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Improved Segmentation of Ultrasound Images for Fetal Biometry Using Morphological Operators

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Abstract— **Currently, radiologists indicate the femur endpoints with an interactive marker device; however, these measurements are subjective and have proved to be inconsistent. The main objective of this work is to obtain a time-efficient morphology-based algorithm to recognize femur contour in fetal ultrasound images, refine its shape for automatic length measurement, and thus, attaining accuracy and reproducibility of measurement.**

To achieve these objectives a cross-sectional study with subjects belonging to different family units of different communities was carried out. The images obtained from the subjects were initially processed using morphological operators to remove the background from the image. Thereafter, to refine the shape of the femur, the images were metamorphosed, using the morphological operators, till a single pixel –wide skeleton of the femur was available in the most time-effective manner. The skeleton-end-points are assumed to be the femur-end-points, and the femur length is calculated as the distance between the end-points to estimate gestational age.

The mean execution time of the proposed algorithm was around 4 seconds. Measurements, performed using the automation algorithm, were found to be closely correlated to those obtained manually. The proposed algorithm was found to be time-efficient, and the results obtained were comparable to those derived through the existing methods for estimation of gestational age.

I. Introduction

The estimation of the pregnancy date is important for the mother who wants to know when to expect the birth of her baby, and, for her health care providers, so they may choose the junctures at which to perform various screening tests and assessments [1]. About two-dozen ultrasonographic measurements were "invented" to accomplish the task of estimating gestational age of the fetus, both for estimating the probable date of delivery, and, for observing the fetal growth; however, a few of them came more in practice; they included biparietal diameter (BPD), fronto-occipital- diameter (FOD), head circumference (HC), and femur length (FL). However, the measurement of femur was, and is considered more dependable because, i) it is not affected by the nutritional or placental insufficiency; ii) it is not affected by variables such as maternal height or weight; iii) it shows no ethnic effect; iv) it is a good alternative in cases of malformation of the fetal head, or when the fetal head shape is dolichocephalic or brachycephalic, or when the fetal position makes head measurements unreliable [2]; and v) it is not influenced by gender[3]. Sonographers currently measure the femur by marking two points on an US display station, and it is compared with some standard growth chart to find the corresponding gestational age. However, this technique is subject to larger inter-and intra-observer variability [4] due to the noisy nature of US images, the varying experience level of sonographers, and the common presence of artifacts extending from the femur.

This paper presents a scheme for the automatic measurement of femur length and the gestational age of the fetus. The next section briefly discusses about the experimental methods used in the acquisition and processing of ultrasound fetal images. Section III describes the algorithm. The experimental results are presented and evaluated in section IV. The discussion in section V, compares the proposed technique with largely reported techniques for femur length measurements.

II. Image Acquisition and Image processing

Original fetal images, with marked and unmarked femur region, were obtained from the clinical patient records at the Himalayan Institute of Medical Sciences (HIMS), Dehradun (India). The images were acquired with informed consent of the subjects under strict ethical guidelines provided by the ethical committee of the HIMS. All images were acquired with a SONOLINE G50 Ultrasound System (Siemens) using curved array transducer, 3.5 MHz, and were then transferred through a film-grabbing Card to a PC with Intel Pentium 4 CPU (2.93GHz). The images were then processed using Matlab-Release 14 version for image analysis. Fig.1 is a typical ultrasound image with a relatively bright and slightly curved structure of fetal femur. The characteristics of such images put forth a challenging task for their processing. The brightness and the texture within the femur region are not always consistent, even in cases where images were acquired under, apparently, the same conditions.

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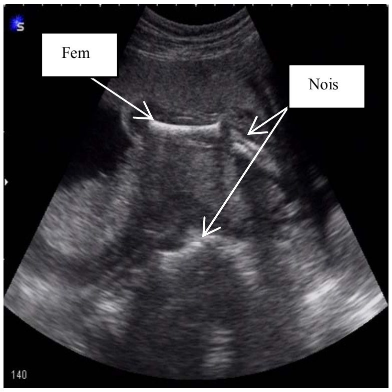

Fig. 1 An ultrasound (US) image with fetal femur

Furthermore, various artifacts and noise, present in the image can approximate the brightness of the femur and can hinder the detection of true femur region. The other common error in the measurement of femur length is the inclusion of a bright spike, referred to as the "distal femur point," which often extends from the distal end of the femur [5].The following section discusses in detail the algorithm used to process the acquired images.

