Automatic femur length measurement for fetal ultrasound image using localizing region-based active contour method

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Abstract. This research aims to apply the localizing region-based active contour (LRAC) method to acquire the femur length in an ultrasound image automatically and to determine the effect of noise removal on the segmentation accuracy. The automatic femur length measurement system includes three main steps. The first step is the denoising process to reduce speckle noise in the ultrasound image. Afterwards, the LRAC method is applied to detect and segment a local region. The segmentation process with a certain number of iterations and a weight of the smoothing terms is started at the selected initial pixel. At the final step, the femur length is measured to estimate the gestational age. The experiment results show that the accuracy of the estimated gestational age increases significantly when the noise reduction technique is employed.

1. Introduction

The ultrasonography is a modality that has high usability and non-invasive. Moreover, the price is quite affordable than other modes such as MRI or CT-scan. The B-mode ultrasound image can be formed from the RF signal [1]. One of the ultrasound tasks is to examine the fetus during pregnancy either to determine its development or to detect abnormalities [2]. Thus, it can prevent pregnancy problems. The standard biometric measurements of the fetus such as biparietal diameter (BPD), occipitofrontal diameter (OFD), head circumference (HC), abdominal circumference (AC), crown-rump length (CRL) and femur length (FL) are utilized to estimate the fetal weight or the gestational age [3].

Femur length (FL) is the alternative parameter to determine the gestational age [4][5]. At first, the femur length (FL) size is carried out to define the existence of dwarfism, and then the FL is considered as an excellent measure to determine the gestational age. The FL is useful to confirm the biparietal diameter (BPD) when the fetal position that is not possible for the BPD measurement task. Some automatic segmentation and measurement methods are developed to be able to reduce the observation time during the prenatal examination using ultrasonography and raise the proficiency of prenatal ultrasound services, as well as to reduce systematic errors due to technical and ability disparity among sonographers [6]. According to Vera, et al. [7], the automatic segmentation in a medical image can improve the ability to analyze an anatomic tissue.
There are many segmentation studies to obtain the femur length automatically on the ultrasound images. Jardim and Figueiredo in [8] applied the deformable contour method with parameter estimation using maximum likelihood. Rahmatullah and Besar [9] proposed a combination of the watershed segmentation method and a 12x12 block averaging seed-point threshold method. Mukherjee et al. [10] offered a thresholding technique to find a candidate area of a femur that combined with the phase symmetry approach. Ponomarev et al. [11] used the combination of multilevel thresholding method and the edge detection technique. Wang [12] utilized the entropy-based approach and the edge-based approach as an alternative. Mathews and Deepa [13] applied SVM classifier to distinguish a femur with other objects after being processed by the thresholding technique. Amoah et al. [14] combined Gabor filters with the thresholding techniques and analysis of structure shapes to obtain the femur automatically. Yu et al. [15] applied the combination of the phase symmetry approach and the saliency visual attention model. Anjum et al. [16] tried to improve the technique that is proposed by Ponomarev et al. [11] by adding a smoothing technique. Khan et al. [17] implemented a thresholding approach using the mean and standard deviation values of the grey levels in the upper middle region of the input image and the deformable active contour model method to segment the femur area.

Ultrasound images have low quality and contain speckle noise. According to Mukherjee et al. [10], the femur area has high intensity because it has high acoustic impedances. The common segmentation approaches in the study literature are based on the global features of an image such as edge information. The edge-based segmentation method is depended on the magnitude of the image gradient for getting an edge location. It is well known that noise has the same gradient level as the edge intensity. Such that using the edge-based segmentation technique in the noisy ultrasound image can produce undesirable areas.

For the same reason, the region growing method and the morphological watershed method provided the unsatisfactory performance for the ultrasound image segmentation. The localizing region-based active contour (LRAC) as suggested by Lankton and Tannenbaum [18] utilized local image statistics to get the image contour. The LRAC can segment an object with various features that are difficult done by conventional global methods[19].

