Monitoring of Unborn Babies Using Bluetooth

Sangita S. Bhong, S. D. Lokhande

Abstract— In this paper we describe our initial approach to proposed solution for mobile fetal heart rate monitoring and evaluation running on Android platform. Additionally the application on the mobile Android device contains viewer of the signal that enables setting of customary thresholds levels for the analysis rules and gives user full control over the settings of the recording device. 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 solutions to help decrease the fetal mortality rate. Measurement of fetal heart rate and uterine contractions is the prominent source of information about the fetal well-being in the late stages of pregnancy and during the delivery. With the stable increase of systematic costs of western medical systems and with the lack of trained personnel especially in the rural areas, telemedicine solutions are destined for large range of users.

Index Terms— Cardiotocography, EFM, Medical sensors,Ultrasound doppler,Autocorrelation, Bluetooth, Android mobile health application, Remote Monitoring.

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1 INTRODUCTION

During the last weeks of pregnancy the frequency of periodic controls can increase up to 5 per week, creating great burden on both – mother and obstetricians. 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.

Cardiotocography (CTG) is a technical means of recording (-graphy) the fetal heartbeat (cardio-) and the uterine contractions (-toco-) during pregnancy, typically in the third trimester. The machine used to perform the monitoring is called a cardiotocograph, more commonly known as an electronic fetal monitor. CTG can be used to identify signs of fetal distress.

Fetal monitors are used to monitor 3 key fetal / maternal parameters:

- Fetal heart rate (FHR)
- Fetal movement
- Maternal contractions (aka 'uterine activity' or 'toco')

Simultaneous recordings are performed by two separate transducers, one for the measurement of the fetal heart rate and a second one for the uterine contractions. Transducers may be either external or internal as shown in fig-1.

External measurement means strapping the two transducers to the abdominal wall of the mother and wired to the central unit via connecting cables [2] as shown in Fig.2.

- The pressure-sensitive contraction transducer, called a tocodynamometer (toco), measures the tension of the maternal abdominal wall - an indirect measure of the intrauterine pressure.
- The fetal heart rate transducer overlays the fetal heart, measures the fetal heart rate.

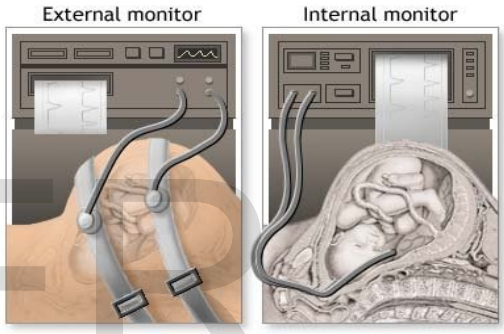

Fig. 1 Types of Fetal Monitoring.

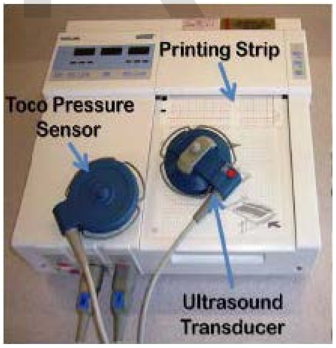

Fig. 2 A standard fetal monitoring device including toco pressure sensor, ultrasound transducer and central/printing unit.

Internal monitoring differs from external monitoring.

- The pressure-sensitive contraction transducer, called a tocodynamometer (toco), measures the tension of the maternal abdominal wall - an indirect measure of the intrauterine pressure.
- The fetal heart rate transducer is replaced by a smaller lead called a 'fetal scalp electrode' (or FSE). It is only used to monitor the baby's heart rate during labour, usually if external monitoring is not being reliable.

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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. Women who carry the Herpes, Hepatitis B or C or HIV viruses are recommended not to have internal monitoring, because it can increase the baby's chances of becoming infected with these viruses.

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.

2 SYSTEM ARCHITECTURE

In this paper we propose an end-to-end low-cost wireless and mobile fetal monitoring system that employs a body-worn fetal monitoring device augmented with wireless networking technology, to enable a new paradigm of care allowing anytime/anywhere monitoring as shown in figure 3.

