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Automatic detection and measurement of nuchal translucency

Giuseppa Sciortino[a], Domenico Tegolo[a,b,c], Cesare Valenti[a,*]

[a] Dipartimento di Matematica e Informatica, Università degli Studi di Palermo, Italy
[b] Centro Interdipartimentale di Tecnologie della Conoscenza, Università degli Studi di Palermo, Italy
[c] Mediterranean Center for Human Health Advanced Biotechnologies, Palermo, Italy

A R T I C L E I N F O

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A B S T R A C T

In this paper we propose a new methodology to support the physician both to identify automatically the nuchal region and to obtain a correct thickness measurement of the nuchal translucency. The thickness of the nuchal translucency is one of the main markers for screening of chromosomal defects such as trisomy 13, 18 and 21. Its measurement is performed during ultrasound scanning in the first trimester of pregnancy. The proposed methodology is mainly based on wavelet and multi resolution analysis. The performance of our method was analysed on 382 random frames, representing mid-sagittal sections, uniformly extracted from real clinical ultrasound videos of 12 patients. According to the ground-truth provided by an expert physician, we obtained a true positive rate equal to 99.95% with respect to the nuchal region detection and about 64% of measurements present an error equal to 1 pixel (which corresponds to 0.1 mm), respectively.

1. Introduction

Down's Syndrome (namely DS), identified in 1886 by Dr. Langdon Down, is a genetic condition that causes a variable degree of delay in mental, physical and motor development. It is caused by the presence of an extra chromosome in the nucleus of every cell (47 in comparison with a normal number of 46) in the twenty-first pair; for this reason DS is often indicated as trisomy 21. Its causes are still unknown and therefore there is no real way of prevention. Early in the 70's, the maternal age was the first element to deduce the probability for the fetus to present a chromosomal defect.

During the last few years it has been demonstrated [1,2] that there is a correlation between DS and some ultrasound and biochemical markers. Maternal age and biochemical markers present in maternal serum (dosages of Free Beta-HCG and Papp-A) are used to identify about 50–70% of fetuses affected by DS [3]. Due to the study of sonographic markers such as nuchal translucency (NT) it is possible to achieve a better detection rate of 90%, which increases to 95% when analysing also the nasal bone. These examinations provide a good alternative to invasive tests, such as amniocentesis (i.e. the analysis of the amniotic liquid) and chorionic villus sampling, which present a greater accuracy but introduce a risk of miscarriage or fetal injury of 2% and 1% for the chorionic villus sampling and amniocentesis [4,5] respectively. Amniocentesis should be performed between the fourteenth and twentieth week of gestation and it is associated with an increased risk of respiratory distress syndrome and pneumonia, while chorionic villus sampling, which may cause general birth defects, should not be performed before the eleventh week.

Nuchal translucency (see Fig. 1) is a fluid fill under the necks skin of the fetus which appears sonographically as an anechogenic area (i.e. a dark zone in greyscale images) between two echogenic regions (i.e. bright zones). The thickness of the nuchal translucency, also called the diameter, is related not only to DS, but also to other genetic abnormalities such as Edwards' (trisomy 18), Palau's (trisomy 13), Turner's syndromes and defects related to the heart [6]. The optimal period to measure the NT thickness lies between the eleventh and the thirteenth weeks, when the NT reaches the maximum thickness, then after this period tends to disappear. During this period it also possible to verify other eventual complications, including miscarriage, stillbirth, preeclampsia, gestational diabetes mellitus, preterm delivery, fetal growth restriction and macrosomia (Table 1).

The measurement of the NT requires non-trivial sonographer skills and the Fetal Medicine Foundation (FMF) has drawn up a protocol about these requirements in order to ensure correct measurement. The purpose of this article is to propose an effective tool to support early diagnosis by the automatic measurement of NT; the proposed methodology is able to automatically locate the neck region, to identify the nuchal translucency and to measure its thickness without any user intervention, thus obviating the inter- and intra- observer variabilities.

* Corresponding author.
E-mail addresses: giuseppa.sciortino04@unipa.it (G. Sciortino), domenico.tegolo@unipa.it (D. Tegolo), cesare.valenti@unipa.it (C. Valenti).

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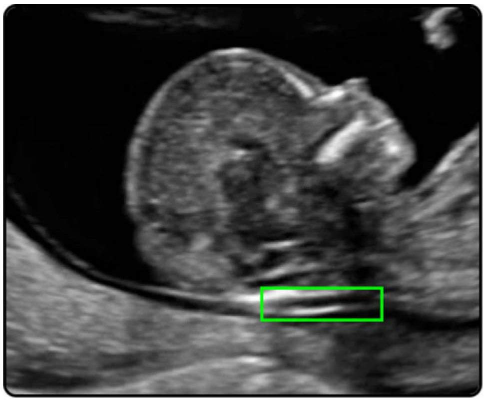

Fig. 1. The green rectangle indicates the hyperechogenic regions that delimit the nuchal translucency.

Table 1
Nomenclature and variables.

