DETECTING FETAL MOVEMENTS USING NON-INVASIVE ACCELEROMETERS: A PRELIMINARY ANALYSIS

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Abstract—**Monitoring fetal movement is important to assess fetal health. Standard clinical fetal monitoring technologies include ultrasound imaging and cardiotocography. Both have limited prognostic value and require significant health resources. We have recently developed a low-cost, passive, non-invasive system to monitor fetal activity, and therefore fetal health. This accelerometer-based system does not require trained operators and can be used outside a clinic. This work is a preliminary study to develop a method to automatically detect fetal movement using this new accelerometer system. We assess the efficacy of using a threshold method over a range of different frequency bands. We also examine using a set of statistical features for a detection method. Our results indicate that neither method performs sufficiently well to automatically detect fetal movement.**

Keywords- acceleration measurement; biomedical signal processing; filtering; statistics; signal detection component;

1. INTRODUCTION

Fetal movement detection is an assessment of fetal wellbeing. Mothers can feel their baby move at 13 weeks gestation. Maternal perception, however, does not appear to be a sufficient surveillance tool [1]. The average sensitivity of maternal perception of gross movements is only 30%. In addition, pregnant women are likely to detect long term movements while missing the short term movements.

There are different technologies for monitoring fetal movement. Probably the most widely used is sonography [2, 3]. Sonography uses ultrasound waves in order to create an image of the fetus. There is, however, some concern amongst clinicians as to the safety of the fetus under prolonged exposure to ultrasound radiation [4]. Other technologies include tocodynamometers [3], piezoelectric [5] or inductive transducers [6].

Recently, we developed a system that uses accelerometers, placed on the maternal abdomen, to monitor fetal movement [7, 8]. The first stage in developing a system capable of diagnosis and prognosis of clinical outcome is to construct a method to automatically detect fetal movement from the recorded accelerometer signal.

The purpose of this study was to examine different methods to automatically detect fetal movement. As a first step to gaining some insight into the nature of this signal, we examined previous work on automatic detection of fetal movement [3, 9]: assuming that a fetal movement causes an increase in amplitude on the measuring signal then simply applying a threshold should be sufficient to distinguish between movement and non-movement. We also looked at different frequency bands to isolate different types of movements, such as rolling and kicking. Our results from applying a threshold method varied greatly between different recordings. Over all recordings this method performed poorly—with average true and false detection rates of 48% and 40%, respectively. Next, we looked at a number of statistical features and tracked them over time to assess whether these features correlated with fetal movement. There was some improvement over the threshold method, but performance was still poor with an average true detection rate of 62% and an average false detection rate of 40%.

2. METHODS

2.1. Study setup

2.1.1 Sensor device

The fetal monitoring system [7] consists of an analog accelerometer (ADXL330, Analog Devices) which is connected to a power supply and a data acquisition system (PowerLab, AD Instruments). The accelerometer is a 3-axis micro electromechanical (MEM) device capable of measuring movement within a ± 3g range with a sensitivity of 300 mV/g. The 3 channels is sampled at a frequency of 100Hz and digitized to 16 bit precision.

2.1.2 Data collection

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Accelerometer data coupled with ultrasound imaging was recorded to design and test the proposed fetal movement detection system [8]. Twenty seven women participated in the study with a mean maternal age of 30.2 years and a standard deviation of 5.31 years; mean gestation was 35 weeks with a standard deviation of 2 weeks. A trained ultrasound operator performed the scan for a period of approximately 40 minutes on four quadrants of the maternal abdomen. The ultrasound probe and accelerometer was positioned in each quadrant for approximately 10 minutes. These ultrasound images were recorded onto a DVD.

2.1.3 Scoring Movements

After the data was collected, the ultrasound images were time-synchronised with the accelerometer recordings. The ultrasound operator scored the ultrasound images to create a binary mask to indicate the presence or absence of fetal movements. We define fetal movement as head, trunk and limbs movements.

2.2. Threshold Detection

As the fetus moves the change in velocity causes acceleration which can be measured by the accelerometer. To automatically detect this movement, we previously used a simple threshold-based detection method [8]. The method assumes that fetal movement will produce a significant increase in amplitude in the signal, similar to other fetal movement technologies [3, 9]. Here, we assess and extend this method. The threshold method is as follows.

