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Wearable Fetal Ecg Home Monitoring System

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Abstract: ***The fetal heart signal is one of the important parameter to monitor during gestational period. It provides information regarding fetal stress condition and oxygen availability in organs. With wearable fetal monitoring system it is possible to monitor the overall health condition of the fetus from home. The paper discusses a prototype fetal ECG monitoring system that can be used by pregnant mother to monitor fetal wellbeing and transmit the data to a remote monitoring station to obtain opinion. The conventional fetal ECG monitoring system uses a gel-based electrode to acquire the signal, which cannot be used for long duration monitoring. The proposed system discusses a dry electrodes made of a textile material which does not use the gels to record the ECG signals.***

Keywords: Fetal ECG, Textile Electrode, Artifacts, Adaptive Filter.

I. INTRODUCTION

The information about fetal wellbeing during gestation and labor can help to detect damages in fetal physiological condition. Fetal heart signal is the main source of information which indicating oxygen availability in organs and distress condition of fetus. There are several methods available to monitor fetal heart rate. For example Cardiotocography (CTG), Fetal ECG, Phonocardiography (PCG), and Magneto-Cardiography (MECF) are the common methods. The most traditional and common method to measure fetal ECG is based on CTG [1]. In CTG, the ultrasound sensor used for measuring abdominal signal and the Toco-dynamometer used to measure uterine contraction. The recent development in the medical electronics field is based on the portable device, which can provide more flexibility to the overall diagnosis and patient monitoring activities. CTG as consider as non-invasive means for portable wearable device fetal monitoring system. There are several disadvantages for this traditional method, as it is not suitable for long term monitoring because of radiation effect. Using this device is possible to determine the condition of the fetus. Most of the time, it is not possible to draw a conclusion about the fetus condition without any other tests [2].

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These disadvantages encourage the development of non-invasive fetal ECG monitoring system. In this technique the electrodes are placed on mother abdomen area to measure fetal heart rate. This method can be used over extended periods. The main disadvantage with this technique is that it has very low signal to noise ratio, which requires a good front-end amplifier and an efficient algorithm to extract the information. The fetal ECG is affected by the noise interference such as maternal muscle noise, electrode contact noise, power line interference, motion artifact and noise in electronic equipment [3].

The electrodes used for the non-invasive fetal ECG mainly gel based which is not suitable for the sensitive skin. Also the gel electrodes restrict the reusability of the device. For long term monitoring the dry electrodes are more preferable than the gel electrodes though the hardness of dry electrode do not provide the necessary comfort for the pregnant women. For recording of bio-potential signals there were various dry electrodes fabricated based on conductive Silicon rubber loaded with Silver particles [4], spiked needle arrays [5], soft conductive polymer [6], carbon nanotube (CNT) based array electrodes [7]. These dry electrodes are not suitable for long duration monitoring of the fetal ECG signals from the abdomen of the mother. The current researcher paid great attention towards textile electrodes, which leads to develop wearable monitoring system. The textile or fabric electrodes defined as textile product uses materials such as fibers and filaments, yarns together with woven, knitted or non- woven structure, which can interact with environment [8]. To design fabric electrodes it necessary to consider different aspects such as selection of materials, structure of fabric and conductive way of biological signal. It is very flexible electrodes with advantages of breathability, moisture permeability, soft and biological compatibility [9]. This type of sensors that can be used for recording bio-potential signals such as Electrocardiogram (ECG), Electromyography (EMG), and Electroencephalography (EEG) sensing. HongyiZhai[10]*et al.* use wearable fabric electrodes made of silver-plated fabric to acquire ECG and processing the signal using micro-processing unit to get abnormality. Similarly, Vojtech*et al.* [11] use the textile electrode knitted in a T-shirt around the position of chest muscle to acquire the ECG signal. In 2006, M. Di Rienzo has been developed a new textile-based wearable system for the unobtrusive recording of cardio-respiratory and motion signals during spontaneous behavior [12].

The advancement of science has lead to development of home-based health monitoring systems. For the neonatal health care home monitoring system the textile electrodes plays a vital role. In 2011, Andrea Fanelli developed Tele fetal care to monitor fetal well being during pregnancy.