Hence, this paper proposes the semi-automatic femur length segmentation in the fetal ultrasound image using the LRAC method. This article also aims to observe the influence of the noise reduction method on the accuracy of the femur length measurement. In the proposed approach, the initial contour is set by a selected pixel of the input image. The acquired femur length is used to predict the fetal gestational age.

2. Materials and methods

2.1 Data acquisition
The ultrasound images in this study are acquired by a portable ultrasound device that consists of a 64-element convex probe transducer with a beamforming device which is connected to a laptop, as shown in Figure 1(a). For the experiment, 11 fetal ultrasound images are obtained from pregnant women at various gestational age. Figure 1(b) is an example of the femur ultrasound image of the 29 weeks fetus.
2.2 Proposed segmentation method

The proposed segmentation method aims to extract the femur area of the fetal ultrasound image and to measure the femur length (FL). The stages of the process are illustrated in Figure 2. The femur segmentation system consists of four steps. Firstly, the preprocessing step is implemented to reduce speckle noise in the ultrasound image. Afterwards, the segmented region is chosen by a pixel in the femur area. Furthermore, the localizing region-based active contour method is applied to extract the femur area. Finally, the femur length is measured by the Euclidean distance formula.

2.2.1. Preprocessing. The purpose of the preprocessing step is to eliminate the speckle noise using a hybrid speckle noise reduction method that is proposed by Hermawati et al. [20]. The technique combines the anisotropic diffusion, the bilateral filtering and the wavelet multiresolution. In the first step, the ultrasound image is decomposed by the wavelet transform into one low-frequency subband and three high-frequency sub-bands. Furthermore, the wavelet coefficients of the low-frequency sub-band are filtered using a bilateral filter, while thresholding approach modifies the wavelet coefficients in the high-frequency sub-bands and then followed by the anisotropic diffusion method.

Figure 3(b) presents the noise reduction result of the image in Figure 3(a). Figure 3(c) and Figure 3(d) shows the noise decreasing of the edge image before and after the noise reduction process. The
Canny edge detector is implemented to obtain the edge images. After the denoising process, the ultrasound image is sharpened using un-sharp masking techniques that applies the Gaussian low-pass filter and high-pass filter, with a standard deviation parameter of the Gaussian low-pass filter and the strength of the sharpening effect of the high-pass filter both equal to 3.

![Original Image](a) ![Denoising Result](b) ![Edge Detection Original](c) ![Edge Detection Denoising](d)

**Figure 3.** The comparison between (a) original image (b) image denoising result (c) edge detection result of the original image (d) edge detection result of the denoising image.

### 2.2.2. Localizing Region-Based Active Contour Method

This research uses the approach of Lankton and Tannenbaum [18] which considers the local image statistics instead of the global ones in the active contour method. The basic idea of the approach is to divide the region along the contour using a small ball into the interior area and exterior area, and evolve it based on local statistical information. The internal energy is measured by the Chan and Vese [21] formula which is referred to a uniform energy modelling. The primary step in this method consists of two parts: initialization and updates. The initialization step is implemented to minimize the energy of the local region. Let \( A_u \) is an interior region and \( A_v \) is the exterior region, then the local curvature flow can be calculated by the following equation [18]:

\[
\frac{\partial \phi}{\partial t}(x) = \delta\phi(x) \int_{\Omega_v} B(x,y) \delta\phi(y) ((I(y)-u_y)^2-(I(y)-v_y)^2)dy + \lambda \delta\phi(x) \text{div} \left( \frac{\nabla \phi(x)}{\sqrt{\nabla \phi(x)}} \right) \tag{1}
\]

