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# Passive Acoustic Signal Acquisition System for Non-Invasive Fetal Heart Sound Monitoring Applications.

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**Citation**

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**Abstract**

A simple, low cost and non-invasive personal computer based system for the acquisition of passive acoustic signal is developed. The system hardware consists of a phonocardiographic sensor, a heart sound signal preprocessing circuit, and a personal computer, while the system software consists of a fetal heart sound acquisition program, a signal analysis program, and a data storage function block. The acquisition program is used to switch on or off of the hardware equipments for initializing the sampling rate, the number of acquisition channels and other relevant setups. The collected data in its original form is saved through storage function block for the purpose of further subsequent analysis. In this study, an attempt has been made to develop a phonocardiography based data acquisition system for non-invasive fetal monitoring applications with many advantages like long term home monitoring and high performance to cost ratio. The system was justified by recording the fetal heart sound from 21 subjects with different gestational period. The result shows that the overall accuracy of the system is 98.02%. The developed system can be efficiently used by a fetal heart sound monitoring system for long-term fetal heart rate monitoring in a fully passive manner.

## INTRODUCTION

Electronic fetal monitoring (EFM) is a method for examining the condition of an unborn in the uterus by noting any unusual changes in its heart rate [1]. The EFM is either performed late in pregnancy or continuously during labour to ensure the normal delivery of a healthy baby. This method was originally introduced in the 1960s and 1970s, with the hope that it would help physicians diagnose fetal hypoxia, or lack of oxygen and abnormal heart rate in the unborn baby.

The fetal heartbeat was first detected in 1818 by a physician listening to a mother's abdomen with a crude funnel-shaped tube [2]. In 1833 a textbook on “Obstetric Auscultation” noted the possible relationship between certain fetal heart rate (FHR) patterns and fetal well-being. Since that time, the clinical utility of FHR monitoring has become well established as a means of assessing the health of the fetus [3]. FHR monitoring is performed during pregnancy in the form of so-called non-stress test (NST). The NST is a time series recording of fetal heart beat in uterus, simultaneous with the abdominal and/or uterine contractions of the pregnant woman [4].

Current methods for EFM rely heavily on Ultrasound Techniques. This has two important disadvantages; firstly, there are significant chances that long-term exposure to ultrasound may harm the unborn, and secondly, the ultrasound machines and its trained operators proves to be an expensive proposition hence could not be utilized for longer period of time [5]. Because of these reasons, the existing instruments are not suitable for carrying out frequent and long-term recording of fetal heart sound, which is highly recommended in high-risk pregnancies.

In view of above considerations, strong need is felt for the development of a data acquisition system for fetal heart sound recording, which will be non-invasive, cost effective, and simple to use. In this paper, an alternative technique is presented in which instead of sensing fetal heart movement by doppler shift technique, natural heart sound is perceived and assessed. This technique is called Phonocardiography. It is fully passive, and can be used for long-term fetal monitoring [6].

The paper is organized as follows: The next section discusses the physiology and characteristics of fetal heart in brief and explains the biological activities, which lead to various signals that can be used for monitoring application. Following this the next section then explains various techniques used for FHR monitoring. The article then discusses the material and method used for the development of said data acquisition system and the last section deals with results and conclusions.

## PHYSIOLOGY AND CHARACTERISTICS OF FETAL HEART

The fetal heart is a dual pump that pushes blood around the body and through the placenta. Blood enters the atrial chambers of the heart at a low pressure and leaves the ventricles at a higher pressure; it is this high atrial pressure that provides the energy to force the blood through the circulatory system. Blood returning from the body arrives at the right side of the heart and is pumped through the placenta to pick up oxygen and release carbon dioxide. This oxygenated blood then arrives at the left side of the heart, from where it is pumped back to the body.

