Segmentation of the nuchal fold in fetal ultrasound images

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ABSTRACT

The thickness of the nuchal fold is one of the main markers for the detection of Down syndrome during the second trimester of pregnancy. In this paper are reported our preliminary results of the automatic segmentation and measurement of the nuchal fold thickness in ultrasound images of the fetal brain. The method is based on a 2D active shape model used to segment the brain structures involved in the measurement of the nuchal fold: cerebellum; brain midline; the outer edge of the occipital plate; and the outer skin edge. The algorithm was trained and tested in 10 different ultrasound images, using leave one out cross validation. We have obtained an average difference of 0.23 mm from the expert measurement of the nuchal fold, with a standard deviation of 0.1 mm.

Keywords: Fetal nuchal fold, ultrasound imaging, active shape model.

1. INTRODUCTION

An increased nuchal fold (NF) thickness is associated with several fetal defects, genetic syndromes and adverse pregnancy outcome [1, 2]. The expert perinatologist uses a transaxial ultrasound volume of the fetal head to determine the NF thickness, the volume is angled posteriorly to include the cerebellum and the occipital bone. The expert selects an adequate ultrasound plane, within the volume, which should include, the following brain structures: septum pellucidum, cerebral peduncles (PC), cerebellar hemispheres (Cereb) and magnum cistern (CM). Following the direction of the median line, the nuchal fold is measured as the distance from the outer edge of the occipital plate to the outer edge of the skin (shown annotated in red in figure 1).

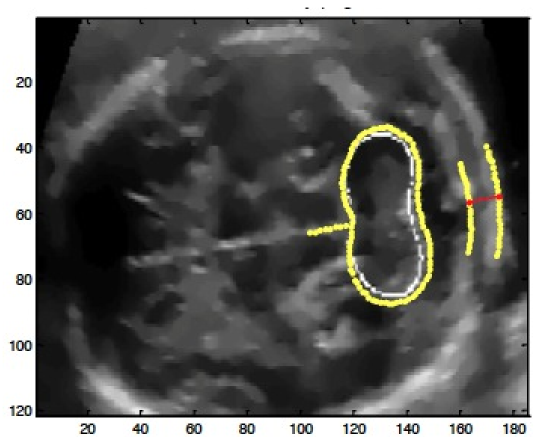

Figure 1. Annotation of the nuchal fold thickness, in a transaxial ultrasound plane. Annotated in yellow: median line; cerebellum; occipital plate; skin edge. The nuchal fold thickness is annotated in red.

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In this work is reported the development of an active shape model for the segmentation of the main anatomical references: the median line; the cerebellum; the outer edge of the occipital plate; and the outer skin edge. The nuchal fold is automatically measured as the distance between the segmented occipital plate and skin edges, along the median line. This paper has four sections. In the following section is described the 2D segmentation of the main anatomical references (cerebellum, median line; the outer edge of the occipital plate; and the outer skin edge). In section 3 the experiments performed and the results of the segmentation of anatomical references, and the calculation of the nuchal fold are reported. Section 4 includes the conclusions of the reported work.

2. TWO-DIMENSIONAL SEGMENTATION OF THE MEDIAN LINE, THE CEREBELLUM, THE OUTER EDGE OF THE OCCIPITAL PLATE, AND THE OUTER SKIN EDGE

A 2D ASM of the median line, the cerebellum, the outer edge of the occipital plate and the outer skin edge was used for the segmentation of these structures on the central image plane of the cerebellum, following the method proposed by Cootes et al. [3]. We used a training set of 9 examples of all shapes as shown in figure 2.

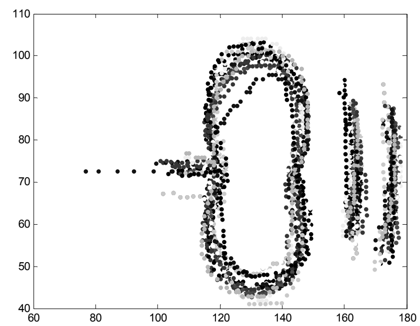

Figure 2. Training set of the ASM of the median line, cerebellum, occipital plate and skin edge

On each shape we sampled a different number of points, to construct a 2D Point Distribution Model (Cootes et al. [3]), of each structure of interest: the median line (8 points), the cerebellum (100 points), the outer edge of the occipital plate (25 points), and the outer skin edge (25 points). In figure 3 is shown the mean shape and 3 of the main modes of variation of the PDM.

