Measuring fetal heart rates accurately and safely--without ultrasound

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The Challenge: Designing a low-power optical fetal heart rate monitor that does not use ultrasound waves and poses no risk to the fetus.

The Solution: Using NI LabVIEW software and NI hardware to design a patent-pending fetal heart rate monitor that features advanced digital signal processing (DSP) techniques.

Fetal heart rate (FHR) detection is the primary methodology for antenatal determination of fetal well-being and assisting in the identification of potential hazards such as hypoxia and distress to the fetus. The expected outcome of early detection is a reduced risk of fetal morbidity and mortality.

Currently, FHR is most commonly detected using Doppler ultrasound where the standard predelivery test of fetal health is the fetal nonstress test (NST). These tests are routinely performed at the hospital with continuous-wave instruments.

Although current ultrasonic FHR detectors are becoming less expensive and less bulky, accurate sensor alignment and some degree of expertise are still required to correctly operate them. In addition, these detectors are sensitive to motion, and the safety of long-term fetal exposure to ultrasound waves has yet to be established. As a result, only short-term testing is practiced.

One alternative is the fetal electrocardiogram (FECG), but the procedure is more complex and less practical. In addition, commercial devices operating on noninvasive FECG are not available today.

More recently, optical methods that are still at the research stage have been proposed, in which halogen and tungsten lamps are used as light sources and a photomultiplier performs detection. These techniques are expensive, require high optical power, and are difficult to implement due to size and power consumption limitations.

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.

Figure 1: OFHR system block diagram showing the hardware modules have been implemented in
The team developed the optical FHR (OFHR) detection system using LabVIEW 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 ration (SNR), and the excitation signal is a chopped light beam. The system performs synchronous detection, and a software subroutine in LabVIEW generates the modulation frequency through a counter port using the NI 9474 digital output module.

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 photodetector 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).

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 1, the diffused reflected light from the maternal abdomen, detected by the low-noise photodetector, 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.

A low-noise (6 nV/rt-Hz) transimpedance amplifier converts the detected current to a voltage level. The reference probe (the 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); M2 refers to the maternal contribution. Synchronous detection is not required at this channel because the finger photoplethysmogram has a high SNR.

The NI USB-9239 24-bit resolution data acquisition module simultaneously digitizes the detected signals from both probes at a rate of 5.5 kHz. The demodulation, digital filtering, and signal estimation are all performed in the digital domain. Software implementation consists of generating a modulation signal, a synchronous detection algorithm, downsampling, high-pass filtering, and an adaptive noise cancelling (ANC) algorithm.

The team used LabVIEW to implement the entire algorithm and part of the instrument. After preprocessing and applying the ANC algorithm, LabVIEW displays results for the fetal signal and the FHR.

Figure 2 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 3 illustrates 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 online 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 Universiti 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.

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 LabVIEW, 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.

References


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(Click here to view the complete list of products used to build the fetal heart rate monitoring system.)

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