Neonatal Heart Rate Detection Using Auxiliary Optical System

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Abstract: - Fetal heart rate (FHR) monitoring is a proven means of assessing fetal health during the antenatal period. Currently, the only widely available instrumentation for producing these data is based on Doppler ultrasound, a technology that is unsuitable for long-term use. For nearly a century, it has been known that the fetal Photoplethysmography (FPPG) can be detected using electrodes placed on the maternal abdomen. The paper describes the design, construction and use of a compact, long-term recorder of three channels of 24 h antenatal trans abdominal data. Preliminary use of the recorder in around 400 short recording sessions demonstrates that FHR records of equivalent quality to those from Doppler ultrasound based instruments can be extracted from such data. The success of FHR derivation is, on average, around 65% of the recording period from around 20 weeks gestation (although this figure is reduced from around 28 32 weeks, and the success rates exhibit a wide range when individual subjects are considered). These results demonstrate that the technique offers, not only a means of acquiring long-term FHR data that are problematic to obtain by other means, but also a more patient-friendly alternative to the Doppler ultrasound technique.

Keywords: - Autonomic nervous system, ECG, Heart rate variability, Fetal Photoplethysmography, Doppler ultrasound, Adaptive Noise Cancelling (ANC).

1. Introduction

Nowadays there is a growing research interest in biomedical optics which utilizes the light to probe structure and function in biomedicine and leads to several noninvasive and nonionized diagnostic and therapeutic methods such as laser surgery, photodynamic therapy, laser Doppler flowery (LDF), and Photoplethysmography (PPG). To understand the fundamentals of such methods, it is necessary to investigate the phenomena of photon-tissue interaction. Photoplethysmography (PPG) is in this day and age extensively use and has been accepted by physicians because of its simple design and relatively low cost per examination. A PPG system with NIR optical sensors can measure the

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blood volume changes in the skin surface layers by registering the attenuation change in the near infrared spectrum. Its biophysical principle is based on the fact that there is a strong contrast in absorption of NIR light between the blood-filled vessels and the ambient bloodless tissue. So through detection of the light remitted from the skin, it is possible to measure the blood volume change of the skin. The PPG system provides a simple and noninvasive method to detect venous diseases at early stage through certain functional tests like VOT (Venous Occlusion Test) and MPT (Muscle Pump Test). One disadvantage of PPG is that it can only measure one small area at one time and thus very difficult to get a spatial distribution of the blood volume change of the skin. Because of the spatial variation of the circulation system, it is necessary to get a mapping of the venous hemodynamics. Multichannel PPG device has been developed to monitor the skin perfusion at different sites, but it introduces more problems with sensor attachment, which makes the test person uncomfortable and introducing more movement artifacts. Also a high spatial resolution is impossible with multichannel PPG because the probe size of PPG is often more than 1cm 2. Another disadvantage of PPG is that the test person has to be measured contactly, which restrict its application to some clinical situation such as monitoring the wound healing process. In this paper, a new noninvasive and non-contact method called Photoplethysmography Imaging (PPGI) is presented. A PPG Imager which arranges a high-quality CCD camera with auxiliary optical system combines the features of both classical PPG measurement and CCD imaging. It can visualize the structure of skin vessels and evaluate the venous hemodynamics as well as the arterial pulsation. PPGI avoids the time –consuming scanning by using CCD as an array of photon detectors so that it can monitor the dynamic changes of dermal perfusion on different parts of skin surface simultaneously and flexibly as shown in the figure 1.

II. Working Principle

Photoplethysmography (PPG) is a simple and low-cost optical technique that can be used to detect blood volume changes in the micro vascular bed of tissue. It is often used non-invasively to make measurements at the skin surface. The PPG waveform comprises a pulsatile ('AC') physiological waveform attributed to cardiac synchronous changes in the blood volume with each heartbeat, and is superimposed on a slowly varying ('DC') baseline with various lower frequency components attributed to respiration, sympathetic nervous system activity and thermoregulation. Although the origins of the components of the PPG signal are not fully understood, it is generally

