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Janusz WRÓBEL*, Janusz JEŻEWSKI*, Adam MATONIA*,
Tomasz KUPKA*, Adam GACEK*, Dawid ROJ*

TELEMEDICAL SYSTEM FOR HOME FETAL MONITORING WITH ONLINE ANALYSIS OF BIOELECTRICALABDOMINAL SIGNALS

This paper presents some aspects of the on-line remote fetal monitoring system based on the GPRS data transmission service and WAN network. The remote signal recording instrumentation consists of bioelectrical signal recorder and tablet PC computer. The central surveillance system located in hospital has a capability of simultaneous monitoring of up to 24 patients, both remotely and within hospital. The system enables analysis, dynamic presentation and archiving of signals and medical data. The clinical interpretation is immediately available in hospital as well as at patient's home or attending doctor office.

1. INTRODUCTION

Cardiotocography (CTG) is commonly used method of fetal monitoring, it enables evaluation of the fetal wellbeing during pregnancy and in labour. The method relies on the analysis of characteristic fetal heart rate (FHR) patterns in relation to the uterine contractions (UC) and fetal movements. The normal heart activity indicates the adequacy of fetal oxygenation and correct functioning of central nervous system. Usually the FHR signal acquisition is based on the Doppler ultrasound technique of monitoring the mechanical activity of the fetal heart. Determination of instantaneous FHR relies on the detection of heart beats based on the analysis of ultrasound beam reflected from the moving valves or walls. The main advantage of the Doppler ultrasound technique is its simplicity of application and non-invasiveness, although the accuracy is too low for the automated signal analysis comprising evaluation of FHR variability at a level of single heart beats. The mechanical method as the indirect measuring technique records the effects of electric excitation i.e. fetal heart movement. Considerably higher accuracy and reliability can be obtained by recording the primary bioelectric signal: fetal electrocardiogram – FECG. Consecutive cardiac cycles can be determined more accurate from the detection of QRS complexes in fetal electrocardiogram than from the analysis of reflected ultrasound beam of a complex shape. Authors developed a mobile instrumentation for acquisition and analysis of the fetal electrocardiogram and uterine contraction activity (EHG) on a basis of bioelectrical signals recorded from maternal abdominal wall. This instrumentation is a source of the FHR and UC signals in the telemedical system being under development. Additionally, the recorder performs analysis of morphological changes in the averaged fetal P-QRS-T complex, whose results can be sent to medical centre.

In medical centres, a need for simultaneous monitoring of many patients leads to widely use of centralized fetal monitoring systems [7]. Recorded signals from all fetal monitors along with results of analysis, are simultaneously presented on the monitoring station in a form of graphical and numerical data. Database contains the archive of traces, analysis results and medical history of patients. The limitation of currently used systems is a lack of possibility to monitor the patient outside the hospital. So far continuous medical care requires a hospitalization of pregnant woman even if there is no a direct risk for patient's health. It results in high cost of longer hospital stay and discomfort for a patient. The optimal solution seems to be a remote fetal monitoring at patient's home.

The use of telemedicine has been increasing worldwide in the last few years. The possibility of remote monitoring without necessity of hospitalization improves the comfort of patients and their unborn children. Patients with high-risk pregnancy as well as with post-term pregnancy are particularly predisposed to cyclic home monitoring sessions for follow-up of the fetal development process [3]. Very carefully preparation of patient's skin is required to obtain the signal of good quality. Additionally, in the first stage of monitoring, when template maternal QRS complexes are created, patient should not move. This a reason that the home monitoring procedure should be carried out by the hospital patient's care staff. The operator with a mobile fetal monitoring instrumentation visits particular patients appointed to be monitored according to a fixed schedule. However, some logistic problems with visit scheduling, especially for large medical centres incorporating numerous patients, should be solved.