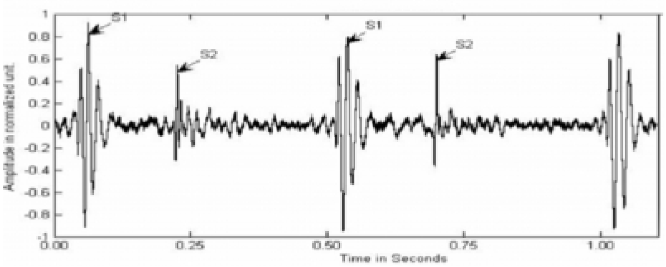
Fetal heart sound is caused due to the vibrations produced by the opening and closing of the four valves, controlling blood flow through the fetal heart. It is also believed that vibrations of heart muscles also contribute to this sound to a large extent. A normal cardiac cycle contains two major sounds:

- Systolic beat S1, caused by the closure of mitral and tricuspid valve.
- Diastolic beat S2, caused by the closure of aortic and pulmonary valves.

Figure 1 shows a typical fPCG of major heart sound. These sounds are produced by the closure of the heart valves.

**Figure 1**

Fig.1. Typical fPCG signal




The first heart sound or “S1” results from the closure of the tricuspid and mitral valves. It is a rather low-pitched and a relatively long sound, which as indicated in Figure 1, represents the beginning of ventricular systole.

The second heart sound or “S2” marks the beginning of ventricular diastole. It is produced by the closure of the aortic and pulmonary (pulmonic) semilunar vanes when the intraventricular pressure begins to fall. This “S2” sound is typically heard as a sharp snap because the semilunar valves tend to close much more rapidly than the AV valves. Because diastole occupies more time than systole, a brief pause occurs after the second heart sound when the heart beats at a normal rate [7].

The frequency spectrum of mechanical vibrations due to fetal breathing and heart activity has been studied through available literature [8]. The significant information in the overall fetal signal is contained in a spectrum between 0.1 to 70 Hz. Fetal mobility and breathing movements result in weak and low frequency sound. This sound is of very low amplitude and cannot be detected by normally used sensors. Fetal heart sound intensity is comparatively high and mostly comprises of two-frequency bands [9]. Low frequency band is from 20 - 40 Hz, and the high frequency band is from 50 - 70 Hz. This analysis of fetal heart sound frequency spectrum is very important for the design of sensing element and associated circuitry [10]. Frequency bands listed above are used for setting the cutoff frequency of active filters applied in the prototype instrument under discussion.

## MONITORING TECHNIQUES

A variety of non-invasive techniques are used for the purpose of fetal monitoring. The fetus is mechanically shielded from outside world so that it can be safely developed in uterus. Thus, only the limited amount of information can be directly obtained about the fetal condition. This information is in the form of various signals picked up from maternal abdominal wall, and they are:

- Electrical potential caused by the bioelectric activity of fetal heart.
- Magnetic field caused by the bioelectric activity of fetal heart.
- Acoustic Vibrations caused by the mechanical activity of fetal heart.

These signals are very weak in amplitude and get overlapped and mixed with corresponding strong maternal signals. Based on the detection of these signals, the methods that are commonly employed in EFM are fetal electrocardiography (fECG), continuous wave ultrasound Doppler-shift based fetal cardiotocography (fCTG) and fetal magnetocardiography (fMCG).

3.1 Fetal Electrocardiography (fECG): The fECG is a well known non-invasive fetal monitoring technique. It is carried out by suitably placing the electrodes on the mother's abdomen to pick up the potential differences on the maternal body surface resulting from the currents flowing within the fetal heart, and there by recording the combined maternal and fetal ECG [11]. With this composite signal, fetal ECG signals are extracted by the rejection of maternal ECG signal, and required FHR is calculated [12].

The major benefits of fECG are that it can provide unobtrusive, long-term and risk-free ambulatory monitoring via small recording units that are simple enough to be used for domiciliary monitoring by the mothers themselves [13]. Apart from the FHR in fECG, morphology of the cardiac waveform also contains diagnostic information. It also has the potential to provide FHR data with beat-to-beat variability.