DS	down's Syndrome, also known as trisomy 21
NT	nuchal translucency
FMF	Fetal Medicine Foundation
H.264	moving Picture Experts Group 4 Part 10 Advanced Video Coding
μ	mean of the values of a given image
σ	standard deviation of the values of a given image
I	input greyscale image
ℓ_i	level i of the low-pass kernel of the *à trous* algorithm
$\mathbf{q}$	generic pixel that spans ℓ_i
$\mathbf{p}$	generic pixel that spans a given image
I_i	level i of the convolution of the *à trous* algorithm
W_i	level i of the wavelet coefficients of the *à trous* algorithm
C	thresholded version of W_6 only
B_i	thresholded version of W_i
k	parameter to threshold W_i in B_i
B	image composition of $B_{4,5,6}$ through voting strategy
$A(A_x, A_y)$	coordinates of the leftmost upper pixel of the nuchal translucency bounding box
$B(B_x, B_y)$	coordinates of the rightmost lower pixel of the nuchal translucency bounding box
(X,Y)	coordinates of the centre of the circle that inscribes the head
R	radius of the circle that inscribes the head
M	abscissa of the rightmost pixel of the mandible
D_r	discrete disk with radius r pixels
ε_r	mathematical morphology erosion with structuring element D_r
δ_r	mathematical morphology dilation with structuring element D_r
ρ	mathematical morphology edge detector

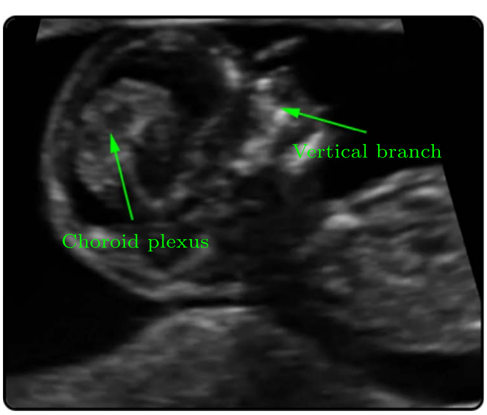

Fig. 2. The presence of the vertical branch of the jaw bone and the choroid plexus indicates that the considered section is not mid-sagittal.

2. Related work

In the literature there are several works about the measurement of NT; in particular Bernardino et al. [7] is one of the first works that attempted to automate the procedure. Their procedure is semi-automatic because the user has to identify by hand the membranes that surround the translucency: they represent the starting points which will be tracked through the edges by Sobel and Canny filters.

A semi-automatic method proposed by Lee et al. [8] is based on dynamic programming and on a non-linear anisotropic filter [9] to reduce eventual speckle noise. This method tends to underestimate the thickness of the NT with respect to the ground truth provided by a physician. Furthermore the applicability of the procedure is limited to images in which the fetus is in a horizontal position.

Catanzariti et al. [10] proposed a method based on dynamic programming; they significantly improved the cost function for the segmentation of the edges which delimit the translucency. Indeed, it does not require any initial parameter, the process is applicable without the intervention of the user, and the selection of the initial points to detect the edges is not necessary. A qualitative analysis showed the efficiency of the method.

In Nirmala et al. [11], images are pre-processed by applying a median filter to remove speckle noise. The user identifies the region in which the NT is present and the mean shift algorithm for segmentation is applied on that region. Subsequently the Canny operator is applied on the segmented images to extract the edges which delimit the NT. A blob analysis is proposed for measuring the thickness of the translucency. The authors report a quantitative comparison between the mean values of thicknesses of the translucency considered normal and abnormal.

In Deng et al. [12] a semi-automatic scheme is proposed: the images are pre-processed by morphological filtering to reduce noise and subsequently a threshold is applied with a value calculated empirically. The user selects two initial points and the edges are located starting from them by a gradient vector flow snake approach; the edges thus obtained are improved by means of a dynamic programming algorithm. Finally the thickness and the area of the NT are calculated. The authors show a qualitative comparison of the results on synthetic and real data.

A hierarchical model for the automatic identification of the nuchal region is proposed in Deng et al. [13]: three support vector machine classifiers are trained to represent the neck region, the head and the body of the fetus. In Deng et al. [14] the same method was revisited by adding another level of the hierarchical model to represent the fetal profile and with improved performance.

Although the technical details were not disclosed, in Moratalla et al. [15] the tool called SonoNT is presented: it is already integrated and commercialized in some ultrasound devices and it allows a semi-automatic measurement of the nuchal translucency which has to be delimited by the user in a box so as to contain the maximum thickness of the NT. The tool tracks the top and bottom edges using the information of the gradient and brightness inside the box and finally it identifies the maximum vertical distance between these two edges.

An automated method to detect and to measure the NT is presented in Supriyanto et al. [16]: the region containing the nuchal translucency is identified with a multilayer neural network which processes sub-samples of the image and returns the degree of belonging to the class representative of the nuchal translucency. Once the points with a higher probability of belonging to the nuchal translucency region are identified, the methodology draws the edges with an automatic algorithm based on intensity measurements, known as “bidirectional iterations propagations forward method”. This approach relies on a preliminary manual classification of the mid-sagittal sections and the final results are based on a correlation index between the average observations provided by a physician and their corresponding automatic measurements.

In 2013, Park et al. [17] proposed a methodology to measure the NT automatically; first the position of the head is identified and then the neck region is located by statistical relationships between them. Dijkstra's algorithm is applied to locate the inner and outer edges of the