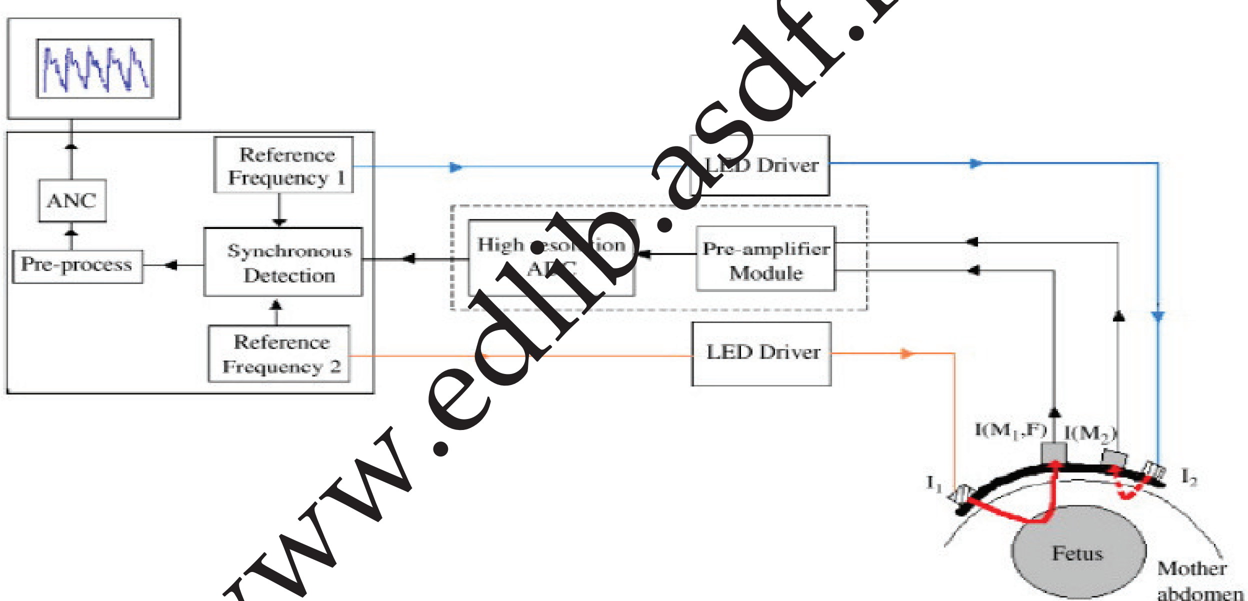

Fig.1: Hardware setup for OFHR detection.

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accepted that they can provide valuable information about the cardiovascular system.

An alternative to ultrasound is using the fetal electrocardiogram (FECG). Invasive FECG uses a scalp electrode and remains reserved to pre-delivery conditions. On the other hand, non-invasive FECG generally needs 3-4 leads, which renders the procedure more complex from a practical perspective where many electrodes need to retain perfect ohmic contact with the subject's body. The FECG is generally utilized later in pregnancy due to its low signal-tonoise ratio (SNR), i.e. between the 28th and 30th week of gestation. It is worth mentioning that commercial devices operating on non-invasive FECG are not available at this moment. However, these techniques are expensive, require a high optical power and are difficult to implement due to size and power consumption limitations.

III. Hardware Design for PPG Measurement of Fetus Heart Rate

A conventional reflectance PPG sensor consists of an LED unit and photo detector in parallel configuration. Since LEDs emit light in a circular pattern, the detected light represents a fraction of the total reflected light emitted toward the photo detector. To increase the incident light, we placed three LEDs symmetrically around the photo detector (see Fig. 2 and 3). Light emitted from each LED had its own circular pattern, and a portion of the light from each LED overlapped at the photo detector. The output signal from the sensor was converted into a voltage and amplified, then filtered with a band pass of 0.05–10 Hz to separate the pulsatile ac component, and filtered with a low-pass cutoff at 0.1 Hz to separate the dc component. The ac and dc signals were digitized at 400 Hz using the microprocessor.

