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SMART SELECTION OF SIGNAL ANALYSIS ALGORITHMS FOR TELECARE OF HIGH-RISK PREGNANCY

Telemedical system for fetal home monitoring with smart selection of signal analysis algorithms is presented in this paper. Fetal monitoring signals are provided by a mobile instrumentation consisting of bioelectrical signal recorder and tablet PC which retrieves and processes the data as well as provides wireless data transmission based on Internet. The fetal surveillance system enables analysis, dynamic presentation and archiving of acquired signals and medical data. Novelty of the proposed approach relies on smart fitting of the algorithms for analysis of the abdominal signals in mobile instrumentation, as well as on controlling of the fetal monitoring session from the surveillance center. These actions are performed automatically through continuous analyzing of the signal quality and the reliability of the quantitative parameters determined for the acquired signals. Using that approach the amount and content of data transmitted through remote channels to the surveillance center can be controlled to ensure the most reliable assessment of the fetal well-being.

1. INTRODUCTION

Fetal monitoring is routinely used to early detect the risk for fetus health and life, and thus it enables selection of a proper time and method of a pregnancy termination. It is based mainly on assessment of the fetal heart activity which is accomplished by recording and analysis of cardiotographic signals. Although the cardiotocography is the basic and commonly used approach to fetal monitoring, there are still unresolved and important problems. They relate to a need for all women in high-risk or post-term pregnancy to be provided with a continuous medical care as well as to increase a low sensitivity and positive predictive value of cardiotocography as regards the assessment of the fetal state. Because of a lack of other options, continuous perinatal care requires a hospitalization of patients even when their health is not at direct risk. It results in higher cost of extended hospitalization and psychological discomfort of the pregnant women. Classical fetal monitoring system facilitates simultaneous monitoring of many patients hospitalized in the maternity ward as well as in the labor and delivery wards [2]. Recorded signals from all fetal monitors, along with results of analysis, are simultaneously presented on the monitoring station. The optimal solution seems to be the fetal

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monitoring at home [7], [17], but with assistance of patient's care personnel from the central surveillance station located in hospital [20].

In this paper we proposed a fetal monitoring system, where the signals are acquired remotely at patients home using portable low cost fetal monitor and wirelessly transmitted to the central computer through the Internet. Authors developed measurement instrumentation for acquisition and analysis of the fetal electrocardiogram and uterine muscle activity on a basis of bioelectrical signals recorded from the maternal abdominal wall [9]. This Mobile Instrumentation (MI) provides the telemedical system being under development with both the fetal heart rate (FHR) and uterine contraction (UC) signals. The signal processing procedures running in Mobile Instrumentation are preliminary adapted to measurement conditions being changed. The proposed strategy is based on the estimated quality of the biosignals recorded from abdominal wall of the pregnant women. Additionally, in the Surveillance Center (SC) a detailed analysis of the FHR signal loss is carried out to control the biosignal interpretation algorithms in the MI. The fetal state is assessed by means of signals interpretation, whose result decides about further diagnostic procedures.

2. METHODOLOGY

Typical centralized computer-aided fetal surveillance systems comprise a set of fetal monitors transmitting the signals to the central computer [1]. The incoming data are analysed on-line and dynamically presented on the screen of a central computer, both in numerical and graphical form. The proposed architecture of the system (Fig.1) was extended by mobile devices for acquisition and wireless transmission of the fetal signals. Since the external channels are assumed to work in on-line mode, the monitoring session will be carried out in real-time [18]. The MI comprises a low cost bioelectrical signal recorder and a tablet PC for acquiring signals, control of the monitoring process and wireless communication through the Internet.

The monitoring station in the SC has two displays for presentation of signals from bedside monitors within the hospital, and data acquired from MIs. An exemplary application allows for simultaneous presentation of traces from up to 24 bedside monitors and 8 MIs. Communication channel is fixed for particular hospital monitors, whereas for the MI it is dynamically assigned during the logging in to the system. Such approach does not limit a number of mobile monitors used in the system, but only a number of simultaneously performed monitoring sessions. User interface for the information displayed by the system should provide the same graphic forms as the classic cardiotocography with regard to quality, aspect ratio and waveforms flowing. Centralized surveillance system includes the patients database, which collects all the signals, together with results of analysis, annotations about alerting situations, personal data for the patient identification as well as the contact data, like home address, phone number and chat logging, especially important in the telemonitoring system. Optional workstation, connected through the local network, provides an instant access to the archive of patients data and acquired signals. It is also possible to access the information stored in the archive from outside the hospital via Internet, which allows the primary obstetrician to view the monitoring records at any time he needs [11].