III. THE SEGMENTATION ALGORITHM

Following the acquisition of the original images, classical and morphological image processing techniques were applied in a series of steps. A summary of the steps of the proposed algorithm is shown in Fig. 2, and each step in respect of processing of an image is discussed below :-

The algorithm first performs a gray scale opening on the input image 'I' using a structuring element having the dimension larger than the width of the femur. A priori knowledge about the general shape and size of the femur is being utilized to select the size of the structuring element. As the largest width of the femurs examined was less than 15 pixels, so a disk shaped structuring element with a size of 15 pixels was chosen for opening the images. The opening is performed to isolate the foreground object, the femur, from the background:

$$J = I \circ SE15 \quad \ldots\ldots\ldots(1)$$

where, 'I' is the input image, J is the opened image, SE stands for the Structuring Element for opening, and its index (15) is the size of the structuring element. To enhance the original image, the background image is then subtracted from it to provide a less noisy image K,

$$K = I - J \quad \ldots\ldots\ldots\ldots (2)$$

where, I is the input image, J is the background image, and K is the subtracted image. The difference image is then closed to further smooth the contours of the foreground object again using a disk shape-structuring element of one (1) pixel size. The closed image is given as,

$$L = K \bullet SE1 \quad \ldots\ldots\ldots(3)$$

where, L is the resultant image, obtained by closing the subtracted image, K, SE stands for the Structuring Element for closing, and its index '1' is the size of the structuring element.

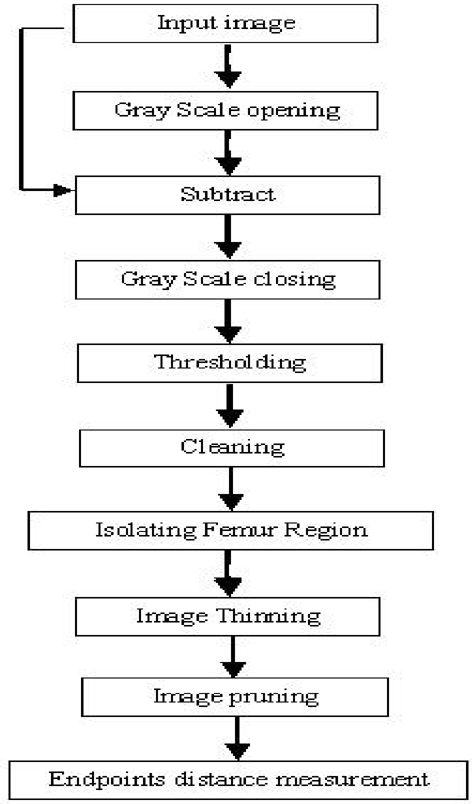

Fig.2 Flow diagram of morphological segmentation algorithm for femur length measurement

A binary image is produced next, by applying a threshold to the enhanced image. The selection of the threshold has to be fixed for the images acquired from the same source, rather than a threshold determined for each image individually. Removing the spurious regions, which are smaller than 25 pixels in length and breadth, cleans the threshold image. The element chosen for this step should be slightly smaller than the width of the true ends of the femur. Again a priori knowledge about the general shape and size of the femur is being utilized to remove undesired regions.

Fig. 3(a) The original US image with fetal femur

The region with the largest length is selected as the femur region, since the subtraction of the background should have removed any larger, bright areas. Ideally, the resulting image will closely approximate the size and shape of the fetal femur in Fig. 3(a). The femur region is then reduced to its skeleton by morphological thinning process to obtain endpoint-to-endpoint femur length measurement. The skeleton of the femur region has some spurious extensions from the femur due to the "distal femur point" discussed in section II. To remove these extraneous spurs, sometimes called parasitic components, we use morphological pruning operation.

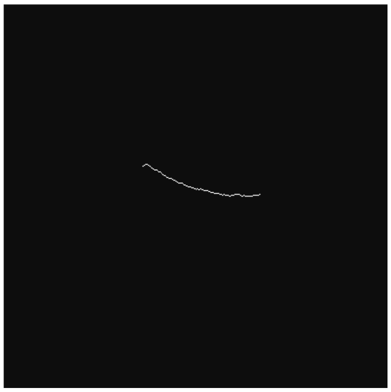

Fig.3 (b) The pruned final image

The Fig. 3(b) shows the final resultant image. The straight length in pixels, between the two end points of the skeleton, is calculated, and the pixel count is divided by a factor, which depends on the resolution of the monitor, to obtain the length in millimeters. Fig. 4 displays the resulting end points superimposed onto the original femur image, which can be used by the sonographer to confirm the endpoint placement.

