Wireless Fetal Monitoring

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Abstract: ***Fetal mortality rate is considered a good measure of the quality of health care in a country or a medical facility. If we look at the current scenario, we find that we have focused more on child mortality rate than on fetus mortality. Even it is a same situation in developed country. Our aim is to provide technological solution to help decrease the fetal mortality rate. Also if we consider pregnant women, they have to come to hospital 2-3 times a week for their regular checkups. It becomes a problem for working women and women having diabetes or other disease. For these reasons it would be very helpful if they can do this by themselves at home. This will reduce the frequency of their visit to the hospital at same time cause no compromise in the wellbeing of both the mother and the child. The end to end system consists of wearable sensors, built into a fabric belt, that collects and sends vital signs of patients via bluetooth to smart mobile phones for further processing and made available to required personnel allowing efficient monitoring and alerting when attention is required in often challenging and chaotic scenarios.***

Keywords: Cardiotocography, remote fetal monitoring, bluetooth, mobile health.

1. Introduction

1.1 Cardiotocography

Cardiotocography is a routine test that is used to detect fetal distress by examining the effect of uterine contractions on fetal heart rate (FHR), by simultaneously measuring FHR and the abdominal strain resultant from uterine contractions. The practitioner identifies the presence of fetal distress, based on variations of FHR during uterine contractions. Fetal heart monitoring assesses the wellbeing of the fetus and has proven effective in preventing fetal mortality in high risk maternal populations [1]. The average fetal heart rate is between 110 and 220 beats per minute, and can vary by 5 to 25 beats per minute. This information is enough to know the fetus development or to tell that it have some problems.

The machine used to perform the monitoring is called a cardiotocograph, more commonly known as an electronic fetal monitor (EFM). Electronic Fetal Monitoring can be of two types – external or internal.

Internal Monitoring involves placing an electrode directly on the fetal scalp through the cervix. While it is the most accurate assessment of true fetal condition, internal monitoring is extremely invasive & has certain health risks. Improper placement of electrode might hurt the baby or result in infection for the mother and the baby.

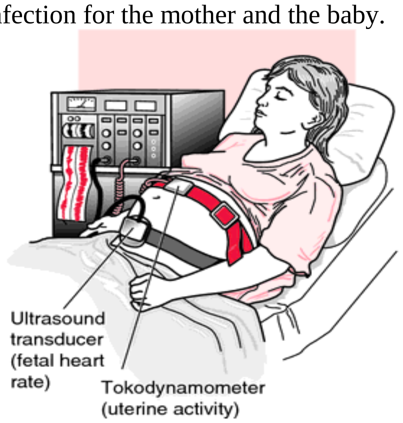


Figure 1: External Fetal Monitoring Technology

As shown in above figure External Fetal Monitoring technology is composed of a bench-top central unit, which consists of a Doppler ultrasound transducer to measure fetal heart rate, a tocodynamometer (toco) to register uterine contractions, speaker, and a printer. The sensors are affixed to the abdomen of the mother, and wired to the central unit via connecting cables [2] as shown in Fig.1 above.

Currently the fetal monitoring devices are large, expensive, and their use is tied to a non mobile clinic or hospital setting. Therefore, high risk obstetric patients requiring fetal monitoring are referred to either a hospital or outpatient clinic setting where monitoring takes place under the physical presence of a technician or nurse. One drawback of this setup is that the pregnant woman (not the monitoring device) has to travel to the clinic or hospital for the monitoring session which potentially is expensive (in time and cost) and risky to the fetus and mother.

We have found that most fetal monitoring facilities for patients in critical condition are currently using wired networks to transfer data. Therefore, monitoring of patients, who are not categorized as high risk, currently is limited to a few times during course of pregnancy which can reduce the efficacy of monitoring as critical incidents may be missed. As a result, pregnant mothers who are in remote or underserved areas with limited access to healthcare may not receive fetal monitoring during pregnancy.

