EXTRACTION AND ANALYSIS OF TRANSABDOMINAL FETAL HEART RATE BY NIR PHOTOPLETHYSMOGRAPHY

J. Muthu Bala Selvi[1] , Mrs.S.Rajalakshmi[2]

[1]Student, M.E. Embedded System Technologies, [2]Assistant Professor, ECE
Sri Sai Ram Engineering College, Chennai-44 (India)

ABSTRACT

Fetal heart rate variability is known to be of great meaning in assessing the fetal health status. It remains standard for the intrapartum assessment of fetal well being and to diagnose the cardiac disorders. Measurements of heart rate on the maternal abdomen provide a valuable alternative for standard fetal monitoring. In this paper, the heart rate is initially measured using an Optical Fetal Heart Rate Detector (OFHR). Then signal conditioning and conversion is applied to the recorded heart rate. Digital synchronous detection and preprocessing techniques are applied to segregate the fetal heart rate from the mixed signal (mother + fetal) by adaptive noise cancelling techniques, whereas PPG from the mother's index finger is the reference input. Removal of the maternal heart rate from the mixed signal provides the fetal heart rate. Finally the resulted fetal heart rate is correlated with the Ultrasonic Doppler fetal heart rate detector values to analyze the performance of the proposed technique. The results act as the beneficiary tool to detect the fetal disorders.

Index Terms –Adaptive Filter, Fetal Heart Rate, Optical , PPG.

I.INTRODUCTION

Heart rate is the major core vital sign to detect the health of an individual. Heart rate is defined as the number of heart beats per minute measured in bpm. The average heart rate of the resting adult is 72bpm. The normal heart rate of an adult ranges from 60 to 100bpm. The normal fetal heart rate ranges from 110 to 160 bpm. Cardiac disorders are the most life threatening disorders amongst the birth defects. Their diagnosis is necessary at the fetal stage as it might provide an opportunity to plan and manage the baby as and when the baby is born. The most dangerous cardiac disorder in fetus is the Congenital Heart Disease (CHD). CHD is the defect in the heart vessels which is present at the time of birth. It obstructs the blood flow in the heart or the vessels near it which causes the blood to flow in the abnormal pattern. The only way of detecting these defects is by monitoring the FHR. There are various kinds of methods to detect FHR. One such traditional method to detect the FHR is by auscultation of the heart sounds by using the stethoscope at the maternal abdomen. This method has the great drawback of not providing the sufficient information for the doctors to diagnose the heart

rate based on the heart sounds since they are very feeble to hear. Generally the methods of detecting the fetal heart rate is classified as invasive and non invasive methods of detection.

Direct fetal electrocardiography (FECG) is one of one of the invasive methods of detection. It is the name of the test to diagnose the cardiac functions of the fetus ate early stage. It is recorded only after the rupture of the membranes by attaching the scalp electrode. This test gives the better reading, but this type of invasive recording may lead to the perforation of the fetus and in turn results in infection and possibilities of scalp injuries to the fetus. These methods may cause some major injuries which leads to some sort of blood loss for the fetus.

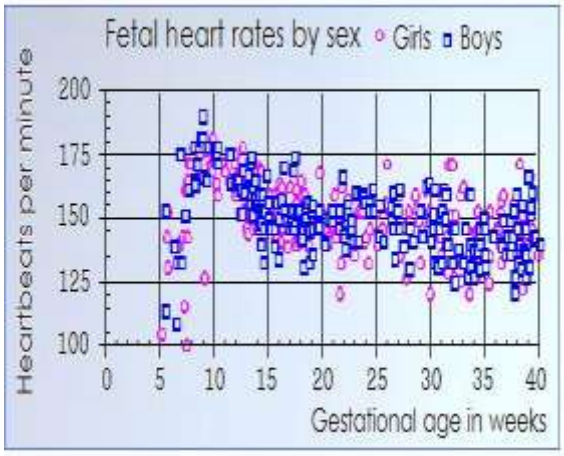

Fig 1.FHR Chart

The hazards which are caused by those invasive methods are eliminated in the noninvasive methods of detecting the FHR. One of the noninvasive methods is noninvasive transabdominal FECG. But these FECG signals have a low SNR due to filtering and attenuation effects of multiple layers of maternal tissue, and interference from noise and maternal ECG. Nowadays, Doppler ultrasound technology is used to examine the heart or blood vessels. It measures the blood flow within the heart without any invasive procedures such as cardiac catheterization. But FHR detection using Doppler ultrasound is always not reliable. This method has some drawbacks. It increases the occurrence of the intrauterine growth restriction. It also causes the thermal and mechanical effects in tissues with the increased O/P power.In this paper, a system for detecting the fetal heart rate based on the transabdominal noninvasive procedures is proposed.The existing systems for fetal heart rate detection are doppler ultrasound and auscultation of heart sounds by the stethoscope.