2. SYSTEM STRUCTURE

Fetal surveillance system can be defined as a set of fetal monitoring bedside devices, which transmit data to the central computer. Instrumentation dedicated to work in the telemedical system is a developed a bioelectrical recorder for analysis of FECG and UC signals from the maternal abdomen. The recorder is equipped with four differential channels for measurement of abdominal signals. Typical configuration of the abdominal electrodes comprises four electrodes placed around the navel and the reference electrode placed above the pubic symphysis. Additionally on the left leg, the common mode reference electrode

* Institute of Medical Technology and Equipment (ITAM), Zabrze, Poland.

is placed. The necessity of using four abdominal leads results from the fact that very often the FECG signal of good quality is present only in one lead, whereas in the others it is practically not observed. Considering abdominal FECG, the basic merit of the presented recording unit is a very low level of its own noise which does not exceed 1 μV (peak-to-peak) measured with reference to the inputs, and a high value of CMRR coefficient (120 dB). These parameters have been obtained thanks to novel recorder electronic circuits structure including complete separation of analog part from the digital part. Each channel is equipped with an amplifier with gain control that allows the amplification of recorded signals from the tens of microvolts up to the level of several volts. The band-pass filter in each channel removes low frequency components and thus prevents the reaching of saturation state by amplifiers in case of strong isoline drift.

The software of the bioelectrical recorder has been developed using the LabView (National Instruments) graphical environment for building signal processing applications. The program enables the appropriate control of recording of bioelectric signals and their analysis (Fig.1). Suppression of the dominating component in the abdominal signal – maternal electrocardiogram (MECG) – is the first, and at the same time, the decisive step in abdominal fetal electrocardiography [1, 6]. The proposed method of MECG suppression is a result our previous research work [8, 9]. It is based on precise subtraction of averaged maternal QRS complex. Reference QRS complexes of maternal electrocardiogram are created from each abdominal signal, and then their scaling and subtraction within the fragments of presence of successive maternal heart beats are performed. The phenomenon of inaccurate pattern synchronization can be eliminated by subtraction of derivative of maternal QRS complex pattern. This leads to full suppression of MECG and does not influence the FECG component. The detection and the exact location of the consecutive QRS complexes in FECG have the main influence on determination of the FHR signal [10]. The decision-making algorithm is used, whose task is to detect the peaks of the detection function which are responses to the occurrences of the QRS complexes.

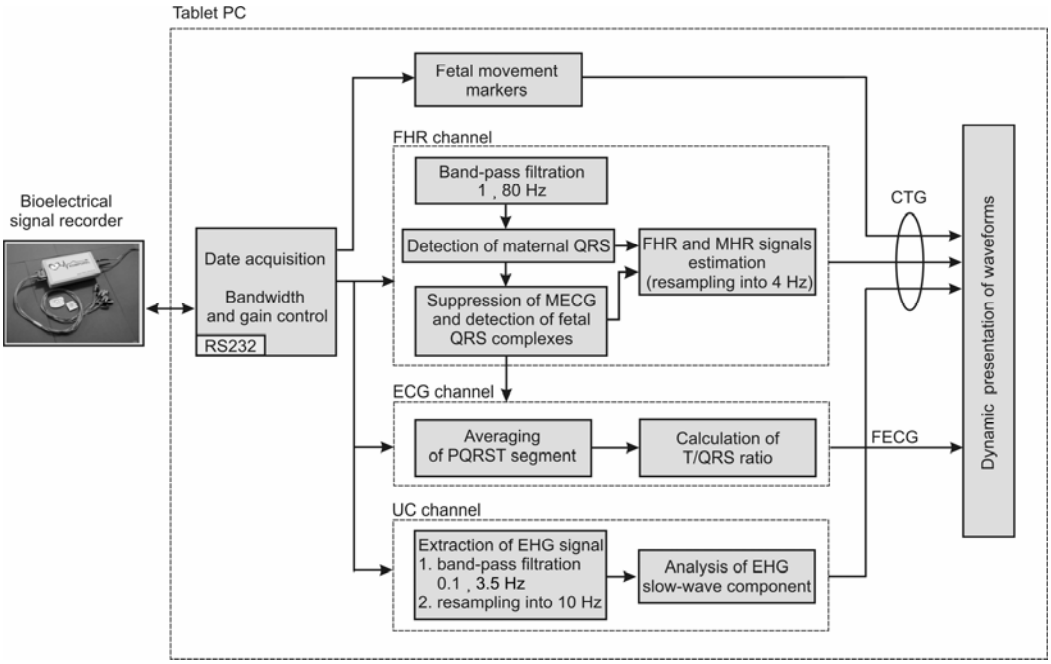

Fig.1 Structure of the remote instrumentation for the acquisition and analysis of the fetal ECG and EHG signals.