This device consists of eight-textile ECG lead and can be used by pregnant women in home without any external support by the clinician [13]. Uri Amir et al US patent no. 0128594A1, stated in the patent document, a seamless, smart fetal monitoring garment which includes knitted conductive textile electrodes for sensing fetal and maternal electrical activity on body surface [14].

With the target to provide health care service to all, the wearable wireless fetal ECG monitoring system has proposed in this paper. The device consists of wearable belt for acquire signal from mother's abdomen and a data acquisition system for signal acquisition and transfer for signal processing. For noise removal and the signal processing, the adaptive filter method has been used [15].

II. MATERIAL AND METHODS

A. Parameters Monitored

To build a home monitoring system for the pregnant women, the wearable wireless system has been developed. This device is capable measuring the fetal ECG along with maternal ECG. The fetal ECG maintain the same pattern as the adult ECG pattern including PQRST complex [16]. Compared to adult ECG, fetal ECG has lower frequency range, around 20Hz-60Hz. The normal fetal heart rate varies. with 110-150 beats/minutes. If the baseline frequency increases more than 60 bpm or less than 110 bpm considered as abnormal condition. Also absence of acceleration and deceleration for more than 45 minutes considered as abnormal [17]. The analysis of fetal ECG can provide the information regarding the fetal stress condition and oxygen availability in organs.

B. Overall System Architecture

The wearable wireless system for fetal monitoring system consists of belt type wearable unit along with the data processing system. The sensors have been attached with belt in the navel area to acquire the abdominal ECG signal. The signal acquired from the abdomen transferred to the data acquisition system. In the data acquisition system, signal passes through the preprocessing and amplifying stages and transferred to the digital processing system for signal analysis. The figure.1 shows the block diagram signal acquisition system.

C. Dry Electrodes

In this proposed work the conductive fiber used as a electrodes which can provide necessary comfort. The textile/fabric electrodes defined as textile product such as fibers and filaments, yarns together with woven, knitted or non- woven structure, which can interact with environment. The sensors made of blended yarn with silver nano particles which provide conductivity in the fiber. The electrode made of textile have antibacterial and anti allergic properties as well as electrical stability when exposed to sweat. It is placed minimum 100mm apart for sufficient potential difference. The textile electrodes provide breathability, moisture permeability, soft and biological compatibility of the device. This type of material is suitable for long duration monitoring system [18].

Here, the sensor for abdominal signal has taken two type of conductive fabric.

The fabric electrodes have designed with proper size and connector to connect with the data acquisition system. In this device total eight electrodes have taken to collect abdominal signal and a reference electrode in the navel area. Two separate electrodes placed near to the chest for mother ECG. All the electrodes stitched on a single belt type embodiment in a specific manner so that it can cover most of the area of abdomen.