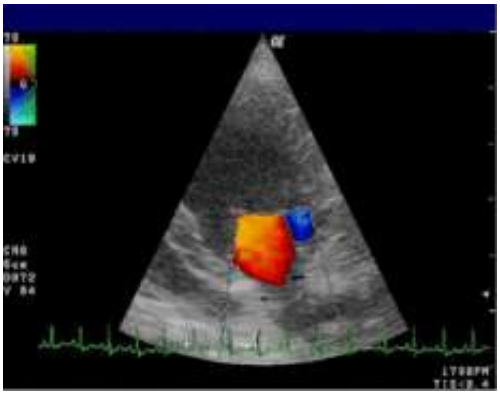

Fig 2. Doppler Ultrasound

But there are some drawbacks lies in these two approaches. The drawback lies in the doppler ultrasound technique is that it provides some hazardous effects to the fetus like intrauterine growth restriction. The auscultation of fetal heart sounds by the stethoscope doesnot provide better accuracy in FHR detection.The proposed system to detect the fetal heart rate is based on the Transabdominal non invasive procedures. It consists of an optical based module to sense the heart rate. Both the source and the detector is based on the optical techniques. This system is less hazardous and more accurate in detecting FHR.Transabdominal procedures are based on the continuous wave Near infrared techniques and pulse oximetry. FECG usage is limited to research studies since it requires multiple leads and advanced digital signal processing techniques. This paper made the measurements on the maternal abdomen using NIR. The migration of photns through the fetal head are done using the phantom tissue in in-utero manner. The errors in saturation is minimized by using the wavelengths in the range of 675-700 and 850-900nm.

In this transabdominal approach of spectroscopy, the optical radiation which is emitted from the mother's abdomen must travel through the maternal tissues and amniotic fluid before rezching the fetal layers and further it has to travel back to the detector loc I(MF) › mother abdomen.

II.SYSTEM DESIGN AND DEVELOPMENT

2.1. System Description

Optical techniques such as Photoplethysmography (PPG) is used for FHR detection. FHR detection based on the Doppler ultrasound provides some hazardous effects. This can be eliminated by the proposed system of FHR detection. Moreover auscultation of sounds by the stethoscope does not provide better accuracy of FHR detection. The proposed system is based on the Digital synchronous detection technique too. This is utilized to enhance the SNR and to provide better accuracy. Adaptive noise cancelling (ANC) using the recursive least square (RLS) algorithm is able to extract the fetal photoplethysmography (PPG) peaks even at the SNR of -34dB. Virtual instrumentation is used as an user interface to display the results of FHR tracings and its value. The PPG of the mother is obtained from her index finger. It is considered as the reference input to extract the FHR from the MHR that is detected at the mother's abdomen.

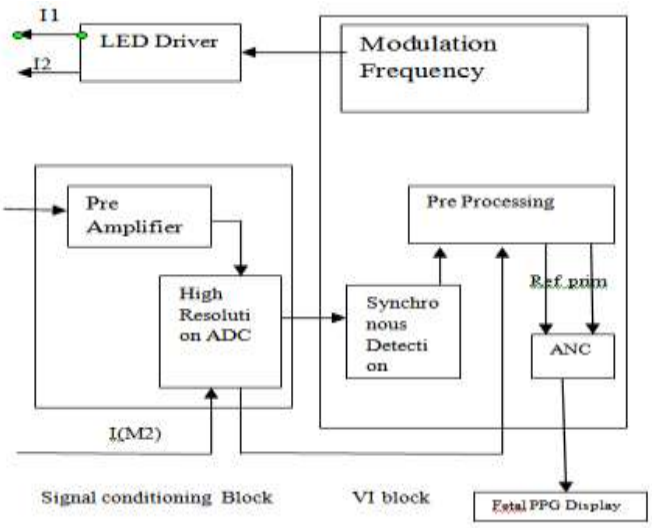

Fig 3. Hardware Setup Block diagram

IR transmitter and receiver diode is used as the source and the receiver to detect the fetal heart rate. Source to detector separation plays a vital role as it affects the detection of the signal. The value at which the source is separated from the detector is based on the three layered tissue model. The three layered tissue are maternal , fetal and amniotic fluids which are present as the barrier for FHR to reach the detector and the source light to reach the fetus. The optical power from the fetal layer increases with the source to detector separation. At a source to detector separation of 2cm , only 3% of the received optical power comes from the fetal tissue layer. At 6cm , the value of the received signal power which reaches at the detector increases to 97%. But at the 6cm of separation, the intensity of the collected light becomes too low for the detector compared to the noise. So a compromise of 4cm of separation is selected as it provides 70% of the received optical power at the detector which comes from the fetal layer.