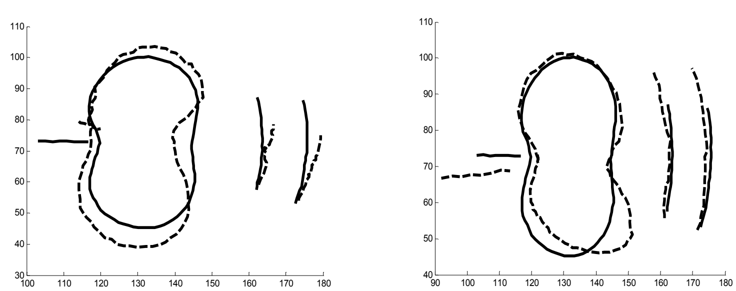

Figure 3. First variation mode of the PDM of the median line, cerebellum, occipital plate and skin edge. Left column: shape variations corresponding to $-3\sqrt{\lambda_k}$; Right column: shape variations corresponding to $3\sqrt{\lambda_k}$

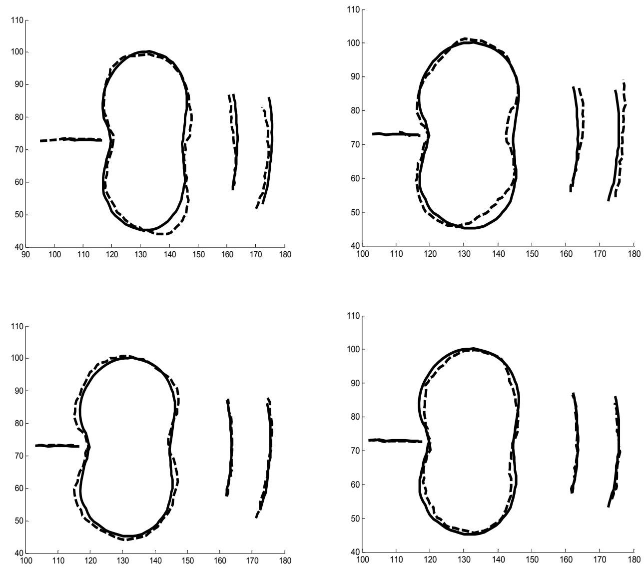

Figure 3. (Cont.) Second and third variation modes of the PDM of the median line, cerebellum, occipital plate and skin edge. Left column: shape variations corresponding to $-3\sqrt{\lambda_k}$; Right column: shape variations corresponding to $3\sqrt{\lambda_k}$

An automatic method for adjustment of a 2D PDM to an object in an image, was reported by Cootes et al.[3] and named Active Shape Model. The method is based on gray level models of pixel profiles for each point of the PDM. These models are used in an iterative search along the normal of each point of the PDM. We sampled gray level models of 21 pixels and used a search profile of 30 pixels. The use of derivatives for image search showed improvements in the accuracy of the adjustment of an ASM. The 2D ASM is manually initialized by placing the average shape in a position roughly located in the center of the cerebellum. The scale is initialized to one, and a rotation of 5.72 ° is used, which is the average slope of the middle line in the set of training images (figure 4).

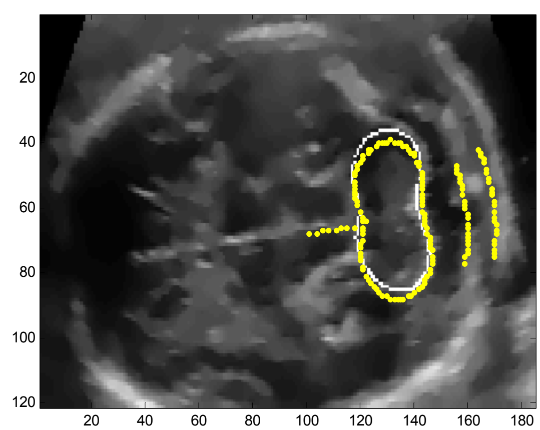

Figure 4. ASM initialization (in yellow) next to the cerebellum (shown in white)

Once the anatomical references in the midplane of the cerebellum have been segmented, it is possible to measure the

NF. First, the midline is extrapolated by linear regression and the NF is measured between the outer edge of the occipital plate and the skin edge, as reported in the following section.

3. EXPERIMENTS AND RESULTS

A set of ten modified axial ultrasound volumes was acquired from different patients at the National Institute of Perinatology (INPer) in México; the gestational time period was 18 to 24 weeks. Informed consent of all patients was obtained. We trained our shape model using a ten mode cross-validation (leave one out), on each validation the training set of the 2-D ASM consisted of 9 annotated images located at the central plane of the cerebellum, containing the median line, the cerebellum, the outer edge of the occipital plate and the outer skin edge, as determined by an expert sonographer.