When the locations of the consecutive occurrences of the QRS complexes are known, it is possible to determine the duration of individual cardiac intervals and to calculate the corresponding instantaneous values of the FHR signal. Considering analysis of FECG morphology the P-QRS-T complexes have been averaged over 50 consecutive cycles. Then the time parameters and T/QRS ratio relating to amplitudes of averaged complexes are calculated. The CTG and FECG data are transmitted to the central computer using uniform communication protocol.

Electrical uterine activity component is separated from the abdominal signal in selected lead, by means of band-pass (0.1 to 3.5 Hz) filtration. The method of extraction of slow wave from electrohysterogram (EHG) signal and for detection of uterine contractions has been described elsewhere [4]. The EHG slow wave is obtained as a result of computation of consecutive root-mean-square values in Hanning windows of 60 s width shifted with the step of 3 s. The telemedical system can cooperate with classical monitoring instrumentation, that enables optimal using of a hospital equipment (Fig.2). Dedicated interface unit can handle both different communication links and different communication protocols. Signals from several monitors are provided through the data collection unit.

The central monitoring system can be equipped with a few displays, each of them allowing for visualization of eight traces. It results in capability of simultaneous monitoring of up to 24 patients. The main system tasks are: the analysis of incoming data, dynamic presentation of traces along with analysis results as well as storing and printing the data. The quantitative parameters describing acquired signals are used to detect alerting situations. The form of information displayed by the system should not affect the interpretation of CTG trace. Since in classic cardiotocography signals are visualized as waveforms printed on thermosensitive paper, the display provides the same graphic forms with regard to quality, aspect ratio and waveforms flowing (Fig.3). For records which are provided by bioelectrical records the window can be displayed with last three averaged fetal P-QRS-T complexes and corresponding values of T/QRS coefficient. In addition, any time-amplitude relationships can be measured and stored in the database with appropriate comment.

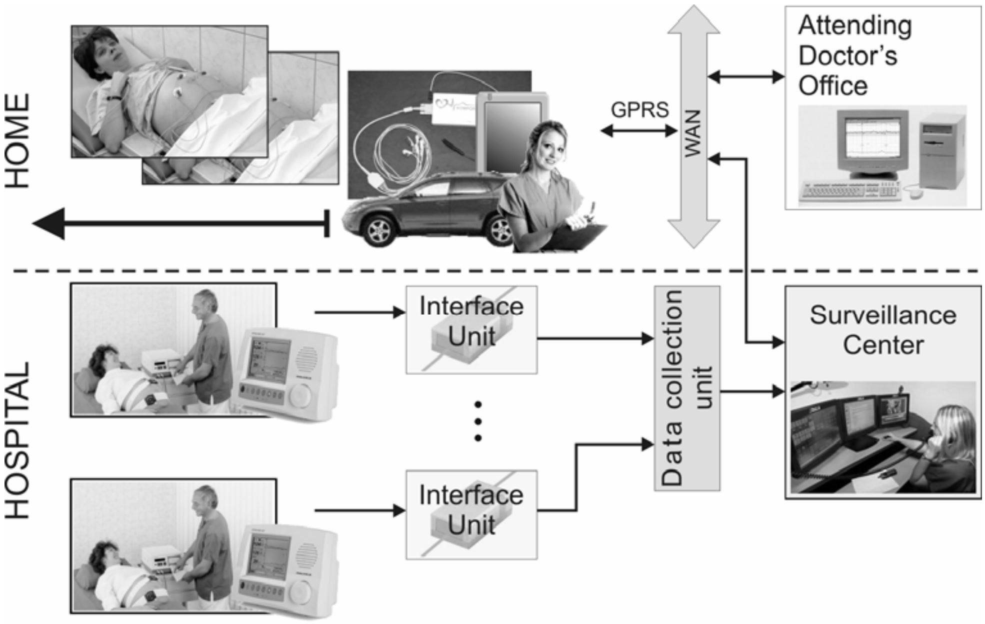

Fig.2 A structure of centralized fetal monitoring system incorporating remote devices as well as classic bedside monitors located in hospital.

