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A hierarchical model for automatic nuchal translucency detection from ultrasound images

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ABSTRACT

The nuchal translucency (NT) thickness is an important parameter in the diagnosis of fetuses. The previous computerized methods often require manual operations to select the NT region, which leads to the time-consuming problem and the detection variability. In the paper, a hierarchical model is proposed for the automated detection of the NT region. Three discriminative classifiers are first trained with Gaussian pyramids to represent the NT, head and body of fetuses respectively. Then a spatial model is proposed to denote the spatial constrains among them. Finally the dynamic programming and generalized distance transform are applied for the inference from the proposed model, which ensures that the optimal solution can be obtained for the NT detection. The direction problem of fetuses is resolved by the introduced "OR" node. The performance of the proposed model is verified by the experimental results of 690 clinical NT ultrasound images.

1. Introduction

Ultrasound imaging is widely used in the diagnosis of fetuses due to its noninvasive nature, real time display, low cost and continuing image quality improvements. In the ultrasound image, the nuchal translucency (NT) which is the accumulation of fluid in the nuchal region can be shown for fetuses during the first trimester [1]. During 10–14 weeks of the gestation, a high proportion of fetuses with trisomies 13, 18 and 21 as well as Turner's syndrome and triploidies have ultrasonographically detectable NT thickness of at least 3 mm [2]. Even in the presence of a normal karyotype, a bigger value of the NT thickness is also associated with structural defects and genetic syndromes [3]. The NT thickness in the first trimester of pregnancy has proved to be one of the most discriminating parameters [4].

The NT thickness is defined as the maximum distance between the upper and lower high-intensity boundaries of the NT region. Nowadays the measurement of the NT is usually carried out by doctors. This requires highly skilled operators and the measurement is often time-consuming. Due to the low resolution and the complexity of NT ultrasound images, there are fewer studies on the computerized measurement of the NT. Bernardino et al. proposed to use the Sobel operator to help doctors manually detect the border of the NT [5]. Lee et al. proposed a cost function to define the boundary of the NT [6,7]. The cost function consisted of the gradient part and the continuous part. Then the NT boundary was searched by the dynamic programming. Based on this work, Catanzariti et al. improved the performance by further modifying the cost function [8]. However all these methods need the operators to manually select the region of interest (ROI) in which the NT thickness is measured. This process is important and essential for the accurate measurement in these methods. However, such manual operation makes these methods semi-automated. It may also be time-consuming to some extent for doctors and lead to the variability of detected data. The automated detection of the NT region can solve these problems. But it is hard to be realized because of the low resolution and complexity of NT ultrasound images and has not been reported in the previous literature.

In the paper, we propose a hierarchical model and try to realize the automated detection of the NT region. The remainder of this paper is organized as follows. Section 2 describes the statistical framework of the proposed model. In Sections 3 and 4, learning and inference from the proposed model are described respectively. Section 5 presents the experimental results on 690 clinical NT ultrasound images. Finally conclusions are drawn in Section 6.

2. Statistical framework

Object detection is an important task in computer vision. With the low-level information (such as pixel, texton level), how to

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efficiently learn the object structure or contextual information is the major problem nowadays [9–11]. From this point of view, it tries to simulate the cognitive process of human visual system [12].

For the NT detection, doctors could recognize the ROI accurately based on the contextual information from the whole ultrasound image rather than only the properties of the NT region. The contextual information in the NT ultrasound image mainly includes the information of the body and head of fetuses [13], which are relatively easy to recognize compared with the NT. The accurate recognition of the NT region is realized only when the NT, body and head of fetuses have the most possible configuration.

Such process can be considered as maximizing the joint probability $p(X_{NT}, X_{head}, X_{body}|I)$, where X_{NT}, X_{head}, X_{body} are the location parameters representing the NT, head and body of fetuses respectively given the ultrasound image I. For further precise description, the probability should be written as $p(X_{NT}, X_{head}, X_{body}|I,\theta_{NT},\theta_{head},\theta_{body})$, where θ_{NT}, θ_{head}, θ_{body} represent the models of the prior knowledge for the NT, head and body of fetuses respectively and are assumed independent each other. Then we can have

$$\begin{aligned} &p(X_{NT}, X_{head}, X_{body}|I,\theta_{NT},\theta_{head},\theta_{body}) \\ &\quad \propto p(X_{NT}|I,\theta_{NT},\theta_{head},\theta_{body}) \cdot p(X_{head}|I,\theta_{NT},\theta_{head},\theta_{body}) \\ &\quad \cdot p(X_{body}|I,\theta_{NT},\theta_{head},\theta_{body}) \cdot p(X_{NT}, X_{head}, X_{body}) \\ &\quad = p(X_{NT}|I,\theta_{NT}) \cdot p(X_{head}|I,\theta_{head}) \\ &\quad \cdot p(X_{body}|I,\theta_{body}) \cdot p(X_{NT}, X_{head}, X_{body}) \end{aligned} \quad (1)$$

where $p(X_{NT}|I,\theta_{NT})$, $p(X_{head}|I,\theta_{head})$, $p(X_{body}|I,\theta_{body})$ are the conditional probabilities for each object. $p(X_{NT}, X_{head}, X_{body})$ denotes the relationship among the NT, head and body of fetuses from the prior knowledge.