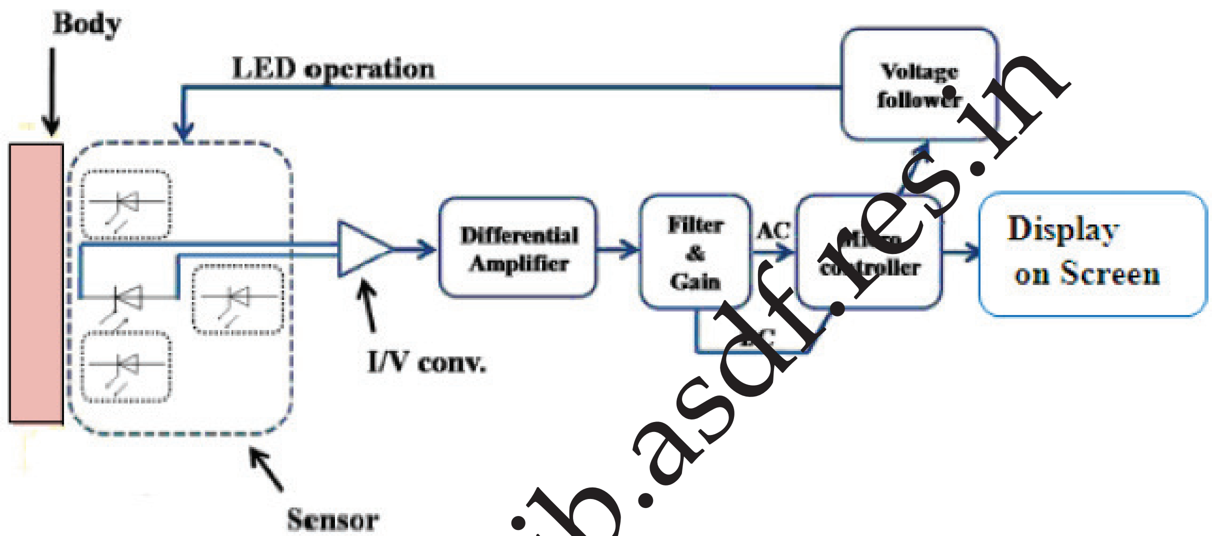

Fig.2: Block diagram for the proposed PPG measurement system that includes an adaptive light intensity control function using dc components.

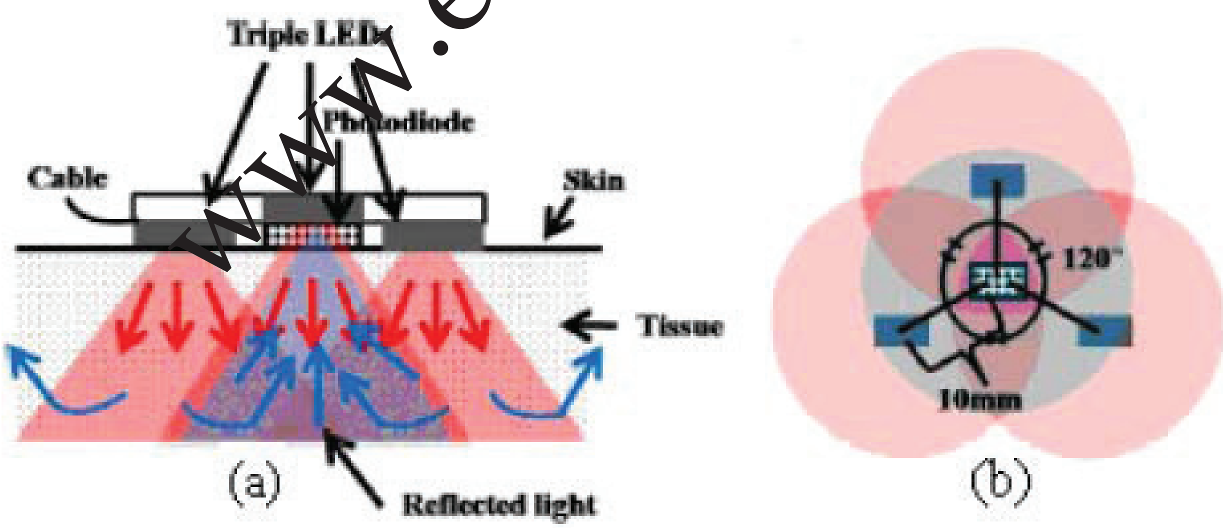

Fig.3: Conceptual diagrams of the proposed PPG sensor with three light sources.
(a) Frontal view. (b) Transverse view.

III. Procedure

The Challenge in designing FHR

The main challenge is to design and develop a low power optical fetal heart rate (FHR) monitor. The signal of interest is the photoplethysmogram (PPG), which is generated when a beam of light is modulated by blood pulsations. The light intensity is modulated by the mother as well as fetal blood circulations, producing a mixed signal which needs to be separated via advanced digital signal processing (DSP) techniques Solution is as the input power of the incident radiation leads to a lower SNR, the excitation signal is a chopped light beam and synchronous detection is performed. Optical Fetal Heart Rate Detection System.