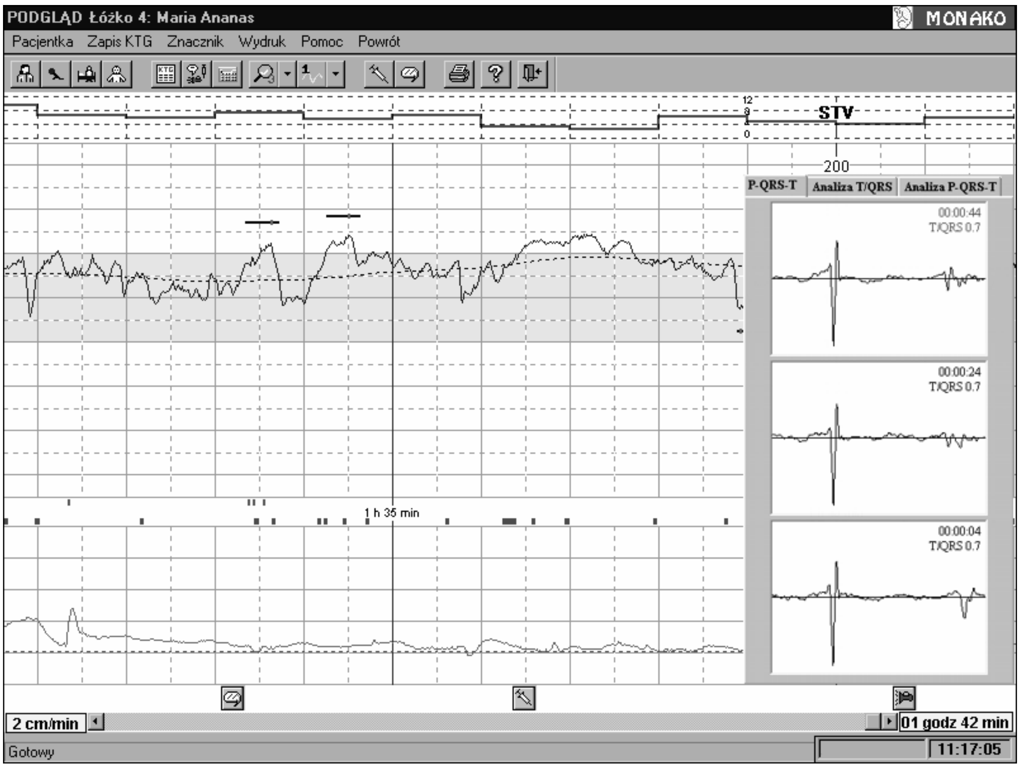

Fig.3 Computer screen of a surveillance centre presenting an enlarged cardiotocographic trace from one of the patients (scale 1 cm/min). The upper signal is the fetal heart rate, the lower one is the uterine activity and markers between them represent detected fetal movements. The horizontal bars directly above the waveforms identify the characteristic trace patterns. On the right side there is a window presenting with last three averaged fetal P-QRS-T complexes and corresponding values of T/QRS coefficient.

2.1. SIGNAL ANALYSIS IN SURVEILLANCE CENTER

The analysis of the fetal heart rate signal comprises a few stages. The first one is estimation of a basal fetal heart rate - the baseline FHR [5]. Changes of the baseline which comprise very slow and usually long-lasting decrease or increase of heart rate, beyond established thresholds are defined as bradycardia and tachycardia. Transient signal deviations from the baseline FHR, of certain amplitude and duration, are indicated as accelerations and decelerations patterns. The system allows to relate accelerations to fetal movements and decelerations to uterine contractions. It also evaluates long-term and short-term FHR variability and calculates a series of quantitative indices. Contractions are defined as an increase of certain amplitude and duration above the so called basal tone. The basal tone represents strain exerted by the uterine muscle when contractions do not occur. Uterine contraction is described by onset time, duration, amplitude and area under the curve.

Cardiotocographic surveillance is based on cyclic monitoring sessions in a form of a non-stress test (NST). The test comprises a minimum of 20 minutes of trace recording with detailed signal together with a final qualitative evaluation. The automatic NST evaluation comprises two blocks: classification and inference. The former relies on attributing a value of a given parameter to a class according to variable discriminant subranges, and then on assigning a logical value to this parameter. The latter leads to transforming the set of logical values into a test result using fixed rules. The results of quantitative analysis of cardiotocographic trace are presented both in numerical and graphical forms. Received data is stored in a system database which includes patient's personal data, monitoring logs, results of analysis, parameters of alerting events as well as all the cardiotocographic signals.