During the critical period of 24-36 weeks gestation, the reliability of this method is 60% [14]. In this period amniotic fluid fails to provide adequate electrical coupling from fetus to the mother. In fECG recordings are obtained from electrodes attached to the maternal surface, and because of interference from the larger maternal ECG, it has low signal-to-noise ratio (SNR). Although there are numerous methods proposed for the rejection of the maternal signal; the automated evaluation of fECG is less accurate than other methods [15]. Another limitation is the signal quality, which directly gets affected by electrode placement. The fECG require electrode adjustment due to fetal movement and therefore long-term recording can be inconvenient for the mother [16].

3.2 Fetal Cardiotocography (fCTG): FHR detection by fCTG is the most popular and widely used method. A cardiotocograph or CTG monitoring is a graphic record of the response of fetal heart to uterine activity as well as information about its rate and rhythm [17]. Ultrasound is sonic (sound) energy at frequency above the audible range. Whenever a beam of ultrasound passes from one medium to another, a portion of sonic energy is reflected and the remainder is refracted. If an ultrasonic wave is reflected off a moving object, the frequency of the reflected wave gets changed. The change in frequency of the reflected wave is a direct indication of reflection from a moving object. The FHR can be easily calculated from the reflected and received ultrasound, since it is modulated by the fetal heart movements [18].

The fCTG signals are available from the 12$^{th}$ week of pregnancy with usually good SNR. Studies have shown that ultrasonic power level generally used in fetal monitoring produces no chromosome damage and / or other apparent damage to the fetus, even after long exposures. Clinical experience has shown that at least 90% of patients who are calm and have normal presentation can be monitored throughout the labour by Doppler FHR system [19-20]. However, this method inherently produces an average heart rate and therefore cannot give beat-to-beat variability. Also the fCTG technique cannot be used for long term monitoring because of its invasiveness in nature [21].

3.3 Fetal Magnetocardiography (fMCG): The fMCG is a non-invasive method to study the fetal heart: the patient (i.e., the mother) is not even touched. Fetal magnetocardiograms are recordings of the magnetic fields generated by the currents flowing within the fetal heart. Usually the component of the magnetic field that is perpendicular to the maternal abdomen is measured. These magnetic fields are extremely weak ($10^{-13}$ tesla). By comparison, the magnetic field of the earth is a million times stronger ($5 \times 10^{-5}$ tesla) [22]. The only sensor that is sensitive enough to monitor such weak fields is a SQUID (superconductive quantum interference device) and currently these SQUIDs have to be cooled by liquid helium [23].

The fMCG has a high signal-to-noise ratio and is remarkably free of maternal interference compared to the fECG. In this technique, measure of fetal heart rate variability (FHRV) has been found to be more objective and accurate than doppler ultrasound measurements [24]. The disadvantage of fMCG is the size, cost and complexity of the instrumentation required, and although smaller devices may become available, ambulatory versions will not be available in the foreseeable future.

Based on above discussion, the fCTG technique have remarkably improved the medical care of unborn during the process of childbirth but suffers with two important disadvantages: firstly long-term exposure to ultrasound is considered to be harmful for the fetal, hence cannot be used for a prolonged duration and secondly ultrasound machines and its operators are economically not viable. Frequent monitoring of fetal at home is preferable; although high quality doppler devices are very expensive hence this technology cannot be used for home care application. As far as the fECG technique is concerned its reliability is very low during the critical period of 24-36 weeks gestation, and also because of interference from the larger maternal ECG, the SNR of the technique is poor. To overcome these problems, fetal phonocardiography (fPCG) is utilized in this work [25]. In fPCG, the fetal heart sound is detected from maternal abdomen by sensitive microphone and then electronically processed for getting audible heart sound, which can be recorded and visualized [26]. The main advantages of this technique are its passivity (non-invasiveness) and its simplicity [27]. It can be used for long term ambulatory home monitoring. Since the fPCG signals recorded from maternal abdominal surface are contaminated by maternal organ sound and ambient noise, this technique requires robust signal processing to extract the fetal heart sound [28].

