A Device for Fetal Monitoring by Means of Control Over Cardiovascular Parameters Based on Acoustic Data

L A Khokhlova1,2, A I Seleznev1,2, D S Zhdanov3,4, I Yu Zemlyakov5,6 and E Yu Kiseleva7,2

1Engineer, LLC Diagnostica +, Tomsk, Russia
2Engineer, Tomsk State University, Tomsk, Russia
3Senior programmer, LLC Diagnostica +, Tomsk, Russia
4Jr. researcher, Tomsk State University, Tomsk, Russia
5Senior researcher, Tomsk State University, Tomsk, Russia
6Chief engineer, LLC Diagnostica +, Tomsk, Tomsk, Russia
7Deputy director for project work, LLC Diagnostica +, Tomsk, Russia
E-mail: hohlova@diagnostic.tom.ru

Abstract. The problem of monitoring fetal health is topical at the moment taking into account a reduction in the level of fertile-age women’s health and changes in the concept of perinatal medicine with reconsideration of live birth criteria. Fetal heart rate monitoring is a valuable means of assessing fetal health during pregnancy. The routine clinical measurements are usually carried out by the means of ultrasound cardiotocography. Although the cardiotocography monitoring provides valuable information on the fetal health status, the high quality ultrasound devices are expensive, they are not available for home care use. The recommended number of measurement is also limited. The passive and fully non-invasive acoustic recording provides an alternative low-cost measurement method. The article describes a device for fetal and maternal health monitoring by analyzing the frequency and periodicity of heart beats by means of acoustic signal received on the maternal abdomen. Based on the usage of this device a phonocardiographic fetal telemedicine system, which will allow to reduce the antenatal fetal mortality rate significantly due to continuous monitoring over the state of fetus regardless of mother’s location, can be built.

1. Introduction
Nowadays the primary trend of perinatal medicine has been changed in the Russian Federation. Delivery in favor of fetus has become a routine practice. The Russian Federation has set a goal to reduce the rate of maternal and infant mortality in no less than 2 times by 2025 [1]. One of the key criteria of outpatient perinatal institutions’ work is the absence of antenatal fetal death cases [2].

A solution for reducing the number of antenatal deaths can be either long-term inpatient hospitalization of high-risk pregnant women or the use of substituting technologies.

Fetus condition in the antenatal period is controlled by means of various methods: survey, visual examination, abdominometry, fundal height measurement, assessment of the fetal position, its movement activity and heart rate as well as different ultrasound examinations. However, traditional clinical methods of examination do not always allow assessing fetus development and detecting certain potentially dangerous conditions, e.g., fetal hypoxia. Despite seeming insignificance of this condition, it is a cause of most intrauterine deaths and multiple complications at the early antenatal period [2].
Cardiotocography is still the primary method for detecting the signs of fetal hypoxia. In this case, the fetal heart rate is registered by an ultrasound detector utilizing the Doppler effect. Nowadays a lot of various models of fetal monitoring devices are available (BabyCare, Bionet, SonicaidOne, OxfordMedical, etc.) [3,4]. However, all of them are used at medical institutions only; therefore, they cannot guarantee a prompt response in case of sudden deteriorations in fetal health. Moreover, the use of these devices is connected with difficulties for high-risk pregnant women who live in the areas located far from medical centers.

Mobile fetal cardiotocography concepts are actively developed in order to solve these problems. The most successful option is the Sense4Baby project that currently undergoes approval procedures in the USA [5]. At the same time, the safety of ultrasound radiation used for cardiotocography is not an established fact.

Besides mobile cardiotocographs, the Monica AN24 system (Great Britain) has become popular within the segment of commercially available autonomous wearable fetal monitoring devices. The AN24 daily monitoring device is meant for registering fetal and maternal ECG, uterine contractions and fetal movement activity under the condition of pregnant woman’s free movement. It is noteworthy, that in order to overcome the problem of signal to noise ratio, the Monica AN24 device depends on the patient’s abdomen receiving a thorough skin preparation with a special abrading solution that removes the stratum corneum of the epidermis [6].

Phonocardiography (PCG) can be an alternative method to acquire information on the fetal cardiac activity. PCG allows recording fetal heart beats in a passive and completely non-invasive way [7]. Signals can be registered by placing an acoustic sensor on the mother’s abdominal surface without using any gel, which is a necessary condition for normal operations of the devices that are used to register fetal ECGs or utilize Doppler sonography. Phonocardiographic signals potentially can be used to detect fetal cardiac pathologies, such as cardiac murmur, premature beats and dyadic/triadic atrial contractions [8]. Standard cardiotocography and other techniques do not provide such opportunities [7].

2. Description of the device for fetal monitoring

In connection with good prospects of the use of phonocardiography methods in the field of antenatal health protection, the LLC Diagnostica + team develops a device for non-invasive monitoring of the state of health of fetus and pregnant woman by analyzing the frequency and periodicity of their heart beats on the basis of acoustic data. The device will be used as part of the monitoring system, which also includes patient smartphone software, providing data on the medical institution server, and obstetrician workstation.