Fetal heart rate (FHR) detection is the primary methodology for antenatal determination of fetal well-being, assisting in the identification of potential hazards such as hypoxia and distress to the fetus. The expected outcome of this early detection is a reduced risk of fetal morbidity and mortality. Currently FHR can be detected by using Doppler ultrasound, where the standard pre-delivery test of fetal health is the fetal non-stress test (NST). These tests are routinely performed at the hospital, generally with continuous-wave instruments. Although current ultrasonic FHR detectors are becoming less expensive and bulky, accurate sensor alignment and some degree of expertise are still required to correctly operate them. Moreover, they are sensitive to motion artifact and finally complete safety of long-term exposure of the fetus to ultrasound waves has yet to be established, therefore only short-term testing is actually practiced.

An alternative to ultrasound is using the fetal electrocardiogram (FECG). Invasive FECG uses a scalp electrode and remains reserved to pre-delivery conditions. On the other hand, non-invasive FECG generally needs 3-4 leads, which renders the procedure more complex from a practical perspective where many electrodes need to retain perfect ohmic contact with the subject's body. The FECG is generally utilized later in pregnancy due to its low signal-to noise ratio (SNR), i.e. between the 28th and 30th week of gestation. It is worth mentioning that commercial devices operating on non-invasive FECG are not available this moment.

More recently, optical methods, still at the research stage, have been proposed where halogen and tungsten by a photomultiplier. In these works, the emphasize was on trans abdominal monitoring of fetal arterial blood oxygenation for pulse-oximetry and by the same means FHR, with wavelengths in the 675-700 nm and 850-900 nm range to get optimum results. However, these techniques are expensive, require a high optical power and are difficult to implement due to size and power consumption limitations. Optical Fetal Heart Rate Detection System.

In this work, a low-power optical technique is proposed based on the PPG to non-invasively estimate the FHR. A beam of LED light (<68 mW) is shone to the maternal abdomen and therefore modulated by the blood circulation of both mother and fetus whereas maximum penetration is achieved at a wavelength of 890 nm. This mixed signal is then processed by an adaptive filter with the maternal index finger PPG as reference input. The Figure shows the optical fetal heart rate detection (OFHR) system block diagram

The fetal probe (primary signal) is attached to the maternal abdomen using a Velcro belt to hold the IR-LED and photo detector, separated by 4 cm. The reference probe is attached to the mother's index finger as generally practiced in pulse oxymetry. As the selected IR-LED could only emit a maximum optical power of 68 mW, the OFHR system operates with an optical power less than the limit of 87 Mw specified by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). In order to modulate the IRLED, the modulation signal is generated at a frequency of 725 Hz using software subroutine through a counter port (NI-USB9474) to the LED driver.

The diffused reflected light from the maternal abdomen, detected by the low-noise photo detector, is denoted as I (M1, F), where M1 and F denote the contribution to the signal from the mother abdomen and fetus, respectively. A low-noise (6 nV/Hz1/2) trans impedance amplifier is utilized to convert the detected current to a voltage level. The reference probe (mother's index finger) consists of an IR-LED and a solid-state photodiode with an integrated preamplifier. The signal from this probe is denoted as I (M2), where M2 refers to the maternal contribution. Synchronous detection is not required at this channel as the finger photoplethysmogram has a high signal to noise ratio (SNR).

V. An Optical FHR Detection System

Our research team proposed a low-power optical technique based on the photoplethysmogram (PPG) signal, which is generated when a beam of light is modulated by blood pulsations, to noninvasively estimate the FHR. The doctor or technician shines a beam of LED light (less than 68 mW) at the maternal abdomen, modulated by the blood circulation of the mother and fetus. Maximum light wave penetration is achieved at a wavelength of 890 nm. This mixed signal can be processed by an adaptive filter using digital signal processing with the maternal index finger PPG as a reference input, Figure 1: OFHR system block diagram showing the hardware modules have been implemented in embedded systems.

The team developed the optical FHR (OFHR) detection system using embedded systems graphical system design software and NI hardware. In the OFHR system, reducing the input power of the incident radiation leads to a lower signal-to-noise ratio (SNR), and the excitation signal is a chopped light beam.