FHR is a fundamental indicator of fetal life. Ideally, we would also like to monitor fetal oxygenation but not being able to physically access the fetus means this is not possible. Monitoring FHR is the next best available option and provides some level of indication of fetal oxygenation and how the fetus is coping in its environment. Unfortunately, fetal monitoring is often relied on as the ultimate indicator of fetal condition. It is not, and never will be. It is just one small piece of a massively complex jigsaw. Managing pregnancy is unique in healthcare, in that you are actually managing two highly interactive lives – mum & baby. While you can talk to, & examine mum, the fetus is remote – it can't communicate and can't be examined. These two lives are highly dependent, one on the other. It is therefore essential to use fetal monitoring in the context of an holistic approach to the whole clinical scenario. It must also be recognised that, while fetal monitoring has a fairly high negative predictive value, it does not have a good positive predictive value. It should therefore be used more as a screening tool for normality, than as a diagnostic tool for detecting abnormality.

The terms normality & abnormality, in the context of fetal monitoring, relate only to how well the fetus is being supported via the placenta in terms of oxygenation, and provides a level of indication as to the development of the autonomic nervous system, and how the fetus is coping with the stresses it may be exposed to in-utero. It is not able to detect congenital abnormalities and any other physiological or developmental conditions fetuses may present with.

There are two methods for detecting & monitoring FHR.

- Doppler ultrasound
- Fetal ECG

2.1 Doppler Ultrasound

Doppler ultrasound is the most widely used technique. This uses ultrasound (just like ordinary sound but at a frequency (pitch) well above the human audio range which is nominally 20Hz to 20 kHz. The ultrasound used in fetal monitors is typically in the range 1 to 2 MHz

An ultrasound transducer is strapped onto the abdomen using an elastic belt. It transmits a beam of ultrasound into the body –ultrasound doesn't travel through air very well, so a water based gel must be applied to the contact area between the transducer and the skin to get best performance.

As human tissue is ~90% water, ultrasound travels extremely well through the body. The ultrasound beam is reflected off any tissue boundary layers in the beam profile (for example a change from soft tissue to muscle or bone, or from the walls of the fetal heart). The reflected signals are detected by the transducer. If the reflecting body (e.g. the fetal heart) is moving, this movement results in a Doppler shift, or a change in pitch of the reflected signal.

The Doppler shift is a phenomenon whereby any movement between the source of a sound (or ultrasound) &

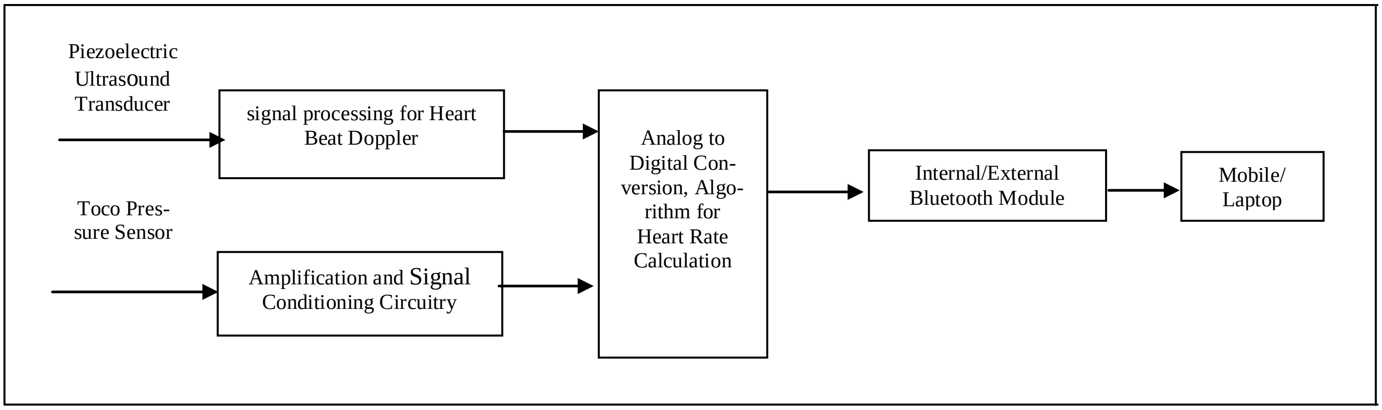

Fig. 3 The architecture of the proposed system.

the receiver of that sound, results in a change in pitch (or shift in frequency) of the sound. For example, when a train approaches a station with its whistle blowing. As the train moves towards you, the pitch of the whistle goes up. As it passes you & moves away, the pitch of the sound drops. The amount by which the pitch of the sound changes is directly proportional to the speed of the train. Another example in everyday life is an approaching/receding police car siren.