## MATERIAL AND METHOD

The developed data acquisition system targets the acquisition & recording of the fetal heart sound from subject's abdomen. This system is based on two parts- the hardware and the software. The hardware section consist of a phonocardiographic sensor, a fetal heart sound signal processing circuit and a personal computer, while the software section consists of a fetal heart sound acquisition program, a signal analysis program and a data storage function block.

## SYSTEM HARDWARE: THE FETAL HEART SOUND IS IN THE FORM OF MECHANICAL VIBRATIONS

passing through tissue structures. These vibrations are relatively weak because of the physical distance and small size of the fetal heart valve. In order to sense this weak heart sound from maternal abdomen, the transducer should be properly placed and its mechanical as well as electrical impedance should be matched with the system. To realize this basic requirement, an acoustic cone with sound wave guide has been developed for sensing fetal heart sound vibrations from subject's abdomen. Use of this acoustic cone improves SNR to a great extent and also facilitates ease of use. Through the acoustic cone, sound is fed into the piezoelectric sensor and the associated circuitry where it is processed and stored.

Fetal heart sound recording system is considerably susceptible to the ambient noise. The abdominal sensor records principally the sound originating from the fetal heartbeats, but this sound gets mixed with damped version of following unwanted sounds.

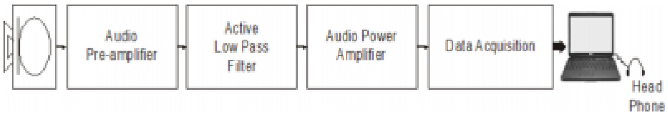
- Movement of measurement head during recording (shear noise).
- External noise originating from the environment (ambient noise).
- Acoustic noise produced by the fetal breathing movements.
- Maternal digestive sound (gut sound).
- Sound of maternal heart and breathing activity.

In fetal phonocardiographic measurement, these unwanted sounds creates major problem even at signal processing stage [29]. To facilitate this, advanced digital signal processing is required. The design and development of such filter is the part of on going research of corresponding author.

The block diagram of the data acquisition system is shown in Figure 2.

**Figure 2**

Fig.2. Block diagram of the Data Acquisition System

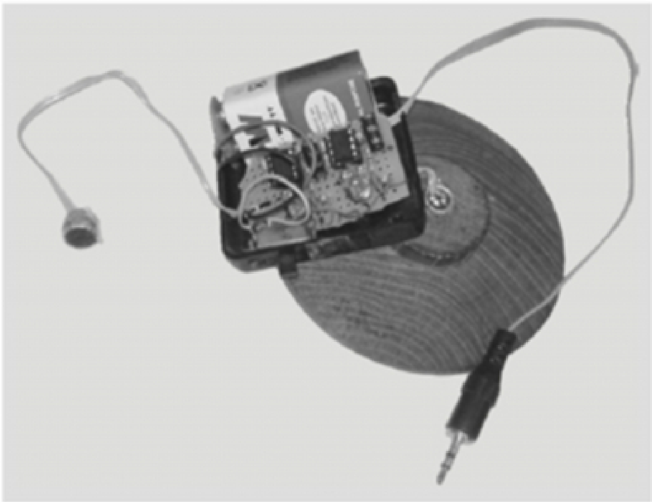



The fPCG requires conversion of mechanical vibrations from subject's abdomen into electrical signals by sensing element. Fetal heart sound is extremely weak hence it cannot be sensed properly by putting the sensor directly on subject's abdomen. To overcome this problem, a highly sensitive Data Recording Module (DRM) is developed [30].

The DRM comprises of an acoustic cone whose front portion (mouth) is closed by a membrane of nearly 75 micron thickness. The membrane tension can be adjusted by rotating the outer ring of the cone. The rear portion (throat) of the cone is connected to a sound wave guide, which finally terminates in a piezoelectric sensor. The air enclosed in this cone acts as a transmission medium between the membrane and the electro-mechanical transducer device. Photographs of the developed prototype DRM are shown in the Figure 3.

