Computer-aided Ultrasonic Assessment of Fetal Breathing Movement

Umit D ULUSAR[a], James D WILSON[b], Pamela MURPHY[c], Curtis L LOWERY[c], Rathinaswamy B GOVINDAN[c], Hari ESWARAN[c]

[a] *Computer Engineering Dpt, Akdeniz University, Antalya, Turkey*
[b] *GIT, University of Arkansas at Little Rock, AR, USA*
[c] *OB/GYN Dpt, University of Arkansas for Medical Sciences, AR, USA*

Abstract: *Fetal breathing movement (FBM) is a good indicator for fetal well-being and can be observed by ultrasound in the developing fetus as early as 10 weeks of gestation. In this study, we present and image processing algorithm for the quantification of FBM activity observed using ultrasound imaging. The algorithm is composed of three steps; spatial filtering, fetal thorax boundary detection, and quantification of the movement. As a result, the fetal breathing movement signal is acquired by using the displacement of multiple points along the fetal thorax and parameters such as; breath-to-breath, inhale and exhale durations of each individual fetal breath have been obtained. Finally, we tested the potential usefulness of the method on three ultrasound recordings and compared its results with expert observations.*

Key Words: Ultrasound; Image Processing; Fetal Breathing Movement

1. Introduction

Fetal breathing movement (FBM) is a complex and voluntary movement of the developing diaphragm which can be detected in the human fetus as early as 10 weeks of gestation [1]. Unlike adult breathing, it is not a continuous activity and is usually observed as a rapid episodic movement similar to a sine wave, irregular in amplitude and rate. As gestation progresses, FBM is seen with increasing incidence at a rate between 30 to 90 breaths per minute [2]. The absence of FBM is known to adversely affect the fetal lung growth [3] and its confirmation can be used as an indicator of fetal well being and health. FBM is one of the five parameters used for the fetal biophysical profile; a comprehensive test performed to measure fetal well-being [4].

Real time ultrasonography is a popular non-invasive imaging technique used for the clinical fetal studies. It is a standard equipment in almost all major hospitals and can provide the visualization of the intrauterine activity. In the clinical studies, FBM is usually observed with ultrasound and quantified by a specialist. However, manual assessment is a time consuming effort and detailed information such as depth and duration of each breath requires an automated analysis.

Experts typically document FBM through visual imaging of the movement of fetal thorax. Automatic detection and analysis of fetal activities with ultrasound images requires complex image processing techniques. Ultrasound images are two dimensional slices of a three dimensional object and images are degraded by distortion, shadowing effects and noise. Besides, significant physiologic knowledge is required to process ultrasound images. Several studies addressed automatic or semi-automatic detection and quantification of FBM. Florido *et al.* used photogrammetric analysis of images obtained with real-time echography [5]. This technique requires still images and is designed to measure a standard set of FBMs. Marcus *et al.* used actocardiogram and real time ultrasonography [6]. This technique can only measure deep and regular breathing movements.

The objective of this work is to present and image processing algorithm for the quantification of FBM activity that can be applied to the ultrasound video recordings. As a result, parameters such as breath-to-breath, inhale and exhale durations of each individual breath have been obtained. Finally, we tested the method on three ultrasound recordings and compared its results with expert observations.

2. Materials and Methods

The algorithm can be divided into two processing stages. The first step involves pre-processing the ultrasound image using appropriate filters for the elimination of the noise and edge enhancement of the important features. The second step involves the movement data extraction by tracing the movement of the boundary defined by the fetal thorax spanning multiple frames. Final output is a time series sampled at the video frame rate that represents the temporal behaviour of the fetal thorax. Processing steps are illustrated in Figure 1. Details of each step are explained. The fetal thorax is assumed to be parallel to the horizontal axis. Otherwise, the image is rotated.

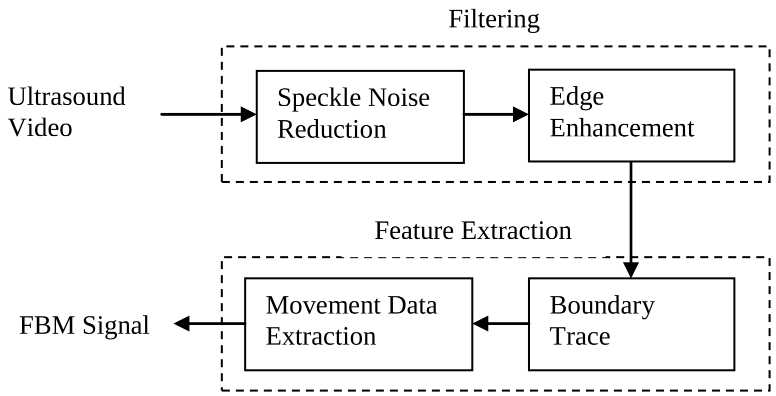

Figure 1-Image processing steps.