Signal at the separation of 6cm is too weak and the signal at the separation of 2cm will result in the leakage of light directly into the detector. So to improve the signal quality and to reduce the amount of leakage of light into the detector a separation range of 4cm is selected. This overcomes the above 2 drawbacks.IR transmitter and IR receiver LED will act as the source and the detector. The source IR LED will emit the light at the abdomen layer and the detector LED will receive the signal. They are separated at the distance of 4cm for the better acquired signal to be reached at the detector. These results show that the expected optical power at the input of the detector is in the range of 10^{-6} to 10^{-10}W/cm^2.

2.3. Mechanical Setup Of the Hardware

The OFHR instrumentation is shown in Fig 3. The primary signal is derived from the fetal probe which is attached to the maternal abdomen to hold IR – LED (both the source and the receiver LED). The probe is attached to the abdomen using a transducer belt. As already said , the source and the detector LED are placed at the distance of 4cm. The reference signal is obtained from the mother's index finger by the method of pulse oximetry. The reference signal is very much necessary since it extracts

only mother's heart rate. The reference probe is attached to the index finger since FHR is very feeble at the finger. The main idea is to extract the FHR from MHR. This is done by taking the difference between the reference and the primary signal which are derived separately at the abdomen and the index finger. This difference process is done with the help of the virtual instrumentation software like labview.The selected IR LED will only emit the maximum optical power of about 55mW. The total OFHR system operates at the optical power which is less than the limit of 87mW that is specified by the International Commission on Non-Ionizing Radiation Protection(ICNIRP). The choice of the modulation frequency for detecting the signal is based on the power spectrum of the ambient noise. The ambient noise must be low and it must be far away from the odd and even harmonics of the power line frequency. So the detection band must be shifted to such a region frequency of 725Hz is selected as it falls between the odd and the even harmonics of the power line frequency and the PSD is close to the baseline. Modulation frequency is generated using a software subroutine through a counter port to the LED driver.

The diffused reflected light from the maternal abdomen is detected by the detector LED is denoted as I(M1F) , where M1 and F denote the contribution to the signal from the mother's abdomen and the fetus respectively. A low noise transimpedance amplifier is utilized to convert the detected current to a voltage level. The reference probe is attached to the mother's index finger consists of an IR-LED to act as the source and the receiver with an integrated pre amplifier (LM358). The signal from this reference probe is noted as I(M2) , where M2 refers to the the maternal contribution. There is no fetal heartbeat involved in this signal since it is measured at the index finger of the mother. Synchronous detection is not required in this channel as the finger PPG has high SNR. The digitization of the two signals are simultaneously done with an ADC at a rate of 5.5KHz. The demodulation , digital filtering and signal estimation are all performed in the digital domain.

2.4 Digital Synchronous Detection And Noise Cancellation

The algorithm is implemented using the virtual instrumentation software Lab VIEW. This is chosen since it is the most user friendly software and a graphical programming environment which facilitates the implementation of the hardware via software. So the entire process of digital synchronous detection, preprocessing and ANC is done using Lab VIEW.The digital synchronous detection is done in software. The digitized signal from the primary probe I(M1F) is filtered by a 30Hz bandwidth band pass filter. Such bandwidth is selected since it passes PPG spectrum. This band pass filter is centered at the centre frequency of 725Hz. This is in turn multiplied by the in-phase reference frequency. This in-phase reference signal is obtained by the following method. The band pass filtered signal is fed into a reference signal generation algorithm (Hann - weighted spectrum) that will automatically calculate the phase of the band pass filtered signal , since the effective spectrum of the PPG signal covers frequencies up to 15Hz only , the output of the multiplier is then low pass filtered at 15Hz to recover the signal of interest.

The pre processing part for the primary signal is shown in fig 3.2.3. It consists of down sampling to 55Hz. This is to reduce the number of computations and the processing time. The minimum computation is needed if the power consumption is a major concern in the practical implementation of the hardware. Inorder to reduce the effect of the maternal signal and to remove the respiration artifact , a high pass filter is used prior to the adaptive filter. The frequency of the maternal signal is different for each individual , the cut off frequency of this high pass filter is the fundamental frequency of the reference signal acquired from the maternal index finger. This frequency is relatively stable during the duration of the recording. The demodulated , preprocessed signal is denoted as $I_{primary.}$ I(M2) is downsampled at the frequency of 55Hz and filtered with a bandpass filter, so that the respiration artifact occurs at 0.1-0.55Hz and the high frequency noises are rejected. The preprocessed signal is denoted as $I_{reference}$.$I_{primary}$ and $I_{reference}$ are fed into an RLS adaptive filter algorithm inorder to estimate the fetal signal $I_{est.}$(F). Finally the FHR is found by estimating the prominent peak of the PSD. This is done by using Yule – Walker autoregressive method.