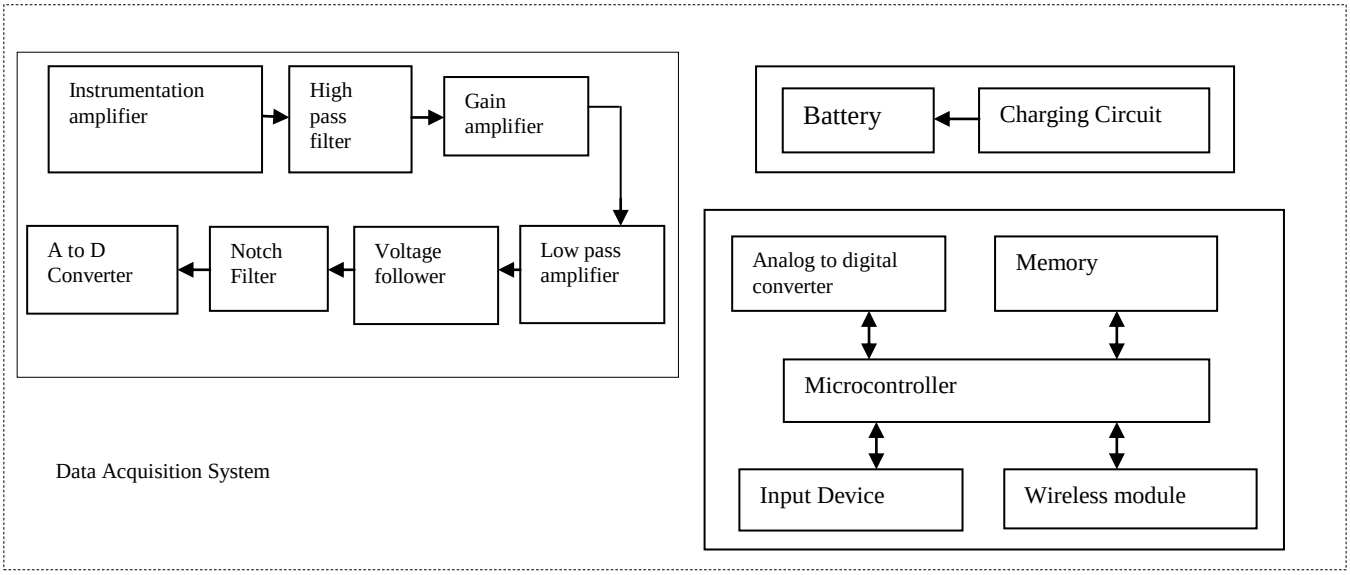


Fig. 1: Block diagram of data acquisition system

Table1. Textile Electrode Material Characteristics

Conductive fiber	Material	Conductivity
Type I	Silver plated Nylon	Highly conductive, Resistance less than 1 Ω per foot

Type II	63% cotton, 35% silver and 2% spandex	Less conductive, resistance 460 Ω per foot.

D. Data Acquisition System

The signal collected from the abdomen has transferred to the data acquisition system, which is fixed with the same embodiment. The data acquisition system consists of analog signal acquisition, digital signal processing board and battery for power supply. The analog signal acquisition board have instrumentation amplifier with specific gain which is fed to the high pass filter with approximate 0.5 Hz cutoff, amplifier with a gain of 100, low pass filter with 50 Hz cutoff, notch filter to reduce 50 Hz noise interference and the voltage follower. The analog signal converted into the digital domain and transferred to the system for further analysis using microprocessor based digital board.

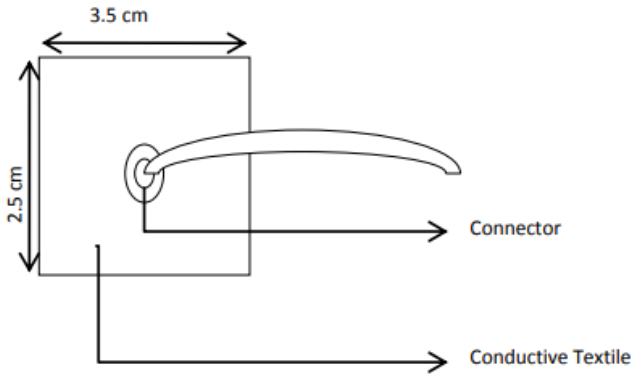


Fig. 2: Measurement of conductive fiber

III. RESULT AND ANALYSIS

A. Signal Acquisition

Fig. 3 illustrates the two types of electrodes using the textile material. The electrodes were tested for the acquisition of the ECG signals. The signals were acquired using both the types of electrodes fabricated and the acquired signals were compared with that of the wet electrodes. The signal recordings from the dry textile electrodes were comparable to that of the wet electrodes. Fig. 4 shows the comparable result of textile electrodes. The first ECG signal is acquired using gel based electrodes and the second ECG signal is acquired using textile electrodes.

Fig. 3: Fabricated conductive textile electrodes (a) Type – I and (b) Type – II conductive fiber

Using the conductive electrodes and data acquisition board, the abdominal signal has collected and it is transferred to the system using digital processor for the signal analysis. Fig. 5 illustrates the fabricated fetal ECG acquisition hardware interfaced to digital signal processor and interfaced to a

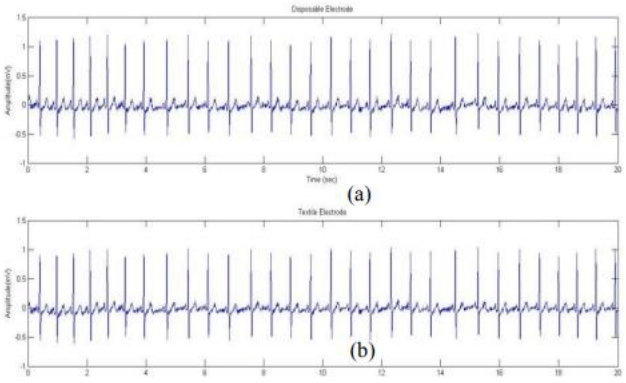


Fig. 4: The ECG signal acquired using (a) gel based electrode and (b) textile electrode using the developed hardware.

laptop using USB interface for data acquisition shown in fig.6.