**Figure 3**

Fig.3. Photographs of the Data Recording Module



The output of the sensor is fed to the preamplifier through a high-pass filter, for amplification and better noise rejection. IC LM 358 is used for this particular purpose, which raises the signal from transducer level to the line level. It is essential that the ambient noise should be kept as low as possible and this is carried out with the help of an active low pass filter having a cutoff frequency of 70 Hz. This cut off frequency value is selected, because as pointed out earlier, the fetal heart sound spectrum lies in the frequency range of 20 to 70 Hz. Active filter is implemented by commonly available operational amplifier IC 741 with suitable resistance capacitor network.

4.2 System Software: The software in this study is used to perform data acquisition and to display digital fetal phonocardiographic signal in a personal computer. It is developed with the intention to acquire and record fetal heart sound which can be efficiently used by a fetal heart sound monitoring system. For this purpose, the system hardware output is fed directly to the Line In port of the personal computer, which contains an on-board signal conditioning, an analog to digital converter and a digital signal processing hardware. MATLAB data acquisition toolbox is used to acquire, process and display the fetal heart sound signals; which will be of great diagnostic importance. The Algorithm for the development of data acquisition software is as follows:

Creation of device object: A device object is created using the analog input command of MATLAB data acquisition toolbox. Device object is the basic toolbox element used to access the hardware device.

Channels addition: Moments later then the device object is created, channels or lines are added to it. These are the basic hardware device elements with the help of which data is acquired.

Configure properties: Using set functions or dot notations, the device object's behavior is established for optimum performance.

Acquisition of data: To acquire data, device object is executed with the start function. This process is also known as triggering of the program.

Wait for acquisition: Following the triggering, acquisition of the data has to be completed before moving on to next step.

Storage: Subsequent to acquisition, the data is transferred and stored in permanent memory for the ensuing processing and analysis.

Clean Up: Immediately after the completion of the acquisition process, device object is removed from the workspace.

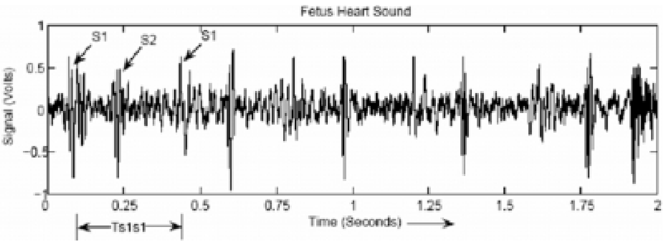
## EXPERIMENTAL AND CLINICAL TRAIL RESULT

The clinical trials were carried out in a government hospital on 21 pregnant women who were in the $36^{th}$ to $40^{th}$ week of pregnancy. For each trial, a 10 seconds data was captured and processed. Figure 4 shows an example of recorded fetal heart signal and the resulting FHR estimation. The signal is acquired from the abdominal wall of a woman with $38^{th}$ week of pregnancy. Which is then transferred to a personal computer in *.wav file through multimedia card and saved for the purpose of subsequent analysis. Matlab data acquisition script is used to process and display the recorded sound waveforms. This signal is then passed through a Butterworth FIR Bandpass filter of the range from 20 Hz to 200 Hz so as to get the waveforms as shown in figure 4. In this recorded waveform, X-axis represents the time in seconds and Y-axis represents amplitude of signal in Volts. Time separation between two consecutive S1 sounds ($T_{S1S1}$ = 0.4 seconds) is manually measured and FHR is calculated using the formula given below:

FHR in Beats per Minute (BPM) = $(1/T_{S1S1}) \times 60$

**Figure 4**

Fig.4. Waveforms of recorded fetal heart sound




In order to justify the performance of the developed system, phonocardiographic data were recorded with simultaneous ultrasound doppler based CTG instrument. It was observed that 15/21 of the fetal heart sounds were clear and distinctive. In case, where the sound could not be heard, it was noted that the pregnant women were very obese. This was not surprising as the CTG machine also experienced the same problem. Some other reasons may include the abnormal placenta position, unfavorable fetal position in the mother's womb and the movement of fetus. Table 1 shows the results of FHR calculated from recorded waveform and simultaneously measured FHR through ultrasound Doppler based CTG.