Real-time ultrasound provides images that are optimized for qualitative analysis. One common problem for ultrasound imaging is the fact that speckle texture, which provides information for the operator, may distort the automatic estimation of boundaries. A Sticks filter is a group of templates that is used to assess the possibility of a linear feature. For a mask size of N, it uses 2N-2 rotating kernels that pass through the center of mask. The technique operates by sliding the mask over the image and calculating the convolution value for each kernel. The maximum convolution value is assigned to the pixel at the center of the kernel. The stick size and thickness affects the Sticks filter's response. A shorter stick suppresses less speckle noise but better matches the tightly curving boundaries while thicker sticks are more responsive to large and diffuse boundaries [7]. Longer sticks smooth small-scale features and curves. The fetal thorax is a long continuous and smooth surface. A stick size of 17 and thickness of one was chosen by visual evaluation because it is short enough that it correlates well with fetal thorax surface, introduces less blurring effect for the boundary and off-boundary pixels, and suppresses much of the speckle noise.

Sobel operator is used to enhance boundaries in the grayscale image. Larger Sobel filters compute the finite differences over longer distances, and are much less sensitive to local changes. Filter size of 11x11 was chosen empirically and only applied to horizontal axis which enhances the thorax boundary and suppresses the other edges.

The change of the area above the boundary of the fetal thorax is used to observe the FBM. For the boundary trace, each frame of the video is converted to binary image by assigning 1 for the intensity values greater than a threshold and 0 for the others. 4-connectivity boundary trace algorithm is used to extract boundary. The threshold value is obtained by using Otsu's method [8].

The previous steps provide a movement signal obtained using each frame of an ultrasound recording. This signal usually contains features of both maternal and fetal movements such as breathing and gross body movements. Maternal breathing generally creates a periodic fetal gross body movement similar to sliding left and right and the corresponding signal can be observed within the frequency band of 0.25-0.35Hz. Similarly, fetal gross body movements create a low frequency (<0.5Hz) large amplitude signal. In order to suppress the effect of the movements other than fetal breathing, the signal is processed by using a 4^{th} order Butterworth band-pass filter with a pass band of 0.5 to 10 Hz. (FBM has a frequency between 0.5 and 1.5 Hz). Finally, the beginning of each breath, inhale and exhale durations were identified using local minima and maxima points of the signal.

For the study, ultrasound imaging (UI) recordings were performed on three fetuses between 35 and 37 weeks gestational age, none of which had any complication during pregnancy. Each mother was informed about the procedure and signed consent was obtained. Sonosite 180 plus portable ultrasound device with C60/5-2 MHz 60 mm curved array transducer is used to obtain ultrasound images. Video was saved in MPEG format with 30 frames per second and 640 x 480 pixel resolution. Durations of the recordings were between 10 to 30 minutes.

3. Results

An example of a FBM signal from a 35 weeks 4 days old fetus during a breathing period between 800th and 850th seconds of the recording is illustrated in Figure 2(a). Red circles are the local minima points, which indicate the beginning of each respiratory cycle. Figure 2(b) illustrates the histogram of the breath durations. The histogram is similar to normal distribution with a mean around 1.1 sec.

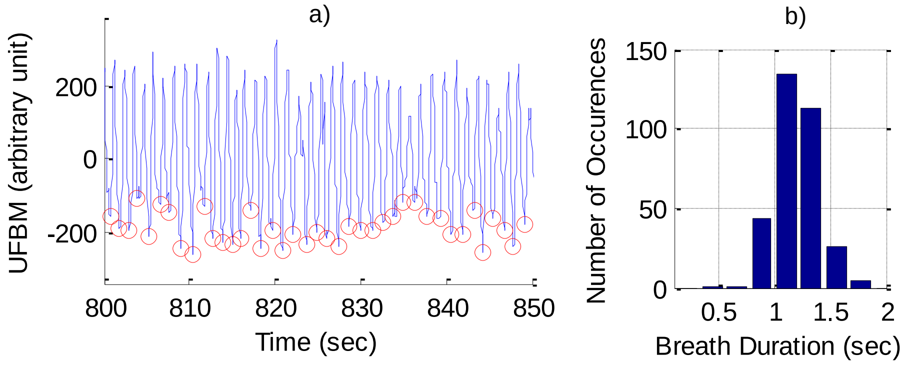

Figure 2-FBM signal observed from subject 3 during breathing. a) shows the signal. Red circles indicate the local minima points, which indicate the beginning of each respiratory cycle. b) shows a histogram of the breath durations observed between 800th and 1200th seconds.