At the receiver side, low-noise amplification and synchronous detection ensures conservation of the information with minimum noise power. A 24-bit NI USB-9239 analog-to-digital converter (ADC) minimizes the effects of quantization noise. Once digitized, the signal is processed via adaptive noise canceling (ANC) techniques to extract the fetal PPG from the mixed signal.

We attached the fetal probe (primary signal) to the maternal abdomen using a Velcro belt to hold the IR-LED and photo detector separated by 4 cm. We attached the reference probe to the mother's index finger. Because the selected IR-LED could only emit a maximum optical power of 68 mW, the OFHR system operates with an optical power less than the limit of 87 mW specified by the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

VI. Results and Discussion

To modulate the IR-LED, the modulation signal is generated at a frequency of 725 Hz using the software subroutine through a NI 9474 counter port to the LED driver. As seen in Figure 4, the diffused reflected light from the maternal abdomen, detected by the low-noise photo detector, is denoted as I (M1, F) so that M1 and F denote the contribution to the signal from the mother's abdomen and fetus, respectively. Filtering and an adaptive noise cancelling (ANC) algorithm. The team used Lab View to implement the entire algorithm and part of the instrument. After preprocessing and applying the ANC algorithm, Lab View displays results for the fetal signal and the FHR. Figure 4 illustrates the laboratory prototype and the graphical user interface of the OFHR system and presents the maternal index finger PPG (top), the abdominal PPG (middle), and the estimated fetal PPG (bottom).Figure 5 and 6: The laboratory prototype and the graphical user interface of the OFHR system.

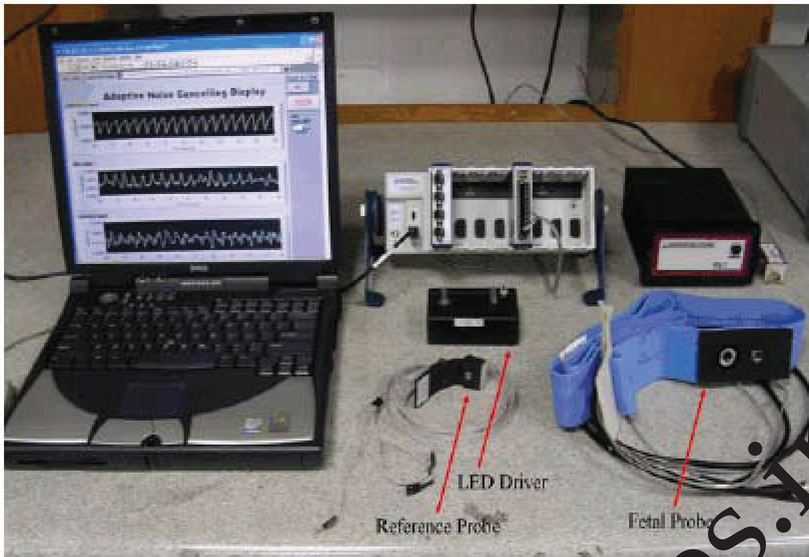

Fig. 4: Graphical user interface of OFHR system. System integrity check menu.

