International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 6 (2017) pp. 813-817


# Home Based Fetal Heart Rate Monitor

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**Abstract**

Fetal heart rate is an important indicator or biological index to know the condition of fetal well-being. This project leads to develop a fetal heart rate monitor that can be used by a pregnant mother in home environment. There are five steps taken to develop a fetal heart rate monitor: 1) data acquisition; 2) data pre-processing; 3) feeding into microcontroller; 4) post-processing and 5) display. The condenser microphone was used as a sensor to acquire fetal heart sound. The sensor acquires the data then undergoes pre-processing which involves amplification and filtration using fourth order low pass butterworth filter. The operational amplifier was used for pre-amplification during filteration; the operational amplifier used is LM 741. The signal acquires after pre-processing stage, sent to the microcontroller (ATMega328) for the computation and transmission of data by developing an algorithm so that the computer can read the signal. Finally, the output (fetal heart rate) was displayed on LCD. In this preliminary study, the developed prototype was tested on 10 pregnant mothers supervised by specialised at the clinical set-up. The accuracy of the prototype fetal heart rate has been confirmed relative to electronic stethoscope. The overall bias for fetal heart rate based on relative verification between prototype and electronic stethoscope is 1.4 % and -1.2% respectively. Hence, the result shows that developed prototype can detect the fetal heart rate of maternal from third trimester onwards. In future the developed prototype device will be tested on larger database to confirm the accuracy of the device.

**Keywords:** fetal heart rate (FHR); condenser microphon; amplificatio; fourth order low pass Butterworth filter; Arduino

## INTRODUCTION

Heart and circulatory system is one of earliest organ developed in the fetus which the fetal experienced the first heart beat by the 3rd week of life [1]. There are differences in term anatomy and physiology of fetal heart and newborn heart. During pregnancy, fetal heart circulation is different compare to newborn heart circulation. Oxygen is supplied to the fetal through placenta, so the heart only functioning to pump the oxygenated blood throughout the body including the lungs [2]. However, the lungs will supply oxygen to the newborn heart same as adult.

Fetal heart rate is a very important parameter that can be monitored which act as an indicator to know fetal well-being [3-5]. During pregnancy, the other way to know fetal well-being is by using fetal movement monitoring [6]. However, there are a lot of shortcomings to monitor fetal movements. It is important to monitor because prevention can be done if there is a detection of abnormalities in fetal heart rate which lead to pre-maturity and miscarriage [5]. It is very essential to monitor especially the maternal that are at high risk and experienced a miscarriage before.

When a heart beats, it pumps oxygenated blood throughout the fetal body. Adequacy of fetal oxygenation is important to prevent hypoxia that affecting the whole fetal body. If hypoxia occurs, there might be a decrease in fetal cerebral blood flow. Therefore, fetal heart rate monitoring able to recognize fetal asphyxia [7]. Fetal asphyxia is severe enough that can lead to neurological damage or even fetal death. In addition, fetal heart rate monitoring can solve two problems which are it serve as a screening test for severe asphyxia and it allows recognition of early asphyxia so that timely obstetric intervention could avoid asphyxia-induced brain damage or death in the newborn [8].

In this study, we present our design of a new compact and low-cost fetal heart rate monitor (FHRM) based on a condenser microphone and Arduino microcontroller. The output of FRHM is the average fetal heart rate which can be displayed on a small LCD. The paper is organized as follows: Section II is a discussion on the methods that were used. This is followed by Section III that presents the overall results and discussion. Finally, a conclusion is presented in Section IV.

## METHODS

Fig. 1 shows the overall block diagram of the complete system for hardware implementation. It consists of five steps which are: data acquisition, data preprocessing, feeding to a microcontroller, digital processing and display.

This study was conducted as a part of the Research University Grant Scheme, supported by Universiti Teknologi Malaysia, Government of Malaysia, under Grant no. Q.J130000.2545.14H66.

