International Conference On Emanations in Modern Technology and Engineering (ICEMTE-2017) ISSN: 2321-8169
Volume: 5 Issue: 3 284 - 287

Various Techniques for Fetal ECG Signal Monitoring

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***Abstract* –** The paper present a various techniques that enables the investigations of the fetal heart rate (FHR) fluctuations. Later, the common problems associated with these techniques are discussed with some solutions. A non-invasive technique is also proposed for fetal ECG monitoring. The proposed system will be designed to measure the fetal heart rate variability for the evaluation of autonomic nervous system (ANS) and to investigate its development as a function of the gestational age and body mass index (BMI). This will be a real time new method to assess instantaneous fetal heart rate variation (beat to beat) during gestation period with automated analysis of FHR variability using Doppler ultrasound method. The method will consists of three steps: Doppler envelope filter, variable threshold detector and non retriggerable monostable multivibrator having adjustable pulse width for heartbeats detection. The performance parameters will be i) coefficient of variance (CVRR) as an index of parasympathetic activity, and ii) a low frequency/high frequency (LF/HF) ratio as a sympathetic activity. The R–R interval variability will show the variation between consecutive heart beats, change over time was eventually adopted to calculate for time-domain, frequency domain analysis. In the frequency domain analysis power spectral density (PSD) of the RR series will be calculated by analyzing powers and peak frequencies of different frequency bands.

Index Terms* –Fetal ECG, Ultrasound, FHR, ANS, BMI.*

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I. Introduction

Heart rate is a variable signal and provides a balance between the sympathetic and parasympathetic nervous systems. The heart rate variation may contain indicators of present disease, or warnings about impending or future cardiac vascular diseases. These indicators may be present at all times or may occur at random during certain intervals in the time scale. It is difficult and time consuming to pinpoint these abnormalities in a huge cardiac data. Heart rate variability (HRV) constitutes a tool for assessing the activities of the autonomic nervous system (ANS). In this work, a computer based analytical system will be proposed to find the heart rate and analyzed it to obtain HRV Power-spectrum for investigation of the ANS during fetal gestational development. Here, the indices such as HRV power-spectra power values (= areas under the power-spectrum plot between spectral peaks) and frequency shift of the peaks from their normal frequency values will be calculated. The efficacy and sensitivity of these indices will differentiate between normal and abnormal growth of fetal [1]-[6].

II. Various Techniques for Fetal ECG Monitoring

Heart Rate Variability (HRV) was first used clinically in 1965 when Hon and Lee noted that fetal distress was accompanied by changes in beat-to-beat variation of the fetal heart rate, even before there was detectable change in heart rate. HRV refers to the beat-to-beat alterations in heart rate. Stress, certain cardiac diseases, and other pathologic states affect on HRV. Here we talk about HRV; we actually mean variability of RR intervals. HRV measurements analyze how these RR intervals, which show the variation between consecutive heartbeats, change over time [3]. Analyses based on the time and frequency domains of heart rate variability using Doppler ultrasound method enable an evaluation of fetal ANS diagnostic indices. These diagnostic indices derived from fetal heart rate data can be utilized to predict the fetal future life growth and can be utilized for preventive measures. Our design system not only measures heart rate variation but also heart rate power spectrum which can be utilized for determining diagnostics indices helpful for the medical community.

Paulo C. Cortez et al. proposes a FHRV analysis based on the evaluation of time domain parameters (statistic measures); frequency domain parameters; and the short and long term variability obtained from the Poincare plot. A normal distribution is presumed for each parameter and a normality criterion is proposed. Specific and overall classifications are proposed to help improve the fetal conditions interpretation, expanding the conventional FHR analysis [9].

A method of estimation of a fetus condition includes abdominal ECG registration, correlation processing of the received data, fetal R-R intervals allocation, estimation of distribution parameters and diagnostic index calculation, describing activity of sympathetic nervous system of fetus. This technique is used in real-time mode and serves as an approach to the problem of fetal stress diagnostics by means of maternal abdominal ECG processing [10].

An analysis based on heart rate variability in normal subjects of various age groups using the various time domains, frequency domain and nonlinear parameters show that, with aging the heart rate variability decreases [11].

Janusz Jezwski et al. compared Doppler ultrasound and direct electrocardiography acquisition techniques for quantification of fetal heart rate variability, and showed that evaluation of the acquisition technique influence on fetal well-being assessment cannot be accomplished basing on direct measurements of heartbeats only. The more relevant is the estimation of accuracy of the variability indices, since analysis of their changes can significantly increase predictability of fetal distress [12].

An estimation of fetal autonomic state by time-frequency analysis of fetal heart rate variability confirmed that there is a neural organization during the last trimester of the pregnancy, and the sympathovagal balance is reduced with the gestational age [13].

Time-domain and frequency domains analysis of heart rate variability using fetal magnecardiography enable an evaluation of fetal autonomic nervous system (ANS) activity. The result show that sympathetic nervous activity increased with gestational age in the normal pregnancy group [14].

A heart rate variability non-invasive monitoring of autonomic nervous system function special measurements, based on time and frequency domain analysis was introduced [15]. The results show that, heart rate variability gives many parameters that are related to the functioning of two branches of autonomous nervous system: sympathetic and parasympathetic system.

The HRV indexes are obtained by analysing the intervals between consecutive R waves, which can be captured by instruments such as electro-cardiographer, digital-to-analog converter and the cardio-frequency meter, from external sensors placed at specific points of the body. The results show that, changes in the HRV patterns provide a sensible and advanced indicator of health involvements [16].

A novel technique for fetal heart rate estimation from Doppler ultrasound signal on a beat-to-beat basis offers a high accuracy of the heart interval measurement enabling reliable quantitative assessment of the FHR variability, at the same time reducing the number of invalid cardiac cycle measurement [18].