**Figure 5**

Table 1: Comparison between FHR measured by two different methods

| Subject No. | Gestation Age in Weeks | FHR from recorded waveform in BPM | FHR through fCTG in BPM | % Error | % Accuracy |
|---|---|---|---|---|---|
| 1 | 40 | 147 | 150 | 2.00 | 98.00 |
| 2 | 38 | 150 | 152 | 1.32 | 98.68 |
| 3 | 41 | 145 | 143 | -1.40 | 98.60 |
| 4 | 43 | 138 | 140 | 1.43 | 98.57 |
| 5 | 39 | 146 | 150 | 2.67 | 97.33 |
| 6 | 42 | 135 | 132 | -2.27 | 97.73 |
| 7 | 40 | 129 | 135 | 4.44 | 95.56 |
| 8 | 39 | 148 | 150 | 1.33 | 98.67 |
| 9 | 36 | 145 | 148 | 2.03 | 97.97 |
| 10 | 44 | 155 | 152 | -1.97 | 98.03 |
| 11 | 40 | 152 | 155 | 1.94 | 98.06 |
| 12 | 41 | 142 | 140 | -1.43 | 98.57 |
| 13 | 36 | 140 | 145 | 3.45 | 96.55 |
| 14 | 37 | 152 | 150 | -1.33 | 98.67 |
| 15 | 38 | 154 | 155 | 0.65 | 99.35 |

Based on the data in table 1, a comparison of FHR measured by the developed system and fCTG was done. The overall accuracy of the system is observed to be around 98.02 %. This value is good enough for a prototype model and the parameters will become more refined and fine-tuned in the final version of the system.

## CONCLUSION

The fCTG is most commonly used clinical diagnostic tool, which provides accurate determination of FHR. These devices are having few inherent limitations due to the use of ultrasound and frequent exposure to ultrasound radiation is not recommended for both fetus and mothers. To overcome this complexity, an alternative technique, fPCG is suggested in which acoustic vibrations produced by mechanical activity of heart is detected. This technique is fully passive and therefore provides absolutely non-invasive fetal diagnostic measurement. A portable fetal heart sound recording system was designed and developed which can be used for NST and for long term monitoring of fetal heart sound in high-risk pregnancies. In this work, it was exhibited that fetal heart sound can be recorded using acoustic signal of fetal heartbeats, and this can be done even in high disturbing and external noise of living environment conditions. The system has been tested on 21 pregnant women with different gestational period. The result from 15 subjects shows that the overall accuracy of the system is observed to be around 98.02 %. The discussed system offers an optimal trade-off between complexity and feasibility and is viable in respect of low cost, stand-alone, battery operated fetal heart sound recording device which could be used for long-term recording in home care use.

## ACKNOWLEDGEMENT

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### References

1. N. Malik, C. Raghunandan, N. Madan, "Foetal Heart-rate patterns in early labour in low and high risk pregnancies & its correlation with perinatal outcome," Journal of Indian Medical Association, vol.100, no.11, pp. 646-650, Nov. 2002.
2. Z. Zhou, "Fetal Heart Rate Detection with a Passive Acoustic Sensor System," Master Thesis, Old Dominion University, 1995.
3. M. Godinez, A. Jimenez., R. Ortiz., M. Pena, "On-line fetal heart rate monitor by phonocardiography," Proceedings of 25th Annual International Conference of the IEEE, vol. 4, pp. 3141–3144, 17-21 September 2003.
4. H. Horio, M. Murakami, Y. Chiba, H. Inada, "Fetal monitor for non-stress-test screening at home," Biomedical Instrumentation & Technology, Association for the Advancement of Medical Instrumentation, vol. 32, no.1, pp.