1.2 Doppler Effect

This Fetal Monitoring system work on the principle of Doppler Effect - sound pitch increases as the source moves toward the listener and decreases as it moves away as shown in figure 2 below.

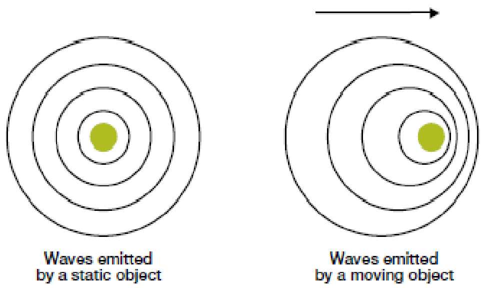


Figure 2: Doppler Effect Example

The piezoelectric crystal which is the first element of Doppler converts compression into charge, and vice versa. A beam of ultrasound rays is passed from the transmitting crystal which is coupled to the mother's abdominal surface. Frequencies around 2 MHz are used because the ultrasound beam at this frequency can penetrate deep enough into the abdomen. The back-scattered ultrasound is detected by the receiving crystal. When the transmitted ultrasonic beam encounters an interface of increased density, a portion of the signal is reflected. The frequency increases if the reflecting interface is moving away from the signal source. As long as the reflecting interfaces are not in motion, the reflected signal has the same frequency as the transmitted signal; however, if the reflecting interface is the surface of a moving organ such as the fetal heart there will be a frequency change (Doppler shift) in the reflected signal.

The device then determines the direction and depth of each returning sound and converts this into an audible output. Thousands of these pulses are computed and converted every second to produce a sound representative of the fetal heart beat. The electronic circuitry of the fetal monitor senses this frequency change and converts it to an electronic signal. The signal is passed through the Envelope Detector which rectifies the signal to convert AC audio input to pulsed DC output. Filtering is used to smooth the final result. This information is transferred wirelessly using Bluetooth protocol for wireless transmission.

2. System Architecture

In this paper we propose an end-to-end wireless and mobile fetal monitoring system which consists of body-worn fetal monitoring device augmented with wireless networking technology, to enable a new paradigm of care allowing anytime/anywhere monitoring.

2.1 Proposed System

The solution consists of a software application that can be run on a mobile phone via bluetooth. This software transforms inexpensive fetal monitoring devices that merely let the user 'hear' the fetal heart beat into a system that calculates fetal heart rate and uterine contractions, stores it over time, tracks fetal movement, and provides this data in the same form as standard hospital equipment. The software on the phone analyses the sound of the fetal heart to calculate the heart rate using a autocorrelation algorithm.

Figure 3 demonstrates the architecture of the proposed system, comprising a wireless sensing interface. Proposed system consists of a set of two half disc 2MHz PZT ultrasound ceramic transducer to detect the heartbeat and a toco pressure sensor to measure uterine contractions, similar to standard fetal monitoring system. We use AVR microcontroller for system control. The Microcontroller provides the following features: In-System Programmable Flash Program memory, EEPROM, SRAM, general purpose I/O lines and programming, flexible Timer/Counters with compare modes, Internal and External Interrupts, a serial programmable USART, a byte oriented Two-wire Serial Interface, an ADC with optional differential input stage with programmable gain, a programmable Watchdog Timer with Internal Oscillator, an SPI serial port, and power saving modes.

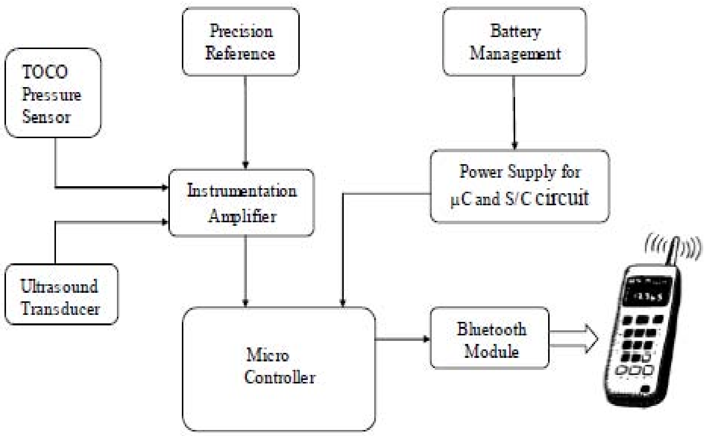


Figure 3: The architecture of the proposed system.