This Doppler shift is detected by the electronics in the fetal monitor & is used to produce an audible sound. Although this sound is actually generated artificially from this Doppler shift phenomenon, it is perceived by users as representing the actual fetal heart sounds. Unfortunately, these 'fetal heart' sounds are often swamped by other sounds produced by other movements in the 'torch beam'. These might, for example, include fetal movement, maternal movement (e.g. Coughing, breathing, etc.) & may also include sounds from the maternal, placental & umbilical cord blood flow.

The user listening to these sounds will normally find it easy to pick out the regular repetitive beat sounds from the fetal heart. However, to do this electronically is extremely difficult – unlike the human brain, the electronics is not easily able to identify specific sounds in amongst all the other sounds.

2.2 Autocorrelation

The electronic technique used in fetal monitors to try to separate out the fetal heart sounds is called autocorrelation. This is generally accepted as the best technique currently available. The autocorrelation formula used in the portable system shown in Fig. 1 can be expressed as:

$$R_x(m) = \frac{1}{N} \sum_{n=0}^{N-|m|-1} x_n x_{n+m} \quad m = 0, \pm 1, \pm 2, \ldots$$

It is valid under the assumption that the echo signal collected from the Doppler probe is random; the total number of the samples considered is N. Auto-correlation function has a feature that provides information on the cycle of the original signal, regardless of its value, waveform or phase. Therefore, the cycle of auto-correlation function is equal to the cycle of original signal. Hence, the continuous fetal heart rate can be obtained through the continuous auto-correlation measurement.

In the implementation of the portable Doppler system presented in Fig. 3 it was determined that for a given sampling frequency, a specific FHR value corresponds to a specific auto-correlation sequence number. Thus, it was found that using the sampling frequency of 1 kHz (corresponding to a sampling period of 1 ms), the FHR of 120 beats per minute (BPM) corresponds to auto-correlation result corresponding to sequence number of 500, whereas the FHR of 180 BPM corresponds to number 333. In other words, as already mentioned, a given FHR value corresponds to a unique autocorrelation sequence. In general, the relationship between the FHR value and the auto-correlation sequence number can be written as:

$$m' = (f_s \times 60)/R_f \tag{2}$$

where m0 refers to the auto-correlation result sequence number, Rf denotes the rate of the FHR value, and the fs, refers to the sampling rate. Using Eq. (2) a reference table listing the relationship between the FHR value and the sequence number of auto-correlation result can be developed.

In practice, once the auto-correlation value for a given sequence number is known the corresponding FHR value can be displayed on the monitor (See Fig. 3). In other words, the auto-correlation result corresponding to the given FHR value is obtained by identifying the maximum amplitude. The system presented in Fig. 3 was tested and it was determined that the FHRs could be detected in the range from 61 to 217, that is the system was capable of processing 157 (157 = 217_60) data points corresponding to sequences of auto-correlation (see Eq. (2)). The excerpts of the auto-correlation reference table are reproduced below;

FHR (beats/ minute)	217	216....	180.....	120.....	62	61
Sequence number	276	278.....	333......	500.....	968	984

2.3 Sensing Hardware

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 ATMega32 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.

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 Microcontroller. 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. 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.

Hrt.Bt : 138bpm
Cntrn : 5%

Fig. 4 Display on LCD Screen of System.

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. We have used 2.4GHz unlicensed frequency band here.

2.4 Android-based application

FHR Monitoring

DATA FROM FHR DEVICE

HeartBeat: 172 bpm
Contraction: 80 %

WAR: High Pulse Rate.
WAR: Contraction Above Threshold.

Fig. 5 Display on Android Mobile Screen .

The Android-based application which is the focus of this paper, runs on any Android-enabled phone with the Android 2.2 or higher. First the menu is presented to the user, where it is possible to select between the modes of the signal acquisition. The FHR signal can be either opened from the storage (e.g. SD-card) – explorer activity is responsible for that. Or the communication can go via bluetooth module – bluetooth activity – and the interaction with the measuring device can be initialized. In any case the data are downloaded to the mobile phone and loaded into the application. In the following step the data are processed in the CTG-processing activity - which will be described in the following section. The last step from the point of view of the Android application design is the visualization – where either user or the clinician can view the signals with some highlighted features.

3 CONCLUSION

The system is non-invasive, which is highly desirable from both the doctors' and patients' point of view. Moreover, the non-invasive nature of system combined with its wear ability makes the system appropriate for healthcare support at remote settings. The system proposes a major shift from a pregnancy information system that is based on the hospital setting to one which can always be carried by the pregnant woman and used anywhere. 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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