39-47, Jan-Feb 1998.
5. T. Kupka, J. Jezewski, A. Matonia, K. Horoba, J. Wrobel, “Timing events in Doppler ultrasound signal of fetal heart activity,” 26th Annual International Conference of the IEEE on Engineering in Medicine and Biology Society, vol. 1, pp. 337-340,1-5 Sept. 2004.
6. P. Varady, L. Wildt, Z. Benyo, A. Hein, “An advanced method in fetal phonocardiography,” Computer Methods and Programs in Biomedicine, vol. 71, no. 3, pp. 283-296, July 2003.
7. M. El-Hanjouri, W. Alkhaldi, N. Hamdy, 0. A. Alim, “Heart diseases diagnosis using HMM,” Proceedings of the IEEE on Electrotechnical Conferrence, MELECON 2002, 11th Meditterranean, pp. 489-492, 7-9 May 2002.
8. F. Kovacs, M. Torok, “An improved phonocardiographic method for fetal heart rate monitoring,” Proceedings of the 20th Annual International Conference of the IEEE on Engineering in Medicine and Biology Society, vol. 4, pp. 1719-1722, 29 October-1 November 1998.
9. H.G. Goovaerts, O. Rompelman, H. P. van Geijn, “A transducer for detection of fetal breathing movements,” IEEE Transactions on Biomedical Engineering, vol. 36, no. 4, pp. 471-478, April 1989.
10. P. Varady, “Wavelet-based adaptive de-noising of phonocardiographic records,” Proceedings of 23rd Annual International Conference of the IEEE on Engineering in Medicine and Biology Society, vol. 2, pp. 1846-1849, 25-28 October 2001.
11. J. F. Pieri, J. A. Crowe, B. R. Hayes-Gill, C. J. Spencer, K. Bhogal, D. K. James, “Compact long-term recorder for the transabdominal foetal and maternal electrocardiogram,” Medical and Biological Engineering and Computing, vol. 39, no.1, pp. 118-125, January 2001.
12. A. Khamene, S. Negahdaripour, “A new method for the extraction of fetal ECG from the composite abdominal signal,” IEEE Transaction on Biomedical Engineering, vol. 47, no.4, pp. 507-516, April 2000.
13. S. L. Horner, W. M. Holls, P. B. Crilly, “A robust real time algorithm for enhancing non-invasive foetal electrocardiogram,” Digital Signal Processing, vol. 5, pp. 184-194, 1995.
14. J. A. Crowe, M. S. Woolfson, B. R. Hayes-Gill, W. Peasgood, M.A. Mohd-Ali, Y. Huang, J. Herbert, X. B. Huang, A. Harrison, N. M. Gibson, E. M. Symonds, N. Reed, M. Mohajer, “Antenatal Assessment using the FECG obtained via Abdominal Electrodes,” Journal of Perinatal Medicine, vol. 24, no. 1, pp. 43-53, 1996.
15. G. Camps, M. Martinez, E. Soria, “Fetal ECG extraction using an FIR Neural Network,” Computers in Cardiology, IEEE Computer Society Press, pp. 249-252, 2001.
16. C. Papaloukas, D. I. Fotiadis, A. Likas, A. P. Liavas, L. K. Michalis, “A knowledge-based technique for automated detection of ischaemic episodes in long duration electrocardiograms,” Medical & Biological Engineering & Computing, vol. 39, no.1, pp. 105-112, January 2001.
17. C. Hanqing, D. E. Lake, J. E. Ferguson II, C. A. Chisholm, M. P. Griffin, J. R. Moorman, “Toward quantitative fetal heart rate monitoring” IEEE Transactions on Biomedical Engineering, Vol. 53, no.1, pp. 111-118, January 2006.
18. K. Krzysztof, K. Tomasz, J. Sienko, “On the wavelet analysis of the Doppler signals of fetal activity” Proceedings of the fifth IASTED International Conference: biomedical engineering, pp. 180-185, 2007.
19. M. S. Han, S. Kim, Y. G. Kim, “A Research of Web-Based Real Time Automatic Fetal Monitoring System,” Journal of Korean Society of Medical Informatics, pp.59-67,December2001.
