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● *Original Contribution*

AUTOMATIC DETECTION OF STANDARD SAGITTAL PLANE IN THE FIRST TRIMESTER OF PREGNANCY USING 3-D ULTRASOUND DATA

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Abstract—Fetal nuchal translucency (NT) thickness is one of the most important parameters in prenatal screening. Locating the mid-sagittal plane is one of the key points to measure NT. In this paper, an automatic method for the sagittal plane detection using 3-D ultrasound data is proposed. To avoid unnecessary massive searching and the corresponding huge computation load, a model is proposed to turn the sagittal plane detection problem into a symmetry plane and axis searching problem. The deep belief network (DBN) and a modified circle detection method provide prior knowledge for the searching. The experiments show that in most cases, the result plane has small distance error and angle error at the same time—88.6% of the result planes have a distance error less than 4 mm and 71.0% have angle error less than 20°. (E-mail: jhyu@fudan.edu.cn)

Key Words: **Sagittal plane detection, Deep belief network, Symmetry detection, 3-D ultrasound data.**

INTRODUCTION

Each year, an estimated 7.9 million children are born with a serious defect of genetic or partially genetic origin (Christianson et al. 2005). Serious birth defects can cause death. For those who survive, such disorders will make them lifelong disabled. Ultrasound imaging is widely used in prenatal screening due to its safety, non-invasive nature, real time display and low cost. In ultrasound images, the nuchal translucency (NT)—the accumulation of fluid in the nuchal region—is visible during the first trimester (Zoppi et al. 2003). The NT thickness is defined as the maximum distance between the upper and lower edge boundaries of the NT region of ultrasound images. The thickness of NT in the first trimester of pregnancy has been proven to be one of the most important parameters in prenatal screening. It has been understood that a high proportion of fetuses with trisomies 13, 18 and 21 as well as congenital heart disease and other genetic syndromes have increased NT thickness (Hyett 2003; Ma 2015; Nicolaides 2004). In clinics, the measurement of NT is manually carried out by a sonographer. Sonographers first need to determine the fetal position and identify the standard mid-sagittal plane. The NT measurement is then done in the standard mid-sagittal plane. These operations require high skill and abundant experience. Increasing deviation away from the mid-sagittal plane may cause underestimation or overestimation of the NT thickness and will eventually result in a larger possibility of misdiagnosis (Abele et al. 2010). However, detecting the mid-sagittal plane is challenging. First, the ultrasound data have a low signal-to-noise ratio (SNR). Second, fetuses at $11–13^{+6}$ wk are quite small, with a crown–rump length (CRL) of about 35–90 mm (Pexsters et al. 2010; Sahota et al. 2009). Several requirements should be met for a standard mid-sagittal plane: the clear presence of the tip of the nose anteriorly, the translucent mid-brain in the middle and the nuchal membrane posteriorly as well as the maxillary bone with a rectangular shape (Plasencia et. al 2007). Third, since the 3-D data are complex with many structures of fetus and mother, and the computation load of 3-D searching is extremely heavy, plane detection in 3-D data is computationally complicated. Due to the importance of the NT, some automatic NT detection methods have been proposed in the literature (Bernardino et al. 1998; Catanzariti et al. 2009; Deng et al. 2012; Lee et al. 2007; Nirmala and Palanisamy 2009; Wee et al. 2010). Most of them are

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applied to 2-D images, focusing on the detection of the NT boundaries based on the region of interest manually selected in the standard mid-sagittal plane (Bernardino et al. 1998; Catanzariti et al. 2009; Lee et al. 2007; Nirmala and Palanisamy 2009). Several approaches for locating the NT region have been published. Wee et al. (2010) trained an artificial neural network to locate the NT region automatically. A hierarchical model is proposed by Deng et al. (2012) for the automatic detection of the NT region using the spatial constraints among the NT, the head and the torso of fetuses respectively. Above all, the existing methods on NT detection are still semi-automatic, as they all require manually identifying the standard mid-sagittal plane.