In this section, subsection A discusses about the condenser microphone, followed by subsection B and C which describes the signal pre-processing and microcontroller. Subsection D and E discuss about the post-processing to detect the fetal heart rate and display tool (LCD). Finally, subsection E describes about the complete system.

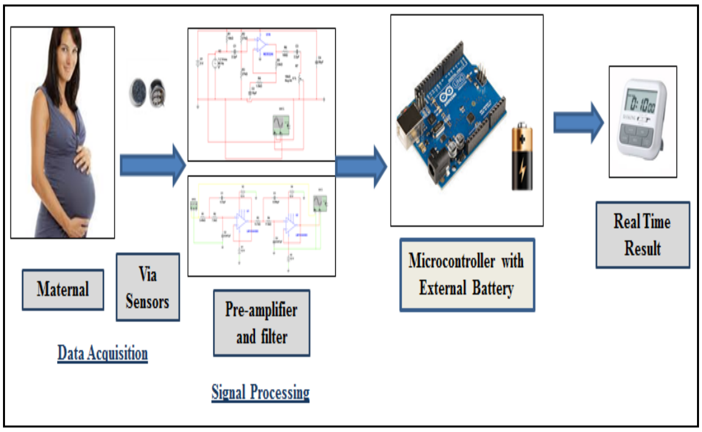


**Figure 1.** Overall block diagram

### *A. Data Acquisition*

Data acquisition stage comprises of one condenser microphone which act as a sensor to detect and acquire the fetal heart sound. Sound produce by fetal heart cannot be heard by human hearing. So, a medium is needed to obtain the signal. Fig. 2 represents a condenser microphone, can response to sounds of all frequencies in its frequency range up to 20 kHz. The frequency of fetal heart sound is up to 200Hz [5] so a cutoff frequency of 200Hz was chosen.

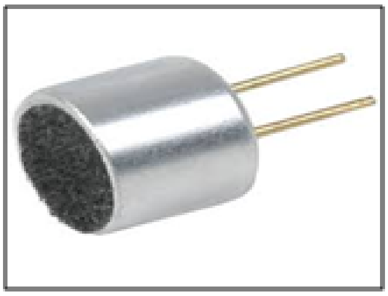

**Figure 2.** Condenser microphone

### *B. Pre-processing*

Data preprocessing consist of pre-amplifier and filter. The operational amplifier used for amplification is NE5532. Simulation of pre-amplification and filtering circuit were done by using Multisim Software separately. The circuit was sketch using the software and the result of the simulation was shown. The purpose of this simulation is to determine whether the circuit functions well or not. The pre-amplification circuit and result show in Fig. 3 and Fig. 4 respectively.