Toco sensor which consists of a pressure transducer configured in a Wheatstone bridge is used for contraction monitoring. An instrumentation amplifier is used to amplify the signal to the ADC input range. The whole system works on 5 VDC supply. The data is processed using Micro-controller. The incoming analog data is converted into its digital form by the internal ADC present inside the microcontroller The received data is first mapped into a defined segment so as to remove unwanted changes in the incoming signal and is transformed using UART into its string form so as to display it on the application developed on Android Mobile For the wireless transmission of data, Bluetooth protocol is used. The data is transmitted serially with the format

<AA><Heart Rate><BB><Contraction>

Correspondingly, the data is received by a Bluetooth enabled android device which decodes the above mentioned format and displays the data accordingly. The Heart rate is measured in BPM (Beats per Minutes) and the contraction is measured in percentage (%). The safe range for heart beat rate is 130<HB<160 and for Contraction, CON<70. When any of these is out of range then an alarm is triggered.

2.2 Bluetooth

In 1994, Ericsson Mobile communications, the global telecommunication company based in Sweden, initiated a study to investigate, the feasibility of a low power, low cost ratio interface, and to find a way to eliminate cables between devices. Finally, the engineers at the Ericsson named the new wireless technology as "Blue tooth" to honor the 10th century king if Denmark, Harald Blue tooth (940 to 985 A.D).

Bluetooth is a low cost, short-range, wireless technology with small footprint, low power consumption and is also reasonable. We used Bluetooth v1.2 module with SPP profile. The module is integrated into HOST system which requires Bluetooth functions. The HOST system could send commands to Bluetooth Module through a UART. Bluetooth Module will parse the commands and execute proper functions. The device is connected to mobile or laptop using a SPP of module.

Bluetooth protocols have spread spectrum techniques in the 2.4 GHz band, which is unlicensed in most countries and known as the industrial, scientific, and medical (ISM) band. Following are three license free bands of Bluetooth-

Three license free bands

2.4 GHz

15 MHz for North America

868 MHz for Europe

- At 2.4 GHZ- 16 channels -data transfer of 250 kbps
- At 915 MHz-10 channels -max 40 kbps transfer rate
- At 868 MHz-1 channel -max 20 kbps transfer rate

We have used 2.4GHz unlicensed frequency band here. So we have used Bluetooth as a communication medium and Bluetooth enabled mobiles are easily available in the market.

2.3 Autocorrelation

Most proposed mathematical algorithms for estimation of FHR baseline are satisfactory when the FHR tracings are regular with long and stable FHR segments. These kinds of tracings are found most commonly during the ante partum and the early hours of delivery. Baseline estimation is more complex when the FHR tracings are irregular and any misinterpretation would affect the overall interpretation of the CTGs.

When interpreting a CTG, there are four main parameters to consider relating to the FHR and uterine contractions (UC) as shown.

- Baseline heart rate (BL)
- Baseline Variability (V)
- Periodic Changes
- Accelerations (Acc)
- Decelerations (Dec)

To estimate the fetal heart rate, the autocorrelation calculation is applied to reconstructed signal. The peak detector is used to find the cycle period. After peak detection, the time intervals of heart beat T(i) are calculated according to the peak positions and fetal heart rate (FHR) can be estimated as:

$$FHR(i) = 60/T(i)$$

Autocorrelation is the cross-correlation of a signal with itself. Informally, it is the similarity between observations as a function of the time separation between them. It is a mathematical tool for finding repeating patterns, such as the presence of a periodic signal which has been buried under noise, or identifying the missing fundamental frequency in a signal implied by its harmonic frequencies.