The hardware part of monitoring system is an mobile electronic device for reception, transmission and primary processing of acoustic data. The general structure of the hardware component of the experimental prototype is presented in figure 1.
The device works in the following way. Acoustic sensors made as compact highly-sensitive contact microphones located in the abdominal area of a pregnant woman register weak acoustic signals of fetal heart beats and convert them into electric signals. Signals are transferred to the analog unit, where they are amplified and filtered in order to reduce the impact of interferences and unwanted noises on the device.

Then the microcontroller (microcontroller unit) uses the analog-to-digital converter to transform analog signals into a digital code. These data are saved in the built-memory and shared with the software component installed on a patient’s smartphone by means of the wireless data transfer unit. Control and indication elements are used to display the device status and operation mode, audio indication (digital-to-analog converter and audio amplifier) inform about dangerous conditions. Next step is the transmission of the obtained data to a medical server and workstation, where obstetrician can assess fetus health condition and monitor the fetal heart rate and, if necessary, appoint additional examinations or take actions in case of a dangerous condition.

Figure 2 presents signals acquired by means of the experimental prototype.

![Figure 2](image)

**Figure 2.** Fetal phonocardiogram. Gestation term: 34 weeks, a) prior to digital filtration; b) after digital filtration.

The key problem connected with the use of acoustic data is proper detection of fetal heart beats in noise-contaminated signals and further processing of these data. Noise contamination of PCG signals is connected with the following factors [7,9]: phonocardiographic signals depends on the fetal presentation; fetal movements cause acoustic noises typical of specifically its movement activity; pregnant woman’s GIT sounds can overlay PCG signals; phonocardiograms contain pregnant woman’s cardiac and respiratory sounds as well as external noises (figure 2a). Additional filtration and amplification of audio records allow acquiring clear fetal heart beats (figure 2b). These signals can be used for further digital extraction of the heart beats and measurement of the fetal heart rate.
3. Summary
The device under development will allow conducting dynamic monitoring over the cardiovascular system of the fetus and pregnant woman without the need for staying inside a medical institution and being under medical personnel’s supervision. In addition, phonocardiography is safe due to the absence of any exposing radiation, so this technique can be used for any period of time according to obstetrician’s recommendations. The device is implemented in the form of a mobile, wearable, data-transferring unit, which will allow timely informing physicians about changes in the fetal health without interfering the patient’s daily life. The smartphone software will eventually provide a visual representation of the fetus health condition gathered by the wearable monitoring device. The signals acquired by means of the experimental prototype can be satisfiable for digital extraction of the heart beats after analogue pre-processing and digital filtration. However for introducing the method described into medical practice, it is necessary to solve the major task of receiving stable signals in various types of fetal presentation and mother’s anthropometric data.

Acknowledgments
The work has been performed within the framework of the State Contract No.14.579.21.0019 (unique agreement identifier #RFMEFI57914X0019) on the subject Developing the device for fetal and maternal health monitoring during pregnancy by means of control over cardiovascular parameters based on acoustic data concluded between the Ministry of Education and Science of the Russian Federation and LLC Diagnostica +.

References
[1] RF Presidential Decree No.1351 as of 10.09.2007 On Approving the Demographic Policy Concept in the Russian Federation for the Period of up to 2025
[2] Frolova O G, Palenaya I I, Shuvalova M P, Sukhanova L P (2011) Regional aspects of stillbirth rates in the Russian Federation in 2008 Obstetrics and Gynecology 1 105–109
[3] Bionet, Compact Fetal Doppler, 05.26.2014. [Online source]. Available at: http://www.bio2net.com/eng/products/products1_1.asp?id=193&category=55&search_type=0 &search_word=&page_size=8&page=1 [Date of reference: 05.26.2014]
[4] Oxford Medical, Fetal heartbeat Detectors – Sonicaid® One, 05.26.2014 [Online source]. Available at: http://www.oxford-medical.ru/detectory_serdcebieniya_ploda_sonicaid_one.html [Date of reference: 05.26.2014]
[5] West Health Institute, Sense4Baby, 05.26.2014. [Online source]. Available at: http://www.westhealth.org/news/press-release-sense4baby-licenses-wireless-fetal-monitor-system [Date of reference: 05.26.2014]
[6] Adam J (2012) The future of fetal monitoring Rev. in Obstet. Gynecol 5(3–4) 132–136
[7] Kovács F, Horváth C, Török M, Hosszú G (2006) Long-term phonocardiographic fetal home monitoring for telemedicine systems Annual International Conference of the IEEE Engineering in Medicine and Biology - Proceedings 3946–3949
[8] Varady P, Wildt L, Zoltañ B, Achim H (2003) An advanced method in fetal phonocardiography Computer methods and programs in biomedicine 71(3) 283–296
[9] Ruffo M, Cesarelli M, Jin C, Gargiulo G, McEwan A, Sullivan C, Bifulco P, Romano M, Shephard R W, Schaik A 2011 Non invasive foetal monitoring with a combined ECG–PCG system Biomedical Engineering, Trends in Electronics, Communications and Software (Croatia, InTech) pp 347–366