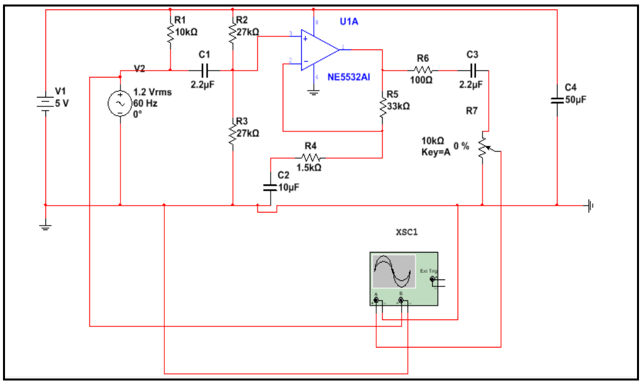

**Figure 3.** Pre-amplification circuit

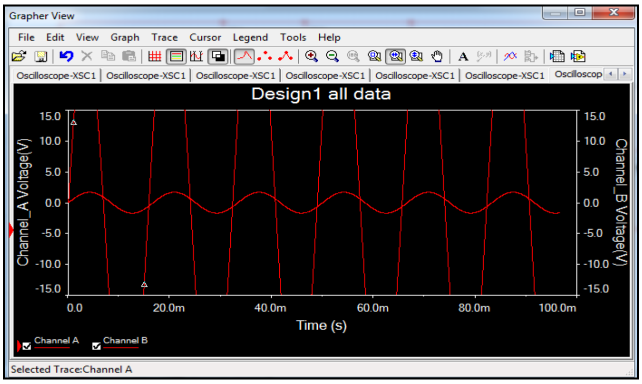


**Figure 4.** Result of pre-amplifier circuit simulation

In order to remove the noises, a filter is used. By using Filter Lab 2.0 software, a fourth order low pass Butterworth filter is created.. The filtration circuit is shown in Fig. 5 and the simulation results are shown in Fig. 6 and Fig. 7. The idea of using fourth order is ideal enough because the higher the number of cascaded stages, the closer the filter to ideal response and it used less usage of components compared to 8$^{th}$ order filter. The operational amplifier used for filtration is LM741.