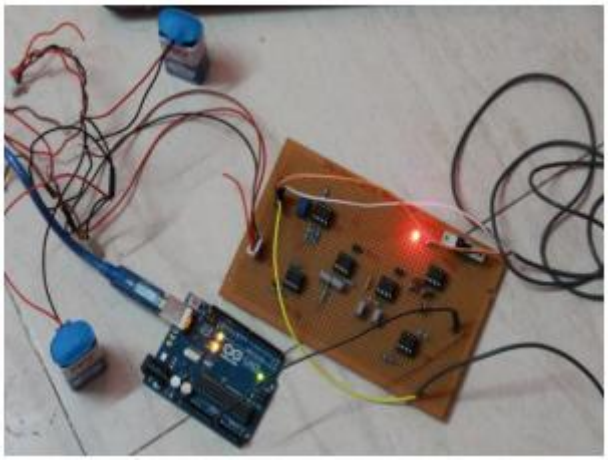


Fig. 5: Data acquisition hardware fabricated

Fig. 7 illustrates the ECG signal acquired from the developed

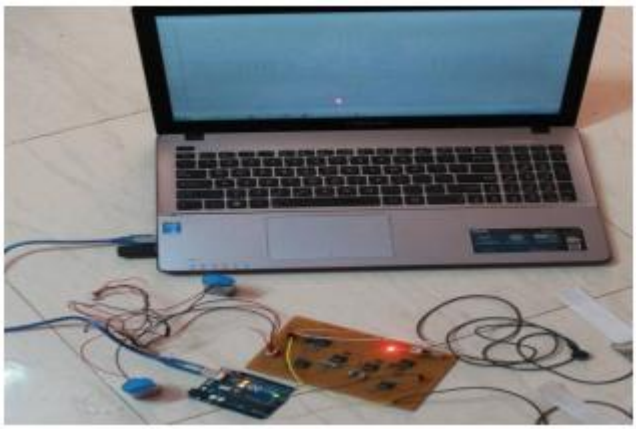


Fig. 6: Experimental Setup

data acquisition hardware.