where \( \delta\phi(x) \) is Dirac delta of a signed distance function \( \phi \). \( B(x,y) \) is a mask function for the local region. \( I(y) \) is an intensity value of a pixel image. \( u_y \) and \( v_y \) represent mean of intensities in the interior \( (A_u) \) and the exterior area \( (A_v) \), respectively. \( \nabla \) is a gradient operator. \( \lambda \) is the weight of smoothing term that keeps the curvature smooth.
Before the region-based active contour process is applied, the femur region is determined by selecting a point in the area. In [18], the initial contour is specified by a rectangle or a circle inside or outside of the region of interest. Figure 4(a) presents an example of the initial step with a selected point in the femur area as shown by a yellow dot. Afterwards, a mask $B(x,y)$ is set to 1 in the 2x2 window around the selected pixel, and it is set to 0 in the other pixels.

The signed distance map function, $\varphi$, depicts the distances of all points in the mask function to the initial position, as illustrated in Figure 4(b), where the lowest intensity represents the smallest distance. The signed distance map function is determined by the level set approach [22]. A narrow band around the zero level set of the distance function, $\varphi$, defined to improve efficiency, as shown in Figure 4(c). $A_\varphi$ denotes the area of the distance function. The interior area, $A_u$, is a region in the distance map function that has a value less or equal to zero, and the exterior area, $A_v$, is outside of the $A_\varphi$. The green colour in Figure 4(d) shows the interior region, $A_u$. The internal energy function, $F$, is computed by the following equation [18]:

$$F = H\varphi(y)(I(y) - u_y)^2 + (1 - H\varphi(y))(I(y) - v_y)^2$$

(2)

where $I(y)$ is a pixel intensity values in the area $A_\varphi$, $H\varphi(y)$ is a Heaviside function of the interior region $A_u$ and $(1-H\varphi(y))$ is a Heaviside function in the exterior area $A_v$. The curvature of the signed distance function is computed by the derivative of each pixel in $A_\varphi$.

**Figure 4.** Initialization step: (a) select a point in femur area (b) level set of the distance map function (c) the narrow band (d) the interior region $A_u$. 

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The updating of the signed distance map function is computed by the subtraction between the intensity value of each pixel and the histogram bins of the interior region, and then the subtraction result is added by the same histogram bins of the exterior area. Both steps, the initialization and the updating, is processed as much as the given number of iterations. Figure 5 shows the region based active contour process for initial iteration (Figure 5(a)) and after 300 iterations (Figure 5(b)).

![Figure 5](image)

**Figure 5.** Example of the segmentation process at: (a) initial iteration (b) after 300 iterations.

### 2.2.3. Femur Length Measurement

The next step is to compute the length of the extracted femur. Figure 6 shows an example of the extracted femur area using the LRAC method.

![Figure 6](image)

**Figure 6.** Example of the extracted femur area.

Suppose the two pixels which form the rectangle area in the outer of the femur regions are denoted by \( p_1(x_1, y_1) \) and \( p_2(x_2, y_2) \). The femur length is the distance between the two pixels that is calculated by the Euclidean distance formula as follows [14]:

\[
FL = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}
\]

(3)

### 3. Results and discussion

This section presents two conducted experiment to analyse the segmentation method. The first experiment aims to determine the best parameters of the localizing region-based active contour method. The ultrasound image of the first experiment is obtained from www.webmedcentral.com [23] as shown in Figure 7. From the manual measurement, it is known that the femur length is 3.34 cm.

Firstly, the weight of smoothing term \( \lambda \) is evaluated for each iteration as shown in Table 1. From the table, it can be seen that the convergence condition is reached at a particular iteration. In other words, in that condition, the increasing of the iteration number will not alter the segmentation results. Vice versa, if the number of iterations is less than the convergent state, the segmentation results do not achieve maximum results. The femur length is also not changed when the convergence condition is reached. Hence, the large number of iterations is more advisable.
Table 2 indicates the comparison between the results of automatic measurements using the proposed method and manual measurements that as equal to 3.34. The convergence condition can be accomplished when the high $\lambda$ is used. If it is set a particular iteration, the small $\lambda$ make segmentation results exceeding the region of interest. From Table 2, it can be seen that the lowest error is achieved when the weight value $\lambda$ is 0.2. So, the weight parameters $\lambda=0.2$ and iterations=300 are chosen for the next experiment.