- Take the magnitude of the three channels $x(t), y(t)$, and $z(t)$ of the accelerometer,

$$m(t) = \sqrt{x^2(t) + y^2(t) + z^2(t)}. \quad (1)$$

  We take the magnitude because we are not interested in the direction of the movement, but rather the presence or absence of movement.
- Filter $m(t)$ with a low-pass filter with a cut off frequency of 20 Hz. We assume that the signal does not contain significant information above 20Hz.
- Downsample the data to 50 Hz, to decrease the computational load. Remove the mean from $m(t)$.
- Split the signal into four different frequency bands: 0 to 0.2Hz, 0 to 2Hz, 2 to 20 Hz, and 0.2 to 20Hz. According to spectral analysis, these frequency bands correspond to regions of observed spectral energy. For this, we apply low-pass and high-pass finite impulse response filters. Take the envelope of the filtered signal

$$r(t) = \sqrt{m^2(t) + H^2\{m(t)\}}$$

  where H is the Hilbert transform operation [10]. Fig. 1 shows an example of generating $r(t)$.
  - Create the detection mask as follows: apply the threshold t_h to $r(t)$ as

$$d(t) = \begin{cases} 0, & r(t) < t_h \\ 1, & r(t) \geq t_h \end{cases}$$

- Calculate $d(t)$ over a range of threshold values for t_h and compare with the ultrasound mask. From this, we calculate the receiver operating characteristic (ROC) curve.

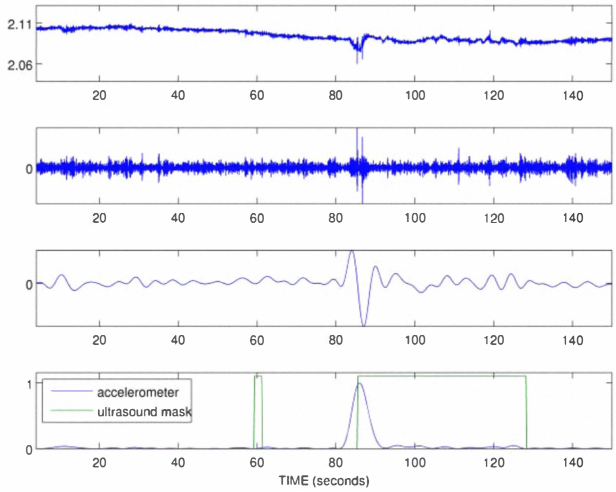

Figure 1. Threshold detection method, from top to bottom: accelerometer signal $\boldsymbol{m(t)}$; removed mean and slow oscillations; low pass filtered from 0 to 0.2Hz; envelope $\boldsymbol{r(t)}$ with ultrasound mask

The ROC is a plot of the true detection rate, the rate of events correctly detected, against the false detection rate, the rate of events incorrectly detected. The detection policy of our system is as following (see Fig. 2):

- if $d(t)$ overlaps a movement event in the ultrasound mask with an overlap of greater than 5%, then this is a true detection; a movement event is defined as a consecutive segment of ones;
- if $d(t)$ overlaps a non-movement event in the ultrasound mask with an overlap of greater than 5%, then this is a false detection; non-movements events are defined as 5 second segments of zeros.

We use an event based detection method because we are interested in detection events themselves, not necessarily detecting the entire duration of the event.

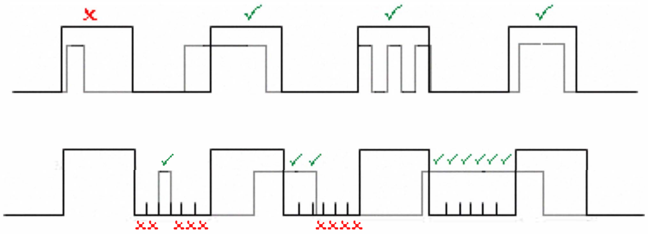

Figure 1. Detection policy for $\boldsymbol{d(t)}$ (gray line) compared with ultrasound mask (black line). Top: when $\boldsymbol{d(t)}$ overlaps a true events by 5% or more, then declare a true detection. Bottom:

When $\boldsymbol{d(t)}$ overlaps a 5 second epoch of non-movement by 5% or more, then declare a false detection.

2.3. Statistical Features Detection

Another approach to the detection problem was to examine some simple statistical features of the signal. We again used the liberal event based detection method to assess the results of the statistical features. We looked at four features: the median, the standard deviation,

$$\sigma = \sqrt{\frac{1}{\mathrm{N}}\sum_{n=1}^{N}[m(n)-\bar{m}]^2}$$

skewness,

$$\gamma = \frac{{}^{1}/_{N}\sum_{n=1}^{N}[m(n)-\bar{m}]^3}{\sigma^3}$$

and kurtosis,

$$k = \frac{{}^{1}/_{N}\sum_{n=1}^{N}[m(n)-\bar{m}]^4}{\sigma^4} - 3$$

where $m(n)$ is the sequence of N discrete sample points of $m(t)$ and $\bar{m} = 1/N\sum_{n=1}^{N} m(n)$ is the sample mean.