III. Some Common Problems

Analysis of Doppler envelope is difficult due to a complex structure of the signal comprising components originating from particular events of the cardiac cycle. Additionally, the shape of envelope changes from beat to beat. Amplitude-based detection methods are less accurate because they may detect events that do not correspond to each other in consecutive cardiac cycles. This consequently leads to incorrect interval determination. Earlier, the processing of acquired signals was implemented using LABVIEW environment virtual instrumentation software system which was costly.

IV. Some Common Solutions

R-R interval indicates instantaneous heart rate which is (1/T *60) beats per minute. This can be derived from electrocardiogram (ECG) by measuring the time between two consecutive QRS complexes. Same results are expected by measuring the time between the two consecutive movements of the same part of the fetal heart. So by focusing the Doppler ultrasound signal on the fixed part of the fetal heart, the waveforms generated are proportional to the velocity of the movements of that part which can be used for detection of the same event in the consecutive cardiac cycle. So detected waveform can be correlated to QRS complexes of the consecutive cardiac cycles. This can be validated by measuring time between two QRS complexes and at the same time measuring time between two detected events from Doppler ultrasound transducer. Timing diagram of direct electrocardiography and Doppler ultrasound method for HRV signal detection is shown in Fig. 1. If practically T1= T2 for the duration of the test procedure then it can be assumed that the HRV signal produced either by direct electrocardiography or Doppler ultrasound can be similar. Hence analysis will be similar.

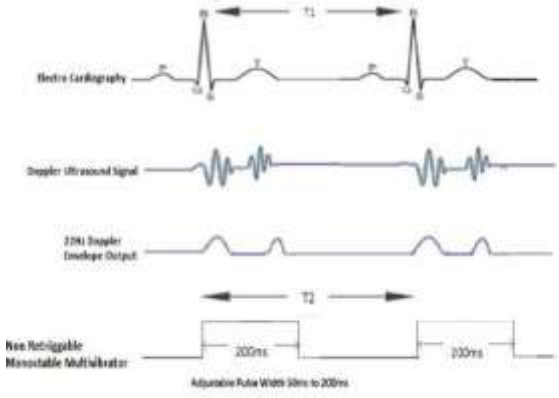

Fig. 1. Timing diagram of direct electrocardiography and Doppler ultrasound method for HRV signal detection.

Fetal heart rate signals will be recorded using Dipel make Doppler ultrasound (DFM-051) machine as can be seen from Fig. 2. Here, Doppler electrodes will be placed on mother's abdomen. The monitor will be equipped with ultrasound transducer which continuously emits (with repetition frequency of 3 kHz) 2 MHz ultrasound waves of a very low power 1.5 mw/ cm^2. The wave reflected from moving parts of fetal heart (walls or valves) returns to the transducer, which has receiving elements. Frequency shifts between emitted and reflected waves is caused by the Doppler Effect and provides information on the speed of moving object on which the ultrasound beam is focused.

Doppler ultrasound transducer will be held on patient abdomen in the direction such that ultrasound waves emitted will pass the fetal heart movement. The reflected waves from a moving fetal heart rate are received by receiving element in the transducer. This signal will be fed to the RF amplifier (2 MHz) and FM demodulator to detect the movement of the fetal heart.

Demodulated detected waveform will have definite events relating to contraction and relaxations of fetal heart. Each event will be a combination of different frequency components relating to motion of fetal heart and angle of incidence of the ultrasound wave on it. This signal will then passed through envelope filter (Band Pass Filter 22 Hz) with centre frequency of 22 Hz which results in generating two simple peaks per cardiac events. This signal will then pass through a variable threshold detector where threshold is kept at half the peak value of incoming signal.

Two separately detected pulses then pass through a non retriggerable monostable multivibrator for avoiding double triggering of a single cardiac event. The adjustable pulse width for this monostable multivibrator is 50 ms to 200 ms giving fetal heart rate range up to 300 BPM. This output will be then given to a personal computer USB port for HRV analysis. At the same time, Doppler signal related to heart movements and contained in the audio frequency range (from 0.2 to 1 kHz) will be fed to the speaker, which helps in correct

positioning of transducer on maternal abdomen. The maternal and per abdomen ECG will also can be monitored during the process for separate filtering and evaluation studies [5].

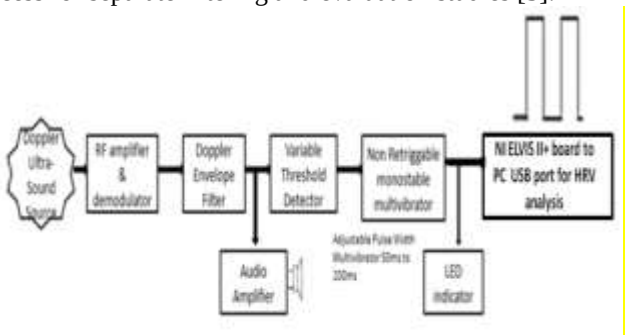

Fig. 2. Conceptual diagram of the real time hardware for Doppler ultrasound signal analysis.

V. CONCLUSIONS

Various techniques that enable the investigations of the fetal heart rate (FHR) fluctuations are discussed. Solutions on various problems associated with all these techniques are discussed. A non-invasive technique is also proposed for fetal ECG monitoring. The proposed system will be designed to measure the fetal heart rate variability for the evaluation of autonomic nervous system (ANS) and to investigate its development as a function of the gestational age and body mass index (BMI). This will be a real time new method to assess instantaneous fetal heart rate variation (beat to beat) during gestation period with automated analysis of FHR variability using Doppler ultrasound method.

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