The autocorrelation technique is a method for estimating the dominating frequency in a complex signal, as well as its variance. Specifically, it calculates the first two moments of the power spectrum, namely the mean and variance. It is also known as the pulse-pair algorithm in radar theory.

The algorithm is both computationally faster and significantly more accurate compared to the Fourier transform, since the resolution is not limited by the number of samples used.

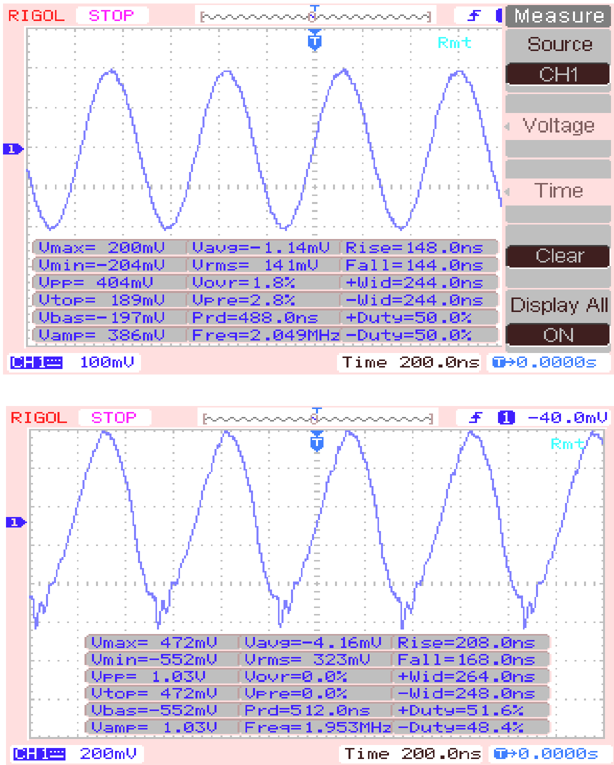


Figure 4: Signal from sensors with and without load.

A standard autocorrelation function is defined as follows:

Where s is the analyzed signal, n is the number of first sample in the autocorrelation window and N is the AF window length expressed in signal samples. The R(i) function expresses the similarity of the analyzed signal and its version shifted in time by i samples.

Due to motion artifacts and/or inappropriate positioning of transducers on a mothers abdomen, the heartbeat detector often misses one or more heartbeats. The algorithm for heartbeat to heart rate conversion embedded on microcontroller eliminates the erroneous measure via comparing input beat period with the previously stored value. In case that current reading is outside of ±25% of the stored value, the algorithm drops the new reading and raises a flag. If 6 consecutive readings are constantly out of that range, indicating that previously averaged heartbeat value is not valid anymore, the new reading is stored as updated measurement result. Signal conditioning can be implemented using a band-pass filter to reject noise. Using an active filter, the signal can be conditioned to determine values.

3. Illustration of System

The below figure shows the implementation for the different components of the sensing unit. The unit integrates the ultrasound transducers, processing and control circuitry, and the internal Bluetooth communication module. Separate belts are used to hold the central unit and toco sensor so that during operation, position of sensors can be independently optimized.