Table 1 reports the measurements for three fetuses. The FBM is not a continuous activity and the number of breaths observed for each fetus varied between 95 and 529. The average breath durations were between 0.97 sec and 1.41 sec. Findings reported in Table 1 are similar to those of early studies on the maturation of fetus [5,9] and consistent with the expert observations.

Table 1 –Fetal breathing movement measured in three fetuses

Gestational age (week)	Number of breathes	Duration of inspiration phase (sec)	Duration of expiration phase (sec)	Total duration of cycle (sec)
37w5d	125	0.54 ± 0.16	0.43 ± 0.14	0.97 ± 0.19
37w6d	95	0.70 ± 0.30	0.71 ± 0.28	1.41 ± 0.34
35w4d	529	0.61 ± 0.12	0.74 ± 0.17	1.35 ± 0.20

4. Discussion

Detailed and precise analysis of FBM is desirable to perform studies on fetuses at different gestational ages and also high-risk fetuses. Though FBM video is often contaminated with artifacts associated with either maternal breathing or fetal movements, we demonstrate that these artifacts may be successfully removed to reveal the fetal breathing movement as a signal. Besides, we show that computational methods can reveal certain aspects such as inhale and exhale durations of FBM that can be used to study how of fetal environment and neurological state affect fetal breathing in subtle ways that would otherwise be difficult to observe.

5. Conclusion

Using ultrasonography, it has been possible to count the occurrence of FBM but other quantities have been difficult to measure such as; breath frequency, inhale, exhale and breath-to-breath durations. In ultrasound recordings, fetal breathing is observed as rhythmic motion of the fetal thorax and diaphragm. The technique we describe operates by quantifying the movement of fetal thorax boundary on each video frame of the ultrasound recording. The FBM signal was obtained by using a large number of points along the fetal thorax, which results in great sensitivity even for shallow breaths. Finally, we applied this method on ultrasound recordings of three fetuses, and presented the average breath, inhalation and exhalation durations. Since real-time ultrasound devices are standard equipment in all major hospitals, this method has applicability with minimal cost and it is suitable for the analysis of fetal breathing for longer durations.

Acknowledgments

We express great thanks to Jessica Temple and Maureen Ware for their participation in patient recruitment. This work has been supported by Akdeniz University Scientific Research Projects Commission.

References

[1] de Vries JI, Visser GH, and Prechtl HF. The emergence of fetal behaviour. II. Quantitative aspects. *Early Hum. Dev* 1985:12(2):99-120.

[2] Nijhuis J ed. *Fetal behaviour: Developmental and perinatal aspects*. Oxford: Oxford university press, 1992.

[3] Greenough A. Factors adversely affecting lung growth. *Paediatr Respir Rev* 2000:1(4):314-320.

[4] Manning FA. Fetal biophysical profile. *Obstetrics and Gynecology Clinics of North America* 1999:26(4):557-577.

[5] Florido J, Cortés E, Soto V, Gutiérrez M. A new photogrammetric method to measure fetal breathing movements. *Ultrasound Obstet Gynecol* 1999:14(2):134-8.

[6] Malcus P, Razvi K, Arulkumaran S, Ratnam SS. Fetal breathing recorded by actocardiogram and real--time ultrasonography. A comparison. *Acta Obstet Gynecol Scand* 1997:76(1):33-7.

[7] Czerwinski R, Jones D, O'Brien W. Detection of lines and boundaries in speckle images-application to medical ultrasound. *IEEE Trans on Med Imag* 1999:18(2):126-36.

[8] Otsu N. A Threshold Selection Method from Gray-Level Histograms. *IEEE Trans Syst Man Cybern* 1979;9(1):62-6.

[9] Florido J, Cortés E, Gutiérrez M, et al. Analysis of fetal breathing movements at 30-38 weeks of gestation. *J Perinat Med* 2005:33(1):38-41.

Corr. Author: Dr. Umit D. Ulusar, Ph.D., E-mail: umitulusar@akdeniz.edu.tr Web: http://www.ulusar.com