Wearable system concept for monitoring of maternal and fetal heart activity

A. Krišč iukaitis[1, 2], M. Lukoševičius[1], R. Petrolis[2], V. Marozas[1], S. Daukantas[1], V. Gintautas[2], A. Lukoševičius[1]

[1]*Kaunas University of Technology, Lithuania*

[2]*Lithuanian University of Health Sciences, Lithuania*

[1]*E-mail: algimantas.krisciukaitis@lsmuni.lt*

Motivation. Although there has been a marked reduction in perinatal morbidity and mortality rates over the past four decades, hypoxia and/or asphyxia of the fetus in the perinatal period, leading to major motor and cognitive disabilities, continues to be a significant health problem worldwide [1]. Adverse intrauterine circumstances can result in abnormal brain development, and can contribute to many neurological disorders such as cerebral palsy and cognitive and behavioral deficits. These neurological problems are caused by conditions that cause chronic placental insufficiency, such as hypoxia and acidemia [2]. The procedures used to identify fetuses at risk are based on invasive intermittent tests that directly detect a decrease in oxygen, or fetal energy balance evaluated by means of pulse oximetry to measure oxygen saturation (SaO_2) in arterial blood. Noninvasive fetal heart rate (FHR) monitoring is also used for detection of hypoxia. However, usage of even continuous FHR monitoring does not reduce the incidence of hypoxic-ischemic encephalopathy, cerebral palsy or perinatal mortality when compared to classical intermittent auscultation [3]. Possible reasons for that could be in technical properties of widely used Doppler ultrasound devices giving averaged estimates of FHR, providing limited information in complicated cases. Despite fetal ECG analysis is shown as more effective than pulse oximetry in reducing the rate of caesarean delivery, provided a more continuous source of information on fetal status, and resulting in better neonatal outcomes [4], it wasn't widely used due to technical difficulty to register the signal. Development of high definition portable signal registering devices, wearable electrodes and network-based data processing systems inspired new attempts to develop devices for fetal ECG registration and analysis.

The origin of fetal hypoxia could be related not only to placental or fetal pathologies. Fetal hypoxia is classified into 3 subtypes according to its origin: (1) pre-placental hypoxia, where maternal organism disorders can cause fetal hypoxia; (2) utero-placental hypoxia, where the maternal oxygenation is normal but the utero-placental circulation is impaired (i.e., preeclampsia, placental insufficiency, etc.); (3) post-placental hypoxia, where only the fetus is hypoxic [5]. The clinical outcomes of all three types of hypoxia are equally severe for the fetus. So, diagnostic means should cover all mentioned types of disorders. We propose that the monitoring system should be wearable and include registration of maternal and fetal ECG, maternal hemodynamics

(photoplethysmographic – PPG and SpO_2) and biomechanical signals (accelerometer – ACC). Galvanic skin response (GSR) and temperature sensors were also added for investigation of causal interrelations between mother and fetus physiological states. The aim of this study is to present the concept and feasibility of such system.

Monitoring system concept. The design of the system for simultaneous monitoring of mother and fetus is shown in Fig. 1. High quality ECG signals are recorded using low noise (1.0 μV_{PP} (70 Hz BW), 24 bits biosignal acquisition front-end *ADS1299* (Texas Instruments Inc.). The abdomen belt sensor includes low noise ACC device for detection of the movement artifacts causing possible ECG signal corruption and for fetal movement registration. The PPG sensor is used for maternal hemodynamics monitoring; GSR and temperature sensors are used to monitor her psychological state and to detect stress.

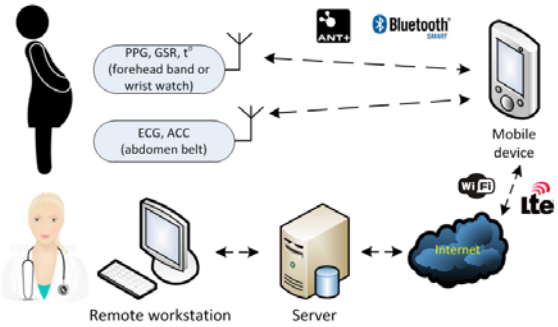

Fig. 1. The system for joint monitoring of mother and fetus

Local signal processing and wireless transmission of the signals to mobile device are realized by means of multi-protocol system on chip *nRF51922* (Nordic Semiconductors).

The mobile device is used to control the sensors (to start/stop the signal acquisition, change settings, or to perform time synchronization) and to give a feedback to the patient (mother) about her health status based on immediate preliminary analysis. The detailed analysis of the acquired signals, computing the trends for visual analysis, generating automatic events and reports, storage of acquired raw data is performed in the remote server. Special Web-application will be developed to manage the information stored in the server and to view the results of analysis.

Algorithms. One of the most difficult tasks in fetal status estimation is detection of fetal heartbeats in abdominal ECG. We developed two pilot algorithms [6, 7] which could be used for that purpose. The algorithms were developed using data from annotated public database used in „Computing in Cardiology / Physionet Challenge 2013" [8].

The first algorithm [6] starts with maternal ECG removal by subtracting averaged cardiocycles from each lead in the original signal. Then it employs Echo State Networks (ESN) [9] and a probabilistic dynamic programming approach to detect fetal heartbeats. The algorithm gives high accuracy and flexibility of the detection but requires annotated data to train it on. This approach also incorporates prior distribution of fetal RR interval durations which allows one to tune the method for detecting specific types of FHR events.