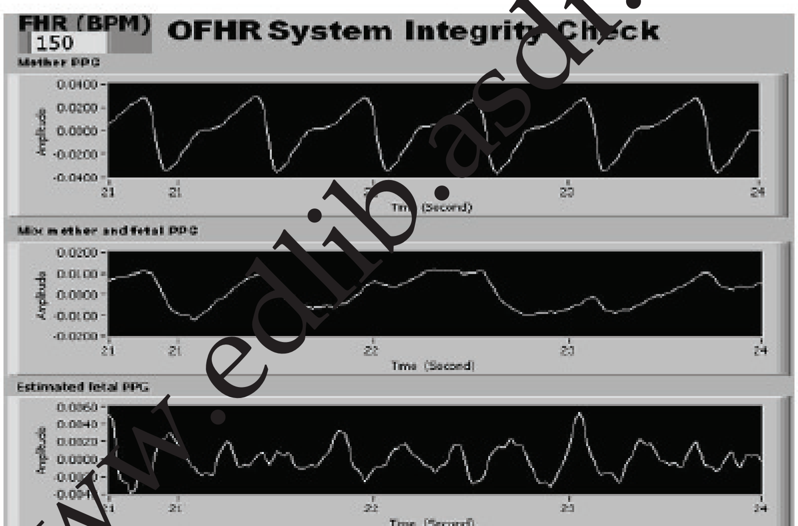

Fig. 5: Graphical user interface of OFHR system

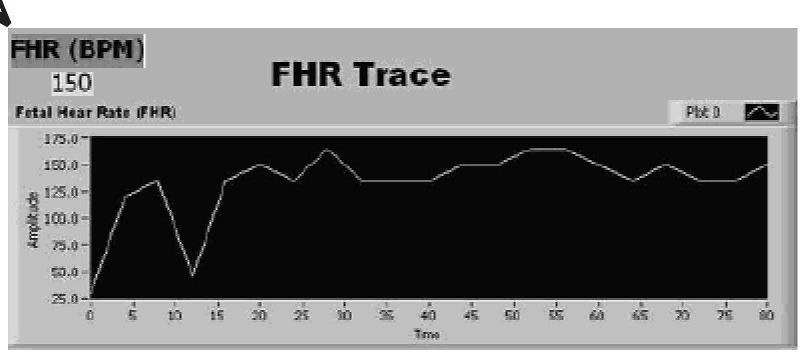

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Fig. 6: FHR trace menu.

Figure 7 illustrates the three selectable displays, including digital synchronous or lock-in amplifier (LIA), adaptive noise cancelling (ANC), and heart rate trace. Figure 7: The three selectable displays, including digital synchronous or lock-in amplifier (LIA), adaptive noise cancelling (ANC), and heart rate trace. The purpose of the first two displays is to assist development, and the third display indicates FHR values versus time. The user can either view the data line or save it for further analysis. After development, we tested our system's functionality with a total of 24 data sets from six subjects at 37 ±2 gestational weeks from the University Kebangsaan Malaysia Medical Centre. The University Ethical Committee reviewed and approved the study, and all patients who participated provided written consent. All fetuses in this study were found to be healthy by an obstetrician and born without complication. In our study, we obtained a correlation coefficient of 0.97 (p-value less than 0.001) between optical and ultrasound FHR with a maximum error of 4 percent. Clinical results indicate that positioning the probe over the nearest fetal tissues, not restricted to the head or buttocks, improves signal quality and detection accuracy. Can be detected by a photo detector. Blood absorbs mostly more light than the surrounding tissue does, and therefore a reduction of the amount of blood gives an increase in the intensity of the detected light. The wavelength and distance between light source and photo detector also determines the depth of penetration (69). Green light is suitable for measurement of superficial skin blood flow, and infrared (IR) or near IR is better for measurements of the deep tissue (muscle) blood flow (73).

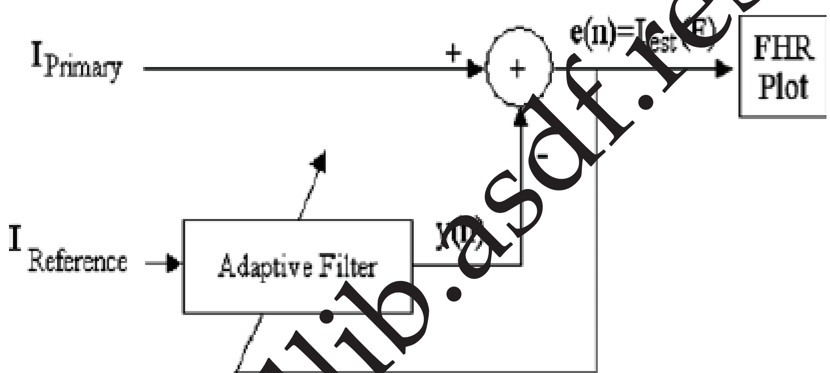

Fig. 7: ANC block diagram

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VII. Advantages

- Low Power Requirement.
- Less Expensive.
- Commercially Available.
- More Accurate Than Other FHR Measurement Techniques.
- Small Components.

VIII. Disadvantages

- Highly Sophisticated Technology.
- Chance of Trouble Shooting is Very High.

IX. Conclusion

Our research team developed a novel OFHR detection system using low-cost and low-power IR light and a commercially available silicon detector. With embedded systems, we rapidly and easily implemented the digital synchronous detection and adaptive filtering techniques. We measured FHR results with acceptable accuracy compared to the standard method of detection (Doppler ultrasound). Moreover, due to the novelty of our solution, we are in the process of filing a patent for its commercial use.

Future Development

Researchers are taking place to achieve more efficient and error less FHR by applying Nanotechnology.

X. References

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