The second experiment evaluates the accuracy of femur length measurement using the proposed segmentation technique to estimate the gestational age. This experiment uses ultrasound images that are obtained from 11 pregnant women with a vary of gestation age. The comparison is conducted between the gestational age estimation with denoising and without denoising process, as presented in Table 3. The Handlock formula of the estimated gestational age (EGA) based on the femur length (FL) is expressed by the following equation [14]:

$$EGA = 1.863 + 6.280FL - 0.211FL^2$$  

(4)
Table 3 illustrates the results of FL measurements and the GA prediction using the proposed method based on ultrasound images obtained in the real experiment with a portable ultrasound device. The iteration parameter declares 300 iterations with the weight of smoothing term $\lambda$ is 0.2.

| GA (weeks) | Without Denoising | With Denoising |
|------------|-------------------|---------------|
|            | FL (cm)   | EGA (weeks) | Error | FL (cm)   | EGA (weeks) | Error |
| 17         | 1.73      | 12.10      | 4.90   | 2.61      | 16.82      | 0.18   |
| 34         | 3.68      | 22.12      | 11.88  | 3.62      | 21.83      | 12.17  |
| 29         | 3.78      | 22.59      | 6.41   | 4.02      | 23.70      | 5.30   |
| 29         | 2.37      | 15.56      | 13.44  | 4.33      | 25.10      | 3.90   |
| 33         | 3.93      | 23.28      | 9.72   | 6.46      | 33.63      | 0.63   |
| 33         | 4.14      | 24.25      | 8.75   | 5.27      | 29.10      | 3.90   |
| 29         | 2.27      | 15.03      | 13.97  | 3.43      | 20.92      | 8.08   |
| 25         | 4.3       | 24.97      | 0.03   | 4.34      | 25.14      | 0.14   |
| 33         | 1.25      | 9.38       | 23.62  | 5.01      | 28.03      | 4.97   |
| 18         | 2.07      | 13.96      | 4.04   | 2.93      | 18.45      | 0.45   |
| 23         | 1.39      | 10.18      | 12.82  | 1.71      | 11.98      | 11.02  |
| Average    | 9.96      | 4.61       |        |           |            |        |

The column of gestational age (GA) in Table 3 consists of gestational age that is calculated based on the last menstrual period. The column of estimated gestational age (EGA) contains a gestational age that is obtained from the calculation of femur length (FL) in cm. The error column denotes the difference between the gestational age and the estimated gestational age. As shown in the error column of Table 3, the denoising process affects significantly to the GA estimation accuracy. Figure 8 shows the improvement of the correlation between GA and estimated GA that is measured by $R^2$. The correlation coefficient without denoising process is equal to $R^2 = 0.1976$, while with denoising method increases to $R^2=0.5183$.

4. Conclusions
The localizing region-based active contour (LRAC) method that integrated with a hybrid speckle noise reducing technique was implemented to extract and calculate the fetal femur length automatically. The femur length result was used to estimate the gestational age. In the LRAC process, the first step was the femur region selection using a pixel. Then the femur area contour was expanded iteratively with an updating algorithm. This method was capable of detecting and segmenting a local region based on the intensity of the pixel initially selected and reaching the convergent condition on a certain number of iterations and the weight of smoothing terms. The
experiment that utilized a low-cost portable ultrasound device showed the influence of the noise reduction step. The applied denoising method could improve the accuracy of gestational age prediction.

For future research, we will develop the fully automatic fetal length measurement system by selection of the starting point automatically. Thus, the designed system can help the inexperienced users such as the midwives, to estimate the fetal weight or the gestational age quickly and easily.

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