A window size of 100 samples (2 seconds) with a 50% overlap between consecutive windows was used to calculate each statistic. We assessed the performance of these features using the ROC, following the same rules as the event based detection.

3. RESULTS

For the threshold-based detection method, our study focused on four frequency bands. In each case our aim was to examine the different durations of the fetal movements: the very slow movements (sucking), the slow movements (rolling, stretching), and the fast movements (kicking, punching) [9]. For each expectant mother, over the four quadrants of the recordings, we tested the detection method. The total ROC for all subjects was the average and standard deviation for each discrete point of the ROC. We calculated the area under the curve (AUC) from the average ROC values.

Initially, the results looked promising. Analysing the results for each quadrant frequently produced encouraging results. Fig. 3 shows an example for one quadrant. Once we averaged over all subjects, however, the results were not as encouraging. Fig. 4 shows the ROC for the combined results, and TABLE I summarizes the different AUCs.

A problem which can occur is that a movement observed on the ultrasound will not be recorded by the accelerometer; and also a fetal movement detected by the accelerometer may be out of the narrow view of the ultrasound. This may explain the poor detection rates. Overall, we conclude that a simple threshold method is not effective, regardless of the frequency band of interest.

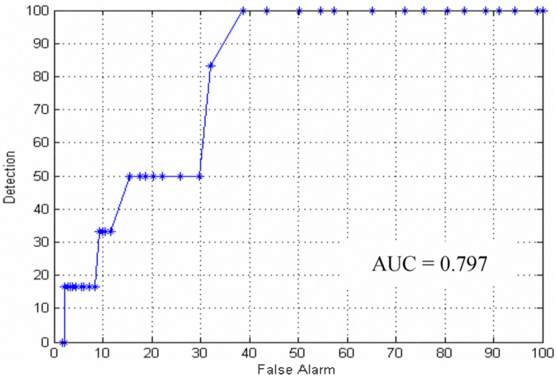

Figure 3. ROC for one quadrant.

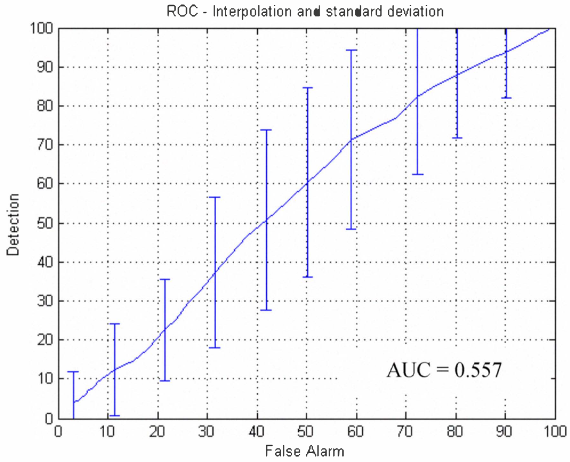

Figure 4. ROC for entire dataset. The line represents the mean value and the error bars represent one standard deviation.

TABLE I
EVENT BASED DETECTION
SUMMARY OF THE AREAS UNDER ROC CURVE (%)
FOR DIFFERENT FILTERING

Filtering	Area Under Curve (AUC)
vLP	0.619731
LP	0.593120
HP	0.557671
NF	0.566513

vLP: very Low-Pass filtering (0-0.2 Hz); LP: Low-pass filtering (0 – 2 Hz); HP: High-Pass filtering (2 Hz – 20Hz); NF: No Filtering

The results of the detection using the statistical features are summarized in TABLE II. Here, we see a small improvement, particularly for kurtosis, as we show in Fig. 5. As kurtosis is a measure of impulsive noise it will highlight the short duration, spike-like movements, such as fetal kicking or punching.

TABLE II
STATISTICAL FEATURES DETECTION
SUMMARY OF THE AREAS UNDER ROC CURVE (%)
FOR DIFFERENT OVERLAPPING AND FEATURES

Feature	Area Under Curve (AUC)
Median	0.601854
Standard Deviation	0.589049
Skewness	0.632254
Kurtosis	0.651192

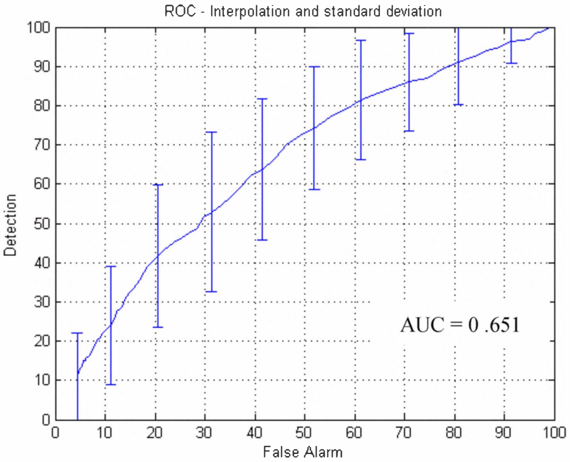

Figure 5. ROC using kurtosis as a feature. Line represents mean and error bars represent one standard deviation.