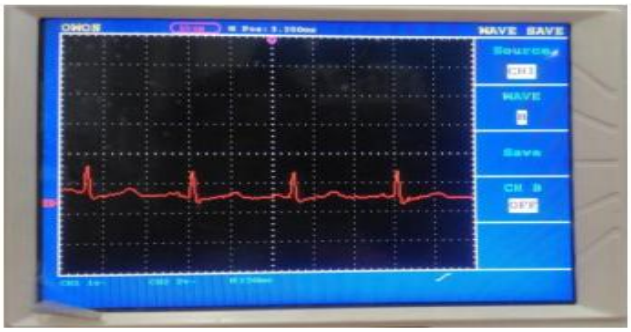


Fig. 7: Signal acquired using data acquisition system

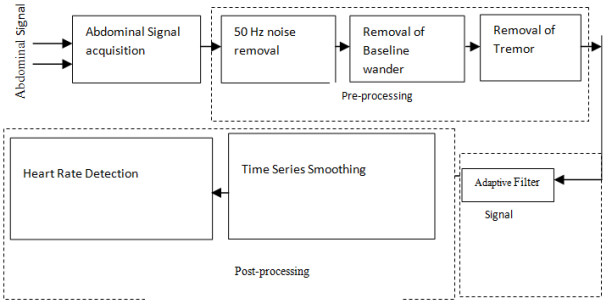


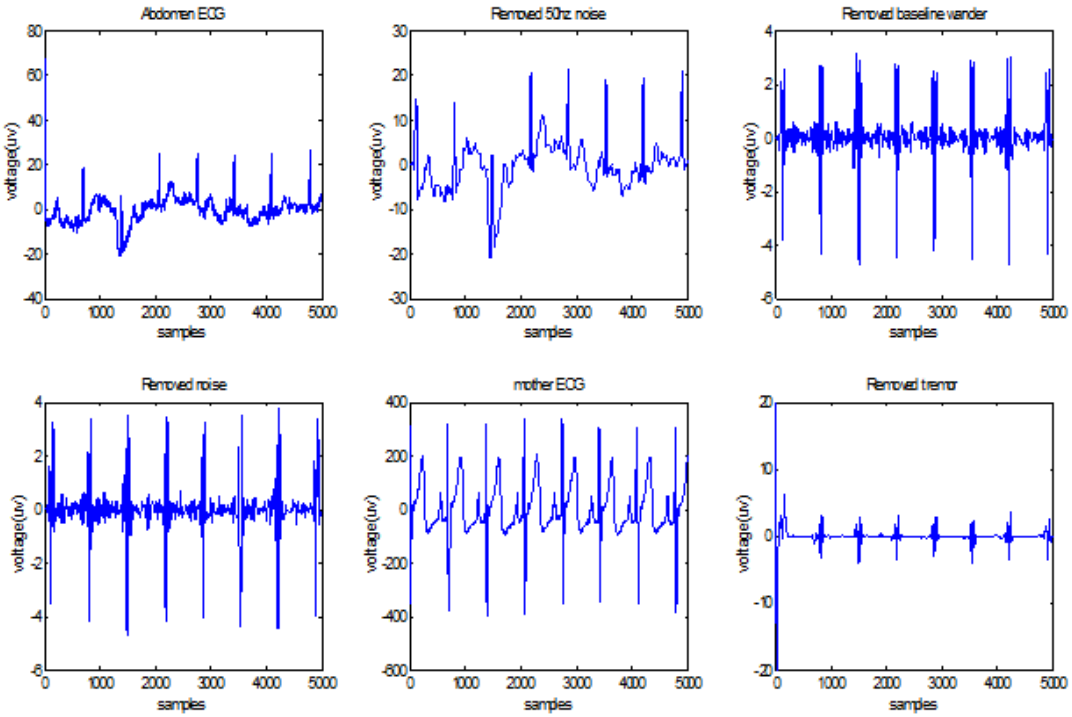
Figure 8: Signal Processing Technique

B. Signal Processing

The signal collected from the abdomen is affected by the noise interference from the various sources. For this reason proper signal processing with artifact removal algorithm is the prime requirement to extract the information from the original signal.

Fig. 8 illustrates the signal processing being applied to the ECG signal to remove the noise in the ECG signal. The signal processing method initially applied to the non-invasive fetal ECG data samples available in the Physionet data bank.

To remove the 50 Hz noise from the compound signal we have used here Kaiser Window method. The abdominal ECG signal shows in fig. 9.a. After removing the 50 Hz noise signal the output signal shown in figure 9.b. For other noise such as base line wander and tremor has been removed by using second order Butterworth band pass filter. Figure 9.d. shows the result after removing entire artifact. Once the artifact removed from the abdominal signal in the preprocessing stage, the maternal signal acquired from the thorax fed to the adaptive filter. Fig. 9.e. shows the maternal signal acquired from the thorax. This method has been used to extract the fetal



ECG from the abdominal signal. In this Adaptive noise cancellation method requires two input datasets; one containing a signal corrupted by noise and another one containing random noise correlated with the noise that corrupted the signal data. Without correlation between two signals, the adaptive algorithm cannot remove the noise from the signal. Here the abdominal ECG signal has taken as the data signal which is corrupted by the maternal ECG signal.

The process of extraction of fetal ECG is to subtract the maternal component from the abdominal signal [19]. Fig. 9 shows the result of adaptive noise cancellation. Figure 9 shows the extracted fetal ECG signal.

IV. CONCLUSION

In this paper, wearable fetal ECG home monitoring system has been proposed. The result has shown good agreement to the standard ECG recording from the gel based electrodes. This work carried out is the initial results of our ongoing efforts in wearable fetal ECG monitoring system. Despite of the lot of development, there are still lots of key areas that require further investigation in the field of fetal electrocardiogram.

The system has the potential to transform neonatal health care across the developing world areas, which are not serviced by healthcare system. Also there is always a chance to develop better signal to noise ratio and the optimal signal processing method for FECG extraction. Advanced cost effective wearable fetal and mother monitoring system will provide a major revolution in the any developing country.

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