Here we establish a hierarchical model for the NT detection as shown as Fig. 1. This graphical model represents the way of the human cognitive process. When given a NT ultrasound image, the whole body of the fetus is first recognized and located. Then the NT region and the head of fetuses can be inferred from the image based on the knowledge of the body. Meanwhile the recognized NT region and head could further support or improve the recognition of the body of fetuses. The established graphical model appropriately denotes such causal relationship among objects of the NT region, head and body. From this point of view, the primary contextual information of the NT region can be represented by such model. The "tree" structure also guarantees the inference process converge to the optimal solution for the NT detection.

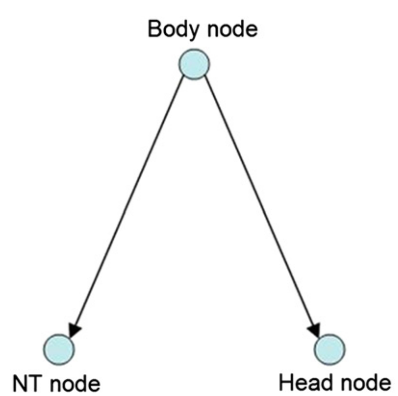

Fig. 1. The hierarchical model for the NT detection.

Based on the graphical model, the prior term $p(X_{NT}, X_{head}, X_{body})$ in Eq. (1) can be factorized as

$$p(X_{NT}, X_{head}, X_{body}) = p(X_{NT}|X_{body}) \cdot p(X_{head}|X_{body}) \cdot p(X_{body}) \quad (2)$$

where $p(X_{NT}|X_{body})$ denotes the spatial relationship between the NT and body while $p(X_{head}|X_{body})$ denotes the spatial relationship between the head and body. The prior term $p(X_{body})$ can be considered as a uniform distribution in the image, which means the body of fetuses has the equal probability to appear anywhere in the image without other prior information. So in the graphical model, each node denotes the conditional probabilities of three different objects and each link denotes the corresponding spatial relationship in Eq. (2). How to efficiently learn the model is described in the next section.

3. Learning the model

Since in practice fetuses may be shown with two different directions in ultrasound images as shown in Fig. 2, we modify the graphical model of Fig. 1 as the one in Fig. 3. The top node is an "OR" node which is utilized to select the result with the right direction. This is done by comparing the responses of its two subtrees.

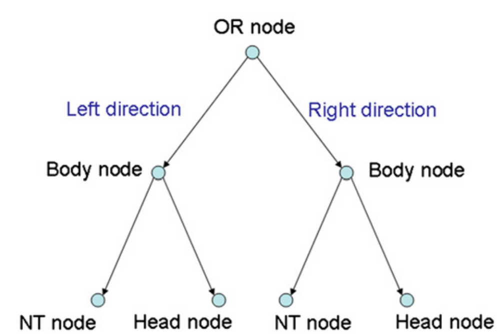

Fig. 3. The modified hierarchical model for real applications.

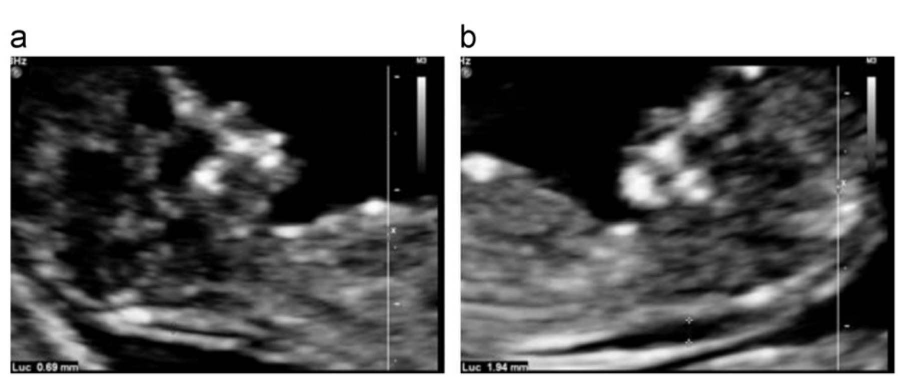

Fig. 2. Fetal ultrasound images with two different directions.