20. A. K. Mittra, “Functional analysis of sensors used in cardiotocography: A trans abdominal fetal heart rate and uterine contraction monitoring machine,” Proceedings of national conference – NCST - 2004, Sensor Technologies, Gwalior, pp. 28-31, 27-28, December 2004.
21. J. R. Sharma, A. K. Mittra, “Cardiotocograph fetal heart rate and uterine contraction monitoring machine: A TQM approach to optimization,” Proceedings of international conference – EISCO - 2005, Kumar Guru College of Technology Coimbatore, pp. 251-257, 5-7, January 2005.
22. Uzunbajakau, S.A., Golbach, E.G.M., Stinstra, J.G., Peters, M.J., “A sensitive magnetocardiograph for fetal surveillance,” Proceedings of the 23rd Annual International Conference of the IEEE on Engineering in Medicine and Biology Society, vol. 1, pp. 378-380, 2001.
23. Rassi, D., “Antenatal fetal magnetocardiography using SQUIDapos;s,” IEE Colloquium on Magnets in Medicine - Hazards and Health Care, no. 9, pp. 2/1 - 2/3, Oct 1995.
24. Verklan, M. Terese, Padhye, Nikhil S., Brazdeikis, Audrius, “Analysis of Fetal Heart Rate Variability Obtained by Magnetocardiography,” Journal of Perinatal & Neonatal Nursing, vol. 20, no. 4, pp. 343-348, October/December 2006.
25. C. Jianfeng, P. Koksoon, S. Ying, S. Louis, “A portable phonocardiographic fetal heart rate monitor,” Proceedings of International Symposium of the IEEE on Circuits and Systems, ISCAS 2006, 21-24 May 2006.
26. Y. M. Lee, M. Moghavvemi, “Remote heart rate monitoring system based on phonocardiography,” Proceedings of student conference of IEEE on Research and Development, SCOReD 2002, pp. 27-30, 16-17 July 2002.
27. F. Kovacs, M. Torok, I. Habermajer, “A rule based phonocardiographic method for long term fetal heart rate monitoring,” IEEE Transactions on Biomedical Engineering, vol. 47, no. 1, pp. 124-130, January 2000.
28. A. K. Mittra, Dr. N. K. Choudhary, Dr. A. S. Zadgaonkar, “Adaptive Noise Cancellation for Advanced Fetal Phonocardiography,” Proceedings of the International Conference on Emerging Technologies and Applications in Engineering, Technology and Science, Saurashtra University, Rajkot, Gujarat, 13-14 January 2008.
29. J.T.E. McDonnell, “Knowledge-based interpretation of foetal phonocardiographic signals,” Radar and Signal Processing, IEE Proceedings F, vol.137, no.5, pp. 311-318, October 1990.
30. A. J. Zuckerwar, R. A. Pretlow, J. W. Stoughton, D. A. Baker, “Development of a piezopolymer pressure sensor for a portable fetal heart rate monitor,” IEEE Transactions on Biomedical Engineering, vol. 40, no. 9, pp. 963-969, September 1993.
31. C. L. Lin, H. C. Wu, T. Y. Liu, M. H. Lee, T. S. Luo, S. T. Young, “A portable monitor for fetal heart rate and uterine contraction,” Engineering in Medicine and Biology, Magazine, IEEE, vol. 16, no 6, pp. 80-84, November-December 1997.
32. M. Brusco, H. Nazeran, “Digital phonocardiography: A PDA-based approach,” Proceedings of the 26th Annual International Conference of the IEEE on Engineering in Medicine and Biology Society, IEMBS 04, vol. 1, pp. 2299-2302, 1-5 September 2004.
33. F. Kovacs, Cs. Horvath, M. Torok, G. Hosszu, “Long-term Phonocardiographic Fetal Home Monitoring for Telemedicine Systems,” 27th Annual International Conference of the IEEE on Engineering in Medicine and Biology Society, EMBS 2005, pp. 3946-3949, 2005.

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