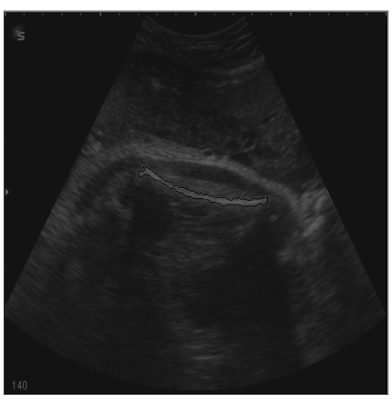

Fig. 4 Femur region superimposed onto the original image

IV. EXPERIMENTATION RESULTS & DISCUSSIONS

Fetal femur images of sixteen subjects, with unmarked and marked femur region were obtained from the clinical patient records at Himalayan Institute of Medical Sciences (HIMS), Dehradun (India). However, fetal images of only seven subjects, which demonstrated the following criteria of normality [7], were taken for the analysis: -

1. No use of oral contraceptive pills, at least for the last 3 months;
2. Regular menstrual cycles, at least for the last three menses;
3. No anomaly known perinatally;
4. Live-born neonates;
5. No family history of dwarfism;
6. No use of alcohol or cigarettes;
7. No diabetes in mothers;
8. No Twin gestation;
9. No any other type of abnormalities.

Table 1 provides gestational age (GA), as calculated by the machine and as calculated by the relation between femur length (FL) and GA, given by Hadlock et al.[6], Honarvar et al.[7] and S.L. Shih et al.[8] at different times, and, as indicated by the equation 4, 5 and 6 respectively,

$$GA(Hadlock) = 10.38 + 0.2256 * FL + 0.001948 * FL2 \quad \ldots(4)$$
$$GA(Honarvar) = (0.262 * FL2/100) + 11.5 + (2 * FL/10) \quad \ldots(5)$$
$$GA(SL\ Shih) = 11.44 + 0.34 * FL \quad \ldots(6)$$

From Table 1 it is observed that the GA as calculated by the relation given by Hadlock et al. in 1982 is always smaller than that calculated by sonograpgher. The GA as calculated by the relationship given by Shih et al. in 2005, in almost all cases is larger than that of the machine evaluated. However, the mean GA of the three relationships used in this study is closely related with the manually evaluated GA.

TABLE 1. COMPUTED FEMUR LENGTH AND GESTATIONAL AGE

Image No.	Doctor Marked		Computer Marked					Total Execution time
				Gestational Age				
	Femur length	GA	Femur length	Hadlock (1982)	Honarvar (2000)	SL Shih (2005)	Mean	
1	69.8 mm	35W 3D	67:50 mm	34W 3D	37W	34W 3D	35W 2D	4.62 sec
2.	39.0 mm	22W 5D	36.78 mm	21W 2D	22W 3D	24 W	22W 4D	4.20 sec
3.	40.9 mm	23W 3D	38.21 mm	21W 6D	23W	24W 3D	23W 1D	3.42 sec
4.	54.4 mm	28W 4D	52.14 mm	27W 3D	29W	29W 1D	28W 4D	3.75 sec
5.	25.4 mm	17W 4D	25.36 mm	17W 2D	18W 2D	20W	18W 4D	4.51 sec
6.	31.0 mm	19W 2D	29.28 mm	18W 5D	19W 4D	21W 3D	19W 6D	3.75 sec
7.	49.2 mm	26W 4D	47.50 mm	25W 3D	27W	27W 4D	26W 5D	3.87sec

The results show a marked reduction in the execution time when compared with the execution time, not only for the algorithm given by Thomas et al. [9], where the complete algorithm required 10 min. to produce the femur length and end point locations for one image, but also to that of the algorithm given by Hanna et al. [10], where the complete algorithm took 4 min. for the evaluation of a fetal growth parameter. The mean execution time for the proposed algorithm for the assessment of GA by evaluation of femur length is just 4 sec. Fig. 5 indicates that there exits an almost linear relationship between the femur length and the mean gestational age.

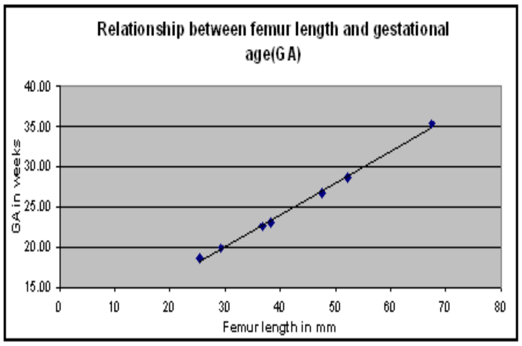

Fig.5 Relationships between FL and mean GA in respect of the subjects under consideration

V. CONCLUSIONS

The proposed new algorithm for fetal femur measurement has been tested on real clinical images, and has shown that the measurements made by the proposed method are consistent and in good agreement with the conventional manual method of measurement. The minor variations may be due to the fact that the relationships between the FL and the GA that has been used to evaluate the GA from the FL, have been developed basing the same on the fetal growth pattern of non Indian fetus. However, the real clinical images that have been used in the present study are of the Indian origin only. The proposed algorithm also provides a possible time-efficient solution to the current inconsistency, difficulty, and subjectivity of fetal ultrasound measurement. Moreover, if the algorithm is implemented in the hardware of the real-time US systems, then it may relieve the sonographer of the tedious manual marking, so that he or she may focus on acquiring good images.

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