Analysis of changes of T/QRS coefficient is carried out in the system as well. As consecutive values of this coefficient are calculated, the so called baseline is plotted using median values calculated in a window of 20 minutes width. The baseline increase of at least 0.05 is marked as significant. Increase of the T/QRS baseline exceeding 0.10 can relate to prolonged hypoxia. A case when T/QRS values are constant and greater than 0.25 all the time since the monitoring started, and the CTG records shows pathological signs, means that monitoring started during late phase of hypoxia i.e. when fetal resources has been already consumed. It is assume that increase of the T/QRS baseline occur, if its duration is longer than 10 minutes. If the duration is below 10 minutes, but the increase value exceeds 0.10 it is called episodic. Complementary diagnostic information allows for verification of suspicious cardiotocographic traces.

2.2. TELEMONITORING CHANNELS

The aim of this project is to develop the new remote fetal monitoring channel as an internal part of the fetal surveillance system. The remote channel is assumed to work on-line, so the monitoring session will be carried out in the real-time. If a continuous data transmission is assured, the monitoring can run in the same way as if the patient would be in hospital (Fig.2). Wireless communication is based on the GPRS data transmission service used in cellular phones system, and WAN network which is used for data transfer between GSM network and the surveillance centre. The architecture of the described system will be extended by mobile instrumentations for acquisition and wireless transmission of fetal signals. Single Mobile Instrumentation comprises a bioelectrical signal recorder and Tablet Personal Computer or at least the Personal Digital Assistant (PDA) as a computer with built–in GSM module, assuring the wireless connection through the WAN network [2]. The computer software enables acquisition of measured data from fetal recorder, dynamic presentation of the incoming signals and on-line evaluation of their quality. Additionally, all the data acquired from the fetal recorder are converted into the format established in surveillance system. The Surveillance Centre will include TCP/IP interface allowing to communicate with mobile instrumentation via internet (Fig.3). The system software has to be extended to assure continuous, error-free data transmission and to enable communication with the patient.

Optional workstation, connected through the local network, provides an instant access to patients data and acquired signals. Workstation can be used to set up the system, to create paper documentation as well as to process the signals recorded in the off-line mode (e.g. in case of total breaking of the communication link). It is possible to access the information stored in the archive from outside the hospital via internet. This feature allows the obstetrician to view the monitoring records at any time he needs. However, due to the personal data protection, the access is permitted only for attending doctor for a given patient.

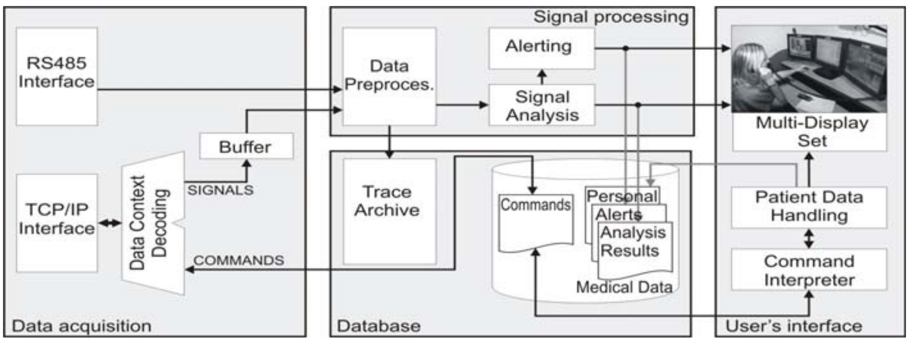

Fig.4 The structure and interactions between different components of the Surveillance Centre from the fetal monitoring system.

3. CONCLUSIONS

We hope that telemedical systems for home fetal monitoring will soon become a standard in large medical centres. The GSM-based devices are commonly available, inexpensive and allow carrying out the monitoring session everywhere within the range of GSM network. However, development of the system requires solving some problems that relate to flexible sharing of control, and ensuring continuous communication between the monitoring station and the mobile instrumentation, as well as creating the optimal set of system commands and confirmations. Due to transmission via internet it is necessary to develop some procedures coping with limitation of connection quality or with its total loss. The proposed system of fetal monitoring will certainly improve patient's comfort and reduce the cost of medical care. Additionally, instant access to database will make the communication between the patient and her attending doctor much easier.

Application of the bioelectrical signals recorder enables information on fetal heart rhythm to be obtained a form of event series (heart beats), that allows for more precise calculation of the FHR instantaneous variability indices, which is carried out in the Surveillance System. Additionally, very important part of information is provided by analysis of the averaged fetal P-QRS-T complex, particularly with evaluation how the T/QRS values changed. This information allows for information allows for verification of suspicious cardiotocographic traces.

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