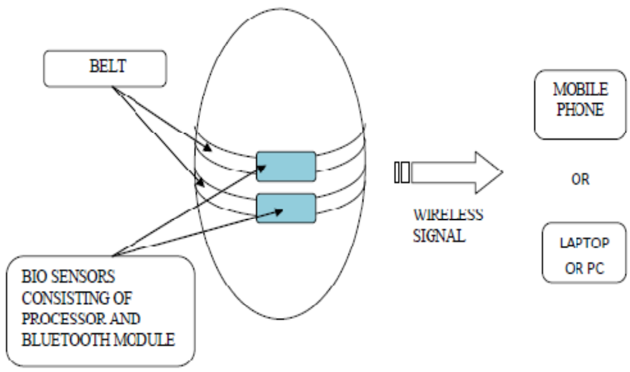
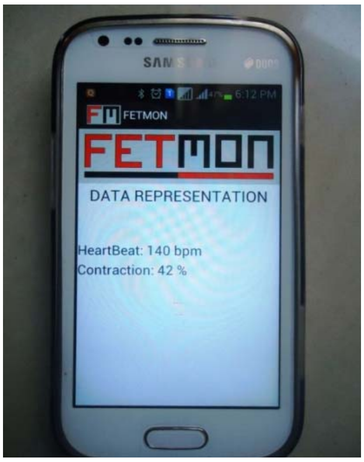


Figure 5: Illustration of the system hardware.

The device has been developed with usability in mind. The user must simply plug in components in order to activate power and data collection. The FHR monitor automatically detects the presence or lack of a connection, to inform the user of the monitor status: such as a valid input connection, Bluetooth transmitter is operating, and flashing for the heart beat and uterine contractions.

Bluetooth module emit non ionizing radiation at frequencies ranging in 1-2.5GHz. The FCC limit on the Specific Absorption Rate (SAR), a measure of the rate of energy absorption by the body when exposed to an RF field [3], for cellular telephones is 1.6 W/kg. The SAR rate of the gateway is comparable to typical smart phones, in the range of 0.5-1.5 W/kg [4-5]. A Bluetooth radio module configured in class II generates a SAR level of ~0.01 W/kg. By using the optional external Bluetooth necklace, rather than the built-in module further diminishes the undesired RF emission exposure to the fetus to an even less significant value.

The gateway has been implemented as an application on an Android based smart phone. It uses internal Bluetooth on the phone to create the link with the sensing hardware. Result is displayed on mobile phone as shown below in fig. 6.



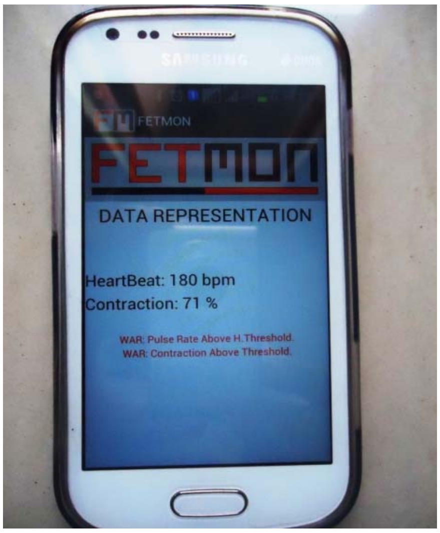


Figure 6: Result displayed on mobile screen

4. Conclusion

The present fetal monitoring technology is both wired and constrained to specific clinical locations. As a result the care provider and patient have to be physically co-located, in time and place, in order to collect the measurements, provide diagnosis, and care.

The proposed system is both wireless and mobile introducing a new paradigm of care. The measurement can be done as close to the mother's location as possible while the data is viewable from any web browser based device including smart phones, tablets, or laptops. This allows replicating the current usage scenario in addition to enabling remote measurement, diagnosis, and care. This is especially beneficial to pre-natal care in developing countries where pregnant mothers may face significant challenges getting to the clinic or hospital multiple times for such a test. The proposed remote monitoring technology makes use of wearable sensors, short range radios. We can also improve the system by use of Wi-Fi and cellular data communication network and cloud infrastructure for remote monitoring and reduces the size and cost of the device, without compromising the quality of measurement.

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Author Profile

Sangita Bhong received the B.E. degree in Electronics Engineering from M. S. Bidve College of Engineering in 2004. During 2004-2013, I worked as a Lecturer in various Engineering Colleges and also having industrial experience.