4. CONCLUSIONS

A threshold method to automatically detect fetal movement from accelerometer signals performs poorly. There may be many reasons for this. First, we know that our comparison measurement, scoring movement from ultrasound images, is not ideal as some fetal movements measured by the accelerometers will not be seen on the ultrasound images. This will limit the accuracy of our results, but in general is an accepted measure [3].

Second, some fetal movements will not register a large deflection of acceleration; movements with approximately constant velocity, for example, will register only small accelerations. The analysis using statistical features shows, comparative to the threshold method, improved detection results. We surmise that other signal processing methods need to be explored to obtain a satisfactory detection method.

Third, the acceleration signal is corrupted by accelerations other than fetal movement. Maternal movement—such as breathing, coughing, laughing—will be present in the acceleration signal. During our analysis, we noticed significant artefact, most likely maternal movement artefact. We intend to study this artifact and develop methods, where possible, to suppress or remove these artefacts. Moreover, the juxtaposition of the accelerometer with the ultrasound probe can produce a damping effect. It has been noticed during some recordings that some large deflections of the acceleration were due to a hand movement of the operator.

Fourth, the detection method is based on a mask created by the ultrasound operator, and therefore there exists some inter-observer variability.

To conclude, developing a fetal detection method from non-invasive accelerometers is not a trivial task. Nonetheless, the benefit of a low-cost, non-invasive, passive device able to monitor fetal health makes the challenge worthwhile.

5. REFERENCES

[1] C. L. Lowery, W. A. Russell Jr, J. D. Wilson, R. C. Walls, and P. Murphy, "Doppler movement detection as a potential screening tool for maternal sensitivity to fetal movement," *Journal of Maternal-Fetal Investigation,* vol. 7, pp. 7-11, 1997.

[2] B. Karlsson, K. Foulquière, K. Kaluzynski, F. Tranquart, A. Fignon, D. Pourcelot, L. Pourcelot, and M. Berson, "The DopFet system: a new ultrasonic Doppler system for monitoring and characterization of fetal movement," *Ultrasound in medicine & biology,* vol. 26, pp. 1117-1124, 2000.

[3] A. Kribèche, F. Tranquart, D. Kouame, and L. Pourcelot, "The Actifetus System: A Multidoppler Sensor System for Monitoring Fetal Movements," *Ultrasound in medicine & biology,* vol. 33, pp. 430-438, 2007.

[4] J. I. de Vries, G. H. Visser, and H. F. Prechtl, "The emergence of fetal behaviour. I. Qualitative aspects," *Early Hum Dev,* vol. 7, pp. 301-22, Dec 1982.

[5] E. Sadovsky, W. Z. Polishuk, H. Yaffe, D. Adler, F. Pachys, and Y. Mahler, "Fetal movements recorder use and indications," *Int J Gynaecol Obstet,* vol. 15, p. 20, 1977.

[6] H. G. Goovaerts, A. A. Wilmsen, M. G. G. Cortenraad, H. P. van Geijn, and O. Rompelman, "Recording and processing of fetal movements and sounds obtained with the Inpho inductive transducer," *Medical and Biological Engineering and Computing,* vol. 29, 1991.

[7] P. B. Colditz, S. P. Brennecke, C. E. East, C. E. Sullivan, S. Crozier, and S. Wilson, "Ambulatory fetal activity monitoring: development of a prototype device," in *PSANZ Perinatal Mortality Group and the Australia and New Zealand Stillbirth Alliance Workshop* Gold Coast, Australia, 2008, p. 13.

[8] S. Wilson, C. E. East, I. Clough, S. Callan, N. Stevenson, M. Mesbah, M. Fuentes, and P. B. Colditz, "Fetal movement detection by solid-state accelerometer and real-time ultrasound imaging data," in *Journal of Paediatrics and Child Health: Oral Abstracts of PSANZ 13th Annual Congress*. vol. 45 Darwin, Australia, 2009, pp. A10-A71.

[9] I. Florentin, G. Inbar, and I. Timor-Tritsch, "Multichannel automatic foetal movement monitoring and classification system," *Medical and Biological Engineering and Computing,* vol. 23, pp. 178-186, 1985.

[10] S. L. Hahn, *Hilbert transforms in signal processing*: Artech House on Demand, 1996.