The second algorithm [7] uses cardiocycle-vise Principal Component Analysis (PCA) for optimal representation of maternal ECG cardiocycles which are subtracted from original signal. Then leads-vise PCA is applied for the remaining signals. PCA concentrates variation represented by several correlated variables into several orthonormal variables. It is expected that fetal ECG, remains of maternal ECG, and noise appear in different new variables. The variable representing only fetal ECG is then used to detect fetal heartbeats.

Results. The fetal heart beats detecting algorithms showed promising results on „*Computing in Cardiology / Physionet Challenge 2013*" data. The results of all participating algorithms were compared according to two criteria: a) accuracy of FHR estimation and b) accuracy of fetal RR interval measurements [8]. Our ESN-based algorithm [6] was in Top-10 according to both criteria of the Challenge, among about 50 contestants, and received an unofficial 3rd place in the open source division.

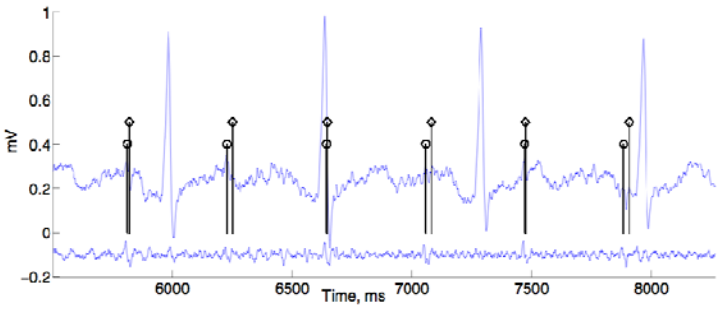

Fig. 2. An excerpt of recorded abdominal ECG (upper trace) with annotations. Stems with diamonds are fetal cardiocycles detected by multi stage PCA, stems with circles are by ESN-based algorithm. Lower trace: the principal component representing fetal ECG.

Multimodal signals of mother and fetus using our prototype system were registered in the Obstetrics and Gynecology Clinics of University Hospital of Lithuanian University of Health Sciences. An excerpt of abdominal ECG with time marks of detected fetal cardiocycles is presented in Fig. 2. Third principal component – the result of multi stage PCA containing extracted fetal cardiocycles is presented below the registered ECG.

Discussion. The study presents the concept of the system which could provide new insights into the solution of problems related to adverse intrauterine circumstances. Multimodal signal registration and analysis is giving promising results in numerous cases of evaluation of health status of the patient. We showed how we could have non-invasively registered signals representing health status of the fetus and the mother. Selection of the optimal set of parameters for diagnostic purposes remains a future work. Simultaneously recorded multimodal signals of mother and fetus also enables new research on their interaction.

We started development of the signal processing algorithms from the most important task in the system – detection of fetal heartbeats. Exact time instance of every heartbeat gives us the possibility to evaluate fetal beat-to-beat variability, diagnostic importance of which was already shown two decades ago. By elaborating algorithms we test various methods for fetal ECG extraction and analysis. The final method will be a combination of best tested algorithms. Development of a system with an optimal lead placement and registering hardware is also a work in progress.

Acknowledgement. This work was supported by the European Social Fund (Agreement No VP1-3.1- ŠMM-10-V-02-004).

References

1. D. K. Stevenson, W. E. Benitz, and P. Sunshine. Fetal and Neonatal Brain Injury: Mechanisms, Management and the Risks of Practice, Cambridge University Press 2003 ISBN 0 521 80691 7.
2. K. So, Y. Chung, H. Lee,E. Kim, and Y. Jeon. The effect of chronic prenatal hypoxia on the development of mature neurons in the cerebellum. J Neurodev Disord. 2013 Jul 3;5(1):17.
3. K. Leslie and S. Arulkumaran. Intrapartum fetal surveillance. Obstetrics, Gynaecology & Reproductive Medicine, 21:3, March 2011, Pages 59–67
4. M. Valverde, A. M. Puertas, M. F. Lopez-Gallego, M. P. Carrillo, M. T. Aguilar, and F. Montoya. Effectiveness of pulse oximetry versus fetal electrocardiography for the intrapartum evaluation of nonreassuring fetal heart rate. Journal of Obstetrics & Gynecology and Reproductive Biology 159 (2011) 333–337.
5. J. C. P. Kingdom and P. Kaufmann, "Oxygen and placental villous development: origins of fetal hypoxia," Placenta, vol. 18, no. 8, pp. 613–621, 1997.
6. M. Lukoševičius and V. Marozas. Noninvasive Fetal QRS Detection using Echo State Network, Proceedings of Computing in Cardiology, 2013
7. R. Petrolis and A. Krisciukaitis. Multi Stage Principal Component Analysis Based Method for Detection of Fetal Heart Beats in Abdominal ECG, Proceedings of Computing in Cardiology, 2013
8. Noninvasive Fetal ECG: the PhysioNet/Computing in Cardiology Challenge 2013: http://physionet.org/challenge/2013/.
9. Herbert Jaeger. Echo state network. Scholarpedia, 2(9):2330, 2007.

Wearable system concept for monitoring of maternal and fetal heart activity

A. Kriščiukaitis[1,2] , M. Lukoševičius[1], R. Petrolis[2], V. Marozas[1], S. Daukantas[1], V. Gintautas[2], A. Lukoševičius[1]
[1]*Kaunas University of Technology, Lithuania,*
[2]*Lithuanian University of Health Sciences, Lithuania*

We present here a design of a prototype system for fetal status monitoring based on analysis of simultaneously registered signals reflecting fetal and maternal physiological parameters. Our fetal cardiocycle detection algorithms showed promising results when tested on annotated PhysioNet database signals and pilot recordings using prototype devices.