Jung et al. (2012) proposed a method for mid-sagittal plane detection using face detection and landmarks, which can evaluate an ultrasonic image corresponding to the mid-sagittal plane or not. Anzalone et al. (2013) proposed an approach to detect the sagittal-view plane based on the location of the jawbone using video stream data. However, these approaches are implemented on 2-D images or video stream data instead of 3-D volume data. Wee et al. (2011), employing 3-D ultrasound data, developed an interactive approach to support the sagittal-view detection for NT measurements. However, the approach is still semi-automatic because it requires manual interactions with an operator. Carneiro et al. (2008) studied the use of the global/semi-local context and sequential sampling for automatically detecting the fetal anatomies in 3-D ultrasound data, where the detection of the sagittal plane is also included. Sofka et al. (2014) used a sequential estimation and integrated detection network to do a similar thing. In such methods, annotated 3-D ultrasound volumes are needed for training. However, these two methods aim at 3-D ultrasound data in which the fetal head appears at most of the data space. Chen et al. (2015) introduced a hierarchical model to automatically detect the standard sagittal plane based on 3-D ultrasound data. This provides an automatic mid-sagittal detection method for complex 3-D data including uterus, fetal head and torso, but the accuracy still needs to be improved. In conclusion, the previous sagittal plane studies still have some shortcomings. For instance, they cannot deal with a 3-D ultrasound data containing many structures of the mother and fetus or do not have enough accuracy. An efficient automatic method for sagittal plane detection is still lacking.

In this paper, an automatic sagittal plane detection method is proposed, which is applied to complex 3-D ultrasound data (containing not only the fetal head, but also other structures of the fetus and mother). The method combines the information of middle slice and the whole 3-D ultrasound data. To avoid the complexity of 3-D rotation and computation, a model with six parameters ($x, y, z, r, \theta, \varphi$) is constructed. Using the model and the symmetry of the fetal head, the sagittal plane detection can be turned into a symmetry plane and axis detection problem. The neighborhood searching method is used for the parameter searching. Considering that searching in the entire data space is complex and time consuming, and that the fetal head has the most symmetry, we narrow the searching space to the fetal head region. The deep belief network (DBN) and modified circle detection are used to detect the position and size of the fetal head. The DBN extracts high level features to detect an image patch fully containing the fetal head. The modified circle detection reduces lots of undesirable edges by directional edge detection, and then determines the accurate position and size of the fetal head by Hough transformation from the edge image. With the accurate parameters of the fetal head, an optimal initial searching point is determined and the searching space for the symmetry plane detection is considerably reduced.

MATERIALS AND METHODS

The experiments are conducted on a data set composed of 346 3-D clinical ultrasound images of fetuses at 11–13^{+6} wk. These data are collected from 204 patients using a Philips iU22 Ultrasound System (Philips, Amsterdam, Netherlands) with a V6-2 probe in the Shanghai First Maternity and Infant Hospital, China. Two or more data are collected at different scanning angles for some of the patients. The study was approved by the institutional review board, and each patient was informed about and consented to participate in the study. The size of data is variable. The mean size along each axis is 431.4 pixels ± 19.3 pixels, 479.1 pixels ± 51.1 pixels and 255.4 pixels ±6.5 pixels, respectively, with the pixel spacing variant in each axis. The data sets are first aligned with a pixel spacing of 0.4 mm.

Method overview

The method can be divided into three steps, among which the first two steps are applied onto the 2-D middle slice and the third step is on the 3-D data set. Assuming that the size of a single 3-D ultrasound data is $M \times N \times L$, the middle slice is the plane $z = L/2$, as shown in Figure 1. First, a DBN is built to detect an image patch fully containing the fetal head from the middle slice of the 3-D ultrasound data. The input of the network is an image patch, and the output is the probability that the patch fully contains the fetal head. By searching the testing slice exhaustively, a result patch with the highest possibility is chosen as candidate one. Second, the position and size of the fetal head in the image patch are detected using an enhanced circle detection method. In order to weaken undesirable edges, a novel directional filter is proposed. Each candidate image patch is divided into eight regions according to the direction, and eight Kirsch edge operators