3.1 Segmentation of the nuchal fold

The reference structures (median line, cerebellum, outer edge of the occipital plate and outer skin edge) were automatically segmented on the midplane using the ASM reported in the previous section. In table 1 are shown the segmentation errors, measured as the Hausdorff distance[4] with respect to expert annotations. In figure 5 are shown 3 different examples of the segmentation results of the ASM.

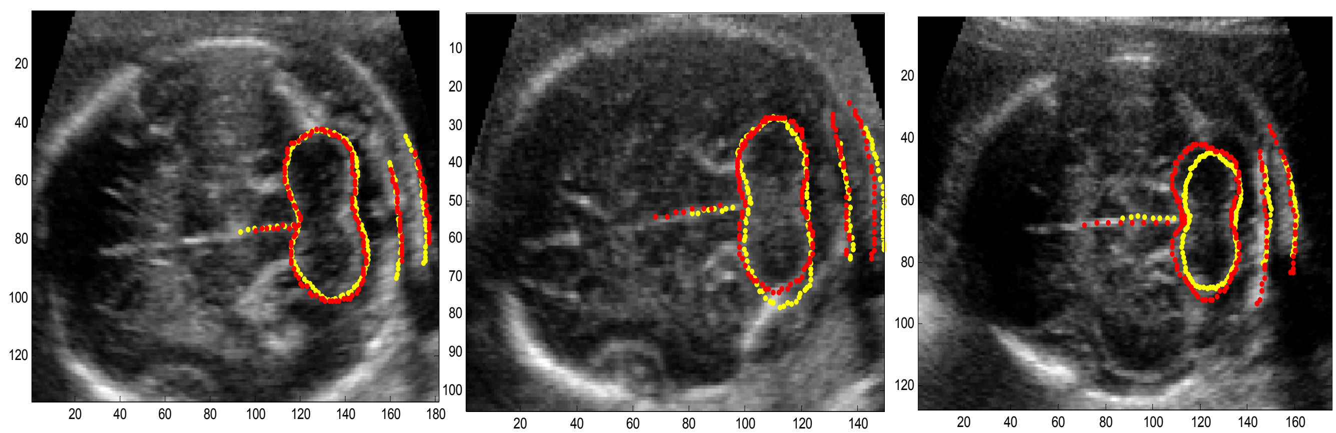

Figure 5. Image segmentation examples (shown in yellow), expert annotation shown in red.

Table 1. Segmentation errors: Hausdorff distances [in mm]

image	midline	cerebellum	occipital plate	skin border
1	3.4769	1.1963	2.6241	2.8862
2	3.7761	1.1328	3.3476	3.9596
3	1.5099	1.3505	1.3763	1.8427
4	1.6719	1.5726	1.043	1.684
5	1.4094	1.6748	1.566	1.7806
6	2.0983	0.7468	2.0666	2.2549
7	5.1646	1.8814	3.2568	3.5694
8	8.2544	2.0596	3.6509	4.7901
9	1.7768	1.7827	2.9402	9.1185
10	7.6057	3.2337	6.0681	5.8101
mean	3.67	1.66	2.79	3.77
std. dev.	2.55	0.67	1.45	2.33

3.2 Nuchal fold measurements

The error in the automatic measurement of the nuchal fold was calculated as:

E= (automatic_value- expert_value)/expert_value

Table 2. Nuchal fold measurements and errors

image	expert [mm]	automatic [mm]	difference [mm]	E [%]
t	5.0132	4.8452	0.1680	3.351
2	4.3621	4.6035	0.2409	5.522
3	4.7636	4.9368	0.1732	3.635
4	4.5267	4.3319	0.1948	4.303
5	5.4591	5.131	0.3281	6.01
6	3.9958	3.8095	0.1863	4.662
7	4.4987	4.3456	0.1531	3.403
8	4.9661	5.1584	0.1922	3.87
9	3.8386	3.6616	0.1770	4.611
10	6.3806	6.8786	0.4979	7.803
mean	4.78	4.77	0.23	4.72
std. dev.	0.74	0.9	0.1	1.39

4. CONCLUSIONS

Our results, in the validation set of 10 images, show an average difference of 0.23 mm between expert and automatic measurement of the nuchal fold, which corresponds to a 4.72% error. This seems encouraging for further development of a fully automatic method for the measurement of the nuchal fold in ultrasound volumes of the fetal brain. The main source of error in the automatic measurement seems to be due to segmentation errors produced by the ASM, further training on a larger set should improve the segmentation results, as well as improved gray level edge training. The variability among several experts needs to be evaluated, during clinical validation, in order to assess the expert errors in nuchal fold measurement. Additionally, in order to have a fully automatic volume analysis method, we will develop a strategy to automatically select the image plane to perform the nuchal fold measurement.

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