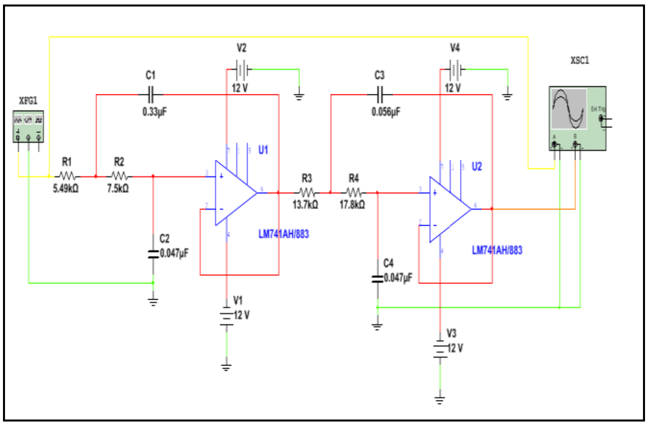

**Figure 5.** Fourth order low pass Butterworth filter circuit

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 6 (2017) pp. 813-817


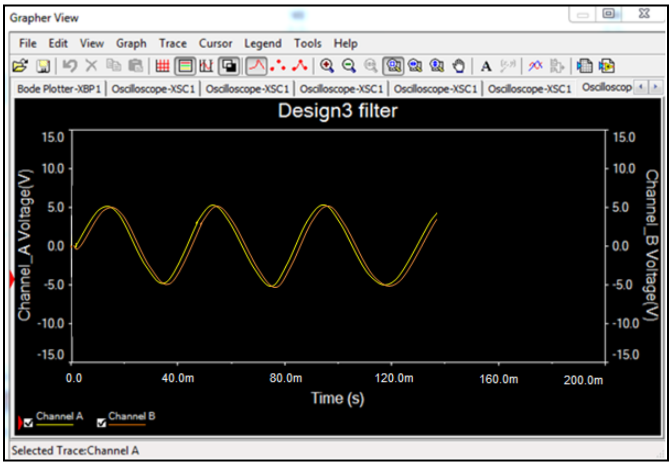


**Figure 6.** Result of fourth order low pass Butterworth filter circuit (25Hz)

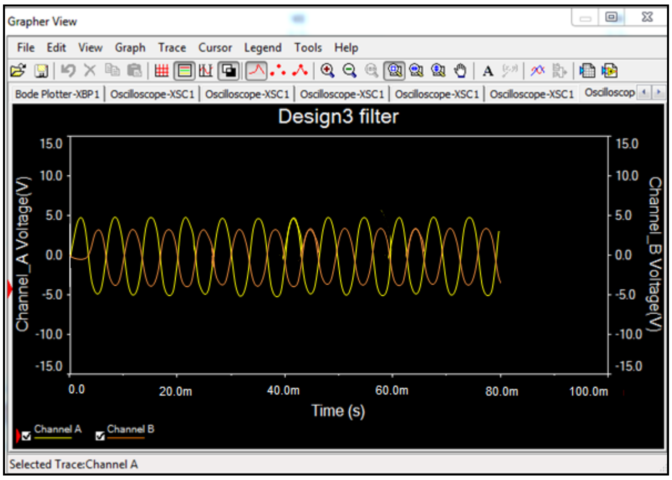


**Figure 7.** Result of fourth order low pass Butterworth filter circuit (200Hz)

Since the cutoff frequency is 200Hz, the output below cutoff frequency will give the same as the input. However, in the practical case, the graph will show 60 to 70 Hz is the maximum and the output will start decreasing after 70Hz. Threshold is used in the programming to remove the effects of those frequencies.

### *C. Arduino Uno (ATMega328)*

Fig. 8 shows an Arduino Uno R3, having inbuilt ATMega 328 microcontroller to process the data. The signal acquired after data preprocessing stage is fed into Arduino Uno R3 as an input for post-processing. The signal input is in analog form so it can be connected to analog input pin at the Arduino Uno. The computer cannot read analog signal form. Therefore, the microcontroller also acts as ADC can convert analog to digital signal form. The coding is uploaded into Arduino Uno by using Arduino Software for further process.


**Figure 8.** Arduino Uno R3

### *D. Post-processing*

Fig. 9 describes the flow chart. In order to obtain fetal heart rate reading, a constant threshold is used. In this study, a threshold of 10 was selected. For the input of this measurement, a filtered signal was provided and a peak detection algorithm was used to detect a peak from the signal. Once a peak is detected, another delay of 300 ms was added.

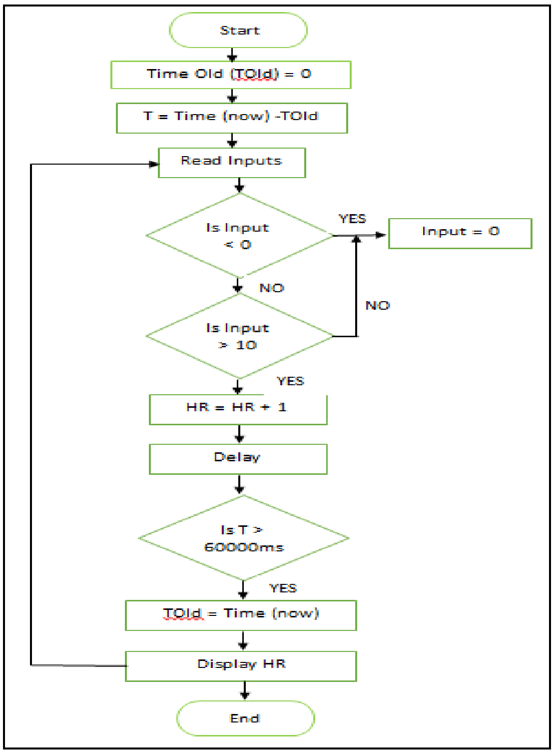


**Figure 9.** flow chart

### *E. Display Tool (LCD)*

The reading of fetal heart rate will then be display on LCD 16x2. The LCD is connected to the microcontroller and be programmed. The result also can be monitored through the serial monitor. On the LCD, it will show average fetal heart rate only as shown in Fig. 10 below. The fetal rate was averaged for a time of 1 minute and optimized averaging time will be classified in further studies.


**Figure 10.** Example of result of average fetal heart rate

*F. Electrical Design Implementation*

Fig. 11 shows the electrical design implementation of fetal heart rate monitor. The LCD 16x2, amplifier and filter are connected to Arduino through pins of Arduino.