2.5. Measurement of Primary and Reference signal

The heart beat can be measured at any spot of the body where the pulse can be felt at the fingers. The number of pulses can be counted within any interval and can easily determine the heart beat in bpm. Here IR and microcontroller based system is proposed for detecting the heart rate at the finger and the abdomen to measure both the reference signal and the primary signal which are measured at the index finger and abdomen of mother respectively. This System uses the optical sensors to measure the alteration in the blood volume at finger tip with each heart beat.Haemoglobin molecules of the blood absorb the infrared light. Each time the heart pumps , the volume of the oxygen rich blood increases in the finger. As a result , the amount of Oxyhaemoglobin molecules also increases in the blood. Absorption of the infrared light is also high and the reflection of the infrared light is low. Then each heart beat slightly alters the amount of the reflected light which can be detected by the IR Receiver. More infrared light is received , less the voltage of the input from the sensor part is produced.

The IR receiver picks an AC signal with some unwanted DC components which comes from non pulsative tissues. Direct crosstalk is avoided if the IR receiver and the IR Transmitter are placed closely. Resistor is connected to IR Receiver to reduce the current drawn by the detection system. If the intensity of the IR light is too high, the reflected infrared light from the tissue will be sufficient enough to saturate the receiver diode all the time and no signal will exist. Thus the intensity of the reflected light must be low to avoid such situation. To avoid this, the value of resistance is connected in series with the IR Transmitter to limit the current and the intensity of the transmitted infrared light.

The signal conditioning circuit consists of LM358 which act as a filter and a comparator. The filtering is achieved by the low pass filtering unit. The filtering is necessary to block the high frequency noises present in the signal. The two stage amplifier and the filter will provide the sufficient gain to boost the weak signal coming from the photo sensor unit and convert it to a pulse. It also act as a

comparator which counts the number of pulses arriving within the certain amount of time. An LED connected at the output blinks at each time the heart beat is detected. The output from the signal conditioner goes to the TOCKI input of the pic microcontroller.Small movementin the organs causes the high frequency noise. So pulse rate filtering is essential. The desired signal can be extracted from the noisy signal using a low pass filter.

The cut off frequency of the filter is set as 2.34Hz.The signal must be amplified for counting the pulse rate by PIC. A two stage signal filter and amplifier circuit using LM 358 is designed for this purpose. This opamp is operated at the voltage range of 5V.The display unit comprises of a 3digit common anode seven segment module that is driven using multiplexing technique. Segment a-g are driven through pins of port B of the PIC microcontroller. Units , tens and hundreds digits are multiplexed through A port pins. During the certain interval of time, the number of pulses arriving at the TOCKI input pin is counted. Resolution of the measurement is 4. PIC runs at 4.0MHZ using an external crystal.

III.RESULTS AND DISCUSSIONS

The output is displayed in the Lab VIEW front panel. The use of this device is so simple. The finger is placed between the IR transmitter LED and IR receiver LED to display the reference signal. The primary signal is measured in the same manner by placing both the source and the detector in the abdomen. The LED gets blinked till the pulses are arrived at the detector. The output will be displayed when there is obstacle in the path of the pulses.The results are displayed as shown in the following figure.

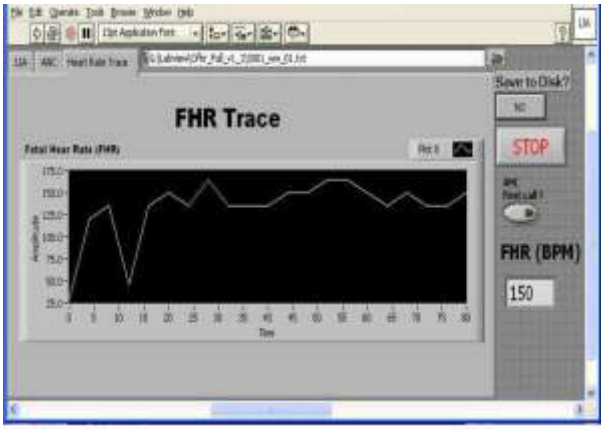

Fig 4.FHR Trace

IV.CONCLUSION

A low cost OFHR detection system is proposed using very low power IR source and detectors. FHR is determined using digital synchronous detection and adaptive filtering techniques. Results are obtained

with the acceptable accuracy. For better results, the probe can be placed near to the fetal tissues. A compact, wearable system composed more number of LED source and detectors can be used to improve the accuracy of the detected FHR. It may also be implemented using an embedded processor like MY- RIO processor to enhance the better results.

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