sensitivity S is the percentage of brain pixels recognized by the algorithm and specificity Sp is the percentage of non brain pixels recognized by the algorithm and are computed using the True Positive (TP), False Positive (FP), True Negative (TN) and False Negative (FN) values of brain extracted by an algorithm.TP and FP are the total number of pixels correctly and incorrectly classified as brain tissue by the automated algorithm. TN and FN are defined as the total pixels correctly and incorrectly classified as non-brain tissue by the automated algorithm (Figure 3).

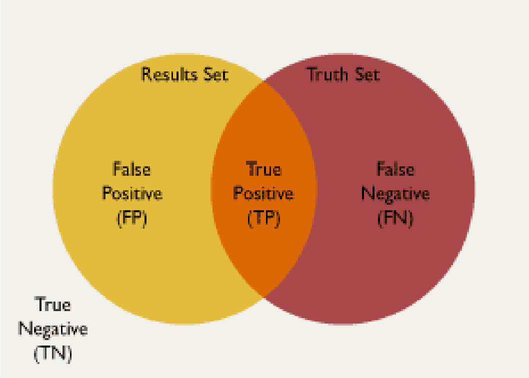

Figure 3. Evaluation metrics

$$S = \frac{TN}{TP+FN} \tag{6}$$

$$Sp = \frac{TN}{TN+FP} \tag{7}$$

Distance measures such as Hausdorff distance (HD) [11,12], compute the distance between manually and automatically segmented regions. The directed Hausdorff distance H_{ab}, (Figure 4) between two sets of points A and B can be obtained in a two stage approach. In the first stage, for each point in A the minimum distance to all points in B is obtained. H_{ab} is the maximum of this set of minimum distances. In the present case, the minimum distance for the i^{th} surface pixel in A to the set of surface pixels in Bis $d^{ab}{}_i$, therefore H_{ab} is the maximum value of the surface distance of all surface pixels in A (equation 8). The Hausdorff distance, H, is the maximum of the directed form for $A \rightarrow B$ and $B \rightarrow A$ in equation 9. Hence we calculate HD between our result and manual segmentation using equation 9.

$$\mathrm{H_{ab}} = \max\{d_i^{ab}\}, i = \{1 \dots n_a\} \tag{8}$$

$$\mathrm{H} = \max\{ H_{ab}, H_{ba} \} \tag{9}$$

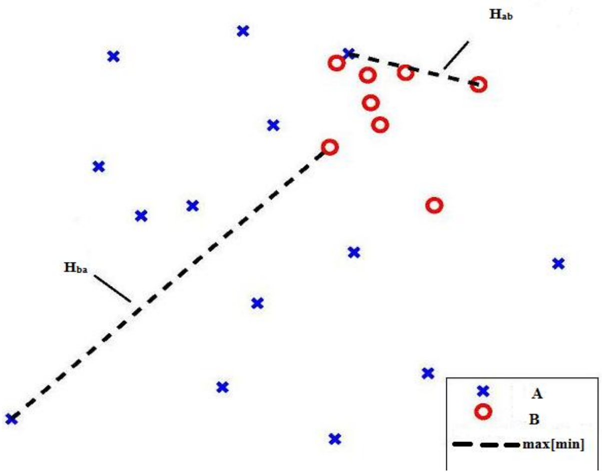

Figure 4. Hausdorff Distance

where a and b are points of sets A and B respectively.

All the parameters D, S and Sp are closer to a value 1 when the segmented results are closer to the gold standard and tends to 0 when it is in complete disagreement. For Hausdorff distance, the smaller the distance, the better is the segmentation. The computed average values of D, S, Sp and HD are given in Table I, for 6 volumes.

TABLE I. AVERAGE VALUES OF D, S, SP AND HD VALUES OBTAINED BY THE PROPOSED METHOD

Test Images		Dice (D)	Sensitivity (Sen)	Specificity (Sp)	HD(mm)
Orientations	**Vol. No.**				
Axial	1	0.9983	0.9970	**0.9817**	2.9298
	2	0.9980	0.9987	0.9566	2.8533
	3	0.9976	0.9981	0.9394	2.8747
	4	0.9977	0.9982	0.8622	3.6920
Sagittal	1	**0.9985**	0.9975	0.9801	**2.7759**
	2	0.9978	**0.9989**	0.9370	3.2491

TABLE II. D VALUE COMPUTED BY DIFFERENT ALGORITHMS

Author	No.of cases	Best Dice value
Bach Cuadra et al. (2009)	4	0.68
Caldairou et al.(2011)	6	0.77
Gholipour et al.(2011)	25	0.97
Kainz et al.(2014)	50	0.90
Keraudren et al. (2014)	66	0.93
Proposed method.	6	0.99

From Table I we observe that best values we got for D, S and Sp are 0.9985, 0.9989, 0.9817 respectively and the HD is 2.7759 mm. In order to compare the performance of our method, the quantitative measures obtained by other studies about the cortex segmentation in terms of Dice coefficient D and hausdorff distance HD are given in Table II and III.

TABLE III. HAUSDORFF DISTANCE COMPUTED BY A.JEREMIE ET AL. [3].

Algorithm	No.of cases	HD value (mm)
Automatic Segmentation of Head Structures on Fetal MRI (2009)	24	3.9
Proposed	6	2.77

The method proposed by M.B.Cuadra et al. [4] showed D values as 0.65 using 4 cases for their study. The main limitation of this work is that the errors performed at central nuclei region, so that they exclude basal ganglia from the segmentation process.B.Caldairou et al. [13] achieved D value around 0.77 with two-step approach including anatomical priors and structural constraints. Gholipour et al. [2] tested their work with 25 cases and showed the better D value 0.97. But their algorithm requires several pre-set threshold values and it is a supervised automated method as well. B.Kainz et al. [14] have presented D score 0.90 with 50 fetuses. The limitation of their work is that it will stop segmenting the region where there is a large anatomical abnormality and for border slices where only a few voxels were detected as brain. K.Keraudren et al. [15] have produced the fetal brain segmentation with mean dice value of 0.93. Table 2 and 3 shows the results for different data sets. The results are presented to know the range of values of the evaluation parameters obtained in different methods and the present one.

For qualitative evaluation, the results were evaluated by visual inspection by Neurological experts. The experts inspected the final outputs and confirmed that the results are acceptable and appreciated. Further works will include fetal brain segmentation for all the orientations with more number of datasets which consists of different gestational weeks

V. CONCLUSION

We have proposed an automated fetal brain segmentation method for fetal MRI. A combination of anatomical knowledge and intensity-based features are used to segment the fetal brain. Experimental results on T2 weighted MRI slices in 6 volumes show that the proposed method give results closer to manually segmented gold standard and is performing better than the earlier semi and fully automatic methods.

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