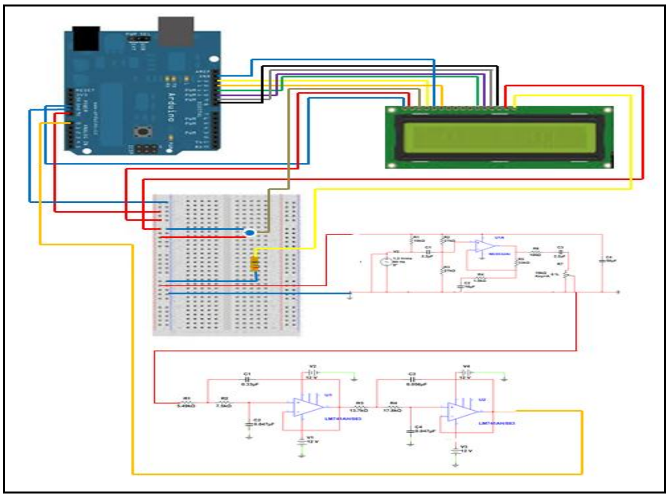

**Figure 11.** Circuit design implementation

## RESULT AND DISCUSSION

Fig. 12 shows the hardware implementation of the prototype of fetal heart rate monitor without casing and Fig. 13 shows the prototype with casing.


**Figure 12.** Hardware implementation of the prototype


**Figure 13.** Final prototype of fetal heart rate monitor with casing

In order to support the performance of developed FHRM, fetus's heart rate recorded using developed prototype was compared with an existing electronic stethoscope. This comparative experiment was performed on 10 pregnant women between 13$^{th}$ to 38$^{th}$ week of gestation age, and average recording time was limited to 1- 2 minutes. Table 1 summarizes the measurements of fetus heart rate using the developed prototype and electronic stethoscope. From the table, it can be seen that the output of prototype is almost at par with the electronic stethoscope, in most of cases. The overall bias of prototype and electronic stethoscope is 1.4 % and -1.2% respectively. This revealed that bias for the inter-device testing is within the tolerance that is $\pm$ 5 for heart rate [9]. However, the limitation of the proposed prototype is that it is only able to detect fetal heart rate during third trimester while unable to sense in first and second trimester.

**Table 1.** Comparison between the prototype and Electronic Stethoscope

| No. | Patient (Weeks) | Electronic Stethoscope (bpm) | Prototype of Fetal Heart Rate Monitor (bpm) |
|---|---|---|---|
| 1 | 33 | 150 | 150 |
| 2 | 22 | 0 | 0 |
| 3 | 27 | 0 | 0 |
| 4 | 32 | 150 | 144 |
| 5 | 34 | 157 | 162 |
| 6 | 34 | 142 | 162 |
| 7 | 20 | 0 | 0 |
| 8 | 32 | 142 | 144 |
| 9 | 13 | 0 | 0 |
| 10 | 38 | 150 | 0 |

## CONCLUSION

This paper presents development of a battery operated, an inexpensive, non-invasive, user-operable and portable standalone fetal heart rate monitoring system that can be used in home environment. The fetal heart sounds is recorded using condenser microphone and pre-processed with bandpass filter that eliminates the unnecessary noise and limit the bandwidth of the fetus's signal. Further, a peak detection algorithm is included to detect the peak with 300 ms delayed. This provides the fetal heart with the significant diagnostic and clinical importance. The device has been tested on 10 maternal in third trimester and a comparison was made with electronic stethoscope conducted by a medical doctor. The result shows that the proposed prototype shows fairly good accuracy based on relative verification to electronic stethoscope under real clinical conditions. Hence, the study revealed that condenser microphone is feasible and can effectively be used in the development of commercial FHRM to use as a home care monitoring system. However, the prototype device need to be tested on large number of maternal for first, second and third trimester to generalize the finding of device.

## ACKNOWLEDGMENT

The authors gratefully acknowledge Universiti Teknologi Malaysia (UTM) for providing the required facilities and laboratory equipments. This study was conducted as a part of the Research University Grant Scheme, supported by Universiti Teknologi Malaysia, Government of Malaysia, under Grant no. Q.J130000.2545.14H66. We also appreciates the cooperation of the mother who joined in our study.

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