Signal analysis in MI: Signals recorded from the maternal abdomen contain the maternal (MECG) and the fetal (FECG) electrocardiograms, electrohysterogram (EHG) as well as many unwanted muscle and low frequency components. Suppression of the dominating component in the abdominal signal the maternal electrocardiogram is the most important step in the abdominal fetal electrocardiography [4], [14]. At first, the spatial filtering based on the generalized singular value decomposition (GSVD) is applied to extract pure dominating maternal electrocardiogram from abdominal signal [10]. Having it the maternal QRS complexes can

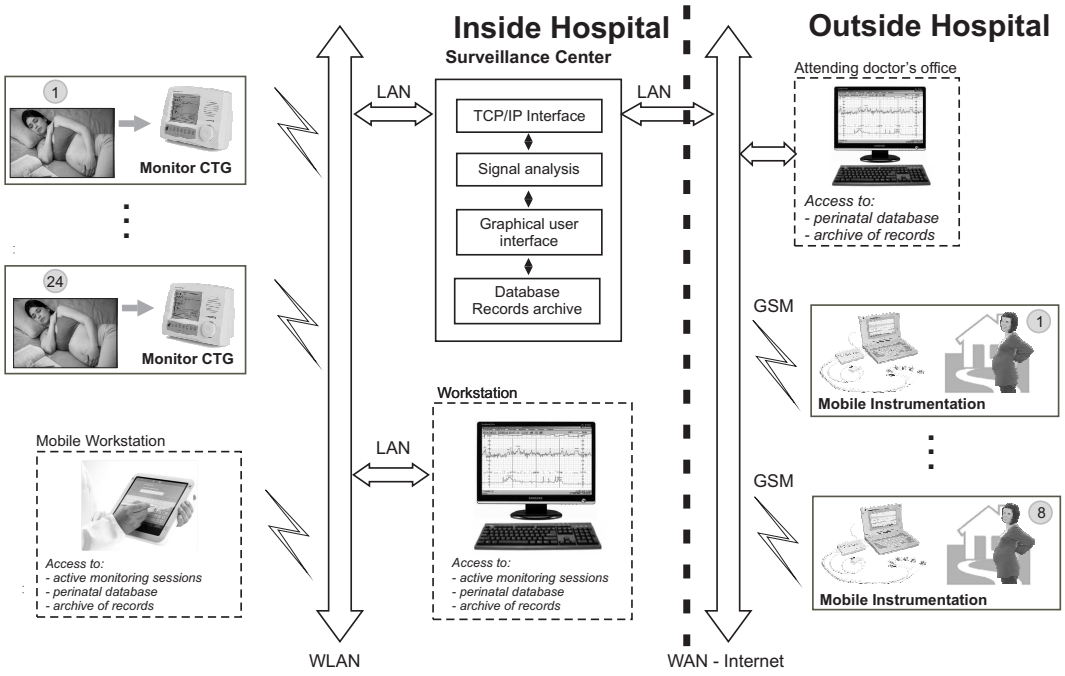

Fig. 1. General idea of the telemedical home fetal monitoring within the centralized obstetrical surveillance system.

be detected very precisely. They are used to determine the maternal heart rate and then to suppress the MECG in the abdominal signals which makes possible further detection of the fetal QRS complexes. The basic approach to MECG suppression is blanking, where an appropriate segment of the abdominal signal comprising the maternal complex is simply replaced by isoline values. Unfortunately, in case of coincidence of maternal and fetal complexes the latter one is rejected causing partial FHR signal loss [15]. Nevertheless, this disadvantage does not affect clinicians interpretation since for classical visual analysis the FHR signal is averaged over periods 2.5s long. Additionally, low computational complexity of the blanking approach leads to significant reduction of power consumption in Tablet PC or PDA computers.

Blanking is applied in each abdominal signal acquisition channel. Simultaneously the quality of final FECG signal is controlled [12]. The signal quality index (SQI) takes values from 0 to 3, where 0 means very poor signal, whereas 3 very good quality. If the SQI reaches the value of three in particular channel then the fetal QRS complexes detection and consecutively calculation of the TRR intervals are carried out for the signal from this channel. The detection function relies on matching filtering and application of a set of decision rules [13]. Only these FHR values which fulfill physiological criteria are finally accepted as correct ones. If the SQI is 2 (a good signal quality) in the best channel, then additional noise suppression based on projective filtering [12] is applied before the QRS detection starts. If none of the channels provides satisfying quality of the signal (SQI is 2 or 3), this means that the one-channel detection with blanking does not ensure good results and causes a significant FHR loss. In that case more precise and advanced MECG suppression method has to be used, i.e. the method based on subtraction of the reference maternal P-QRS-T complex [10], [14] which is continuously rescaled and modified. Suppression takes place in every abdominal channel, and thus the fetal QRS detection is multichannel. In this approach the additional noise removal procedure is applied to improve the FECG quality before detection process starts. Any channel with SQI equal to 0 is excluded from the fetal QRS detection (Fig.2).

SC decides about a way of analysis of the recorded signals to evaluate the fetal state. If the result of the interpretation of monitoring record is unclear the additional analysis of morphology of the fetal P-QRS-T complex is performed [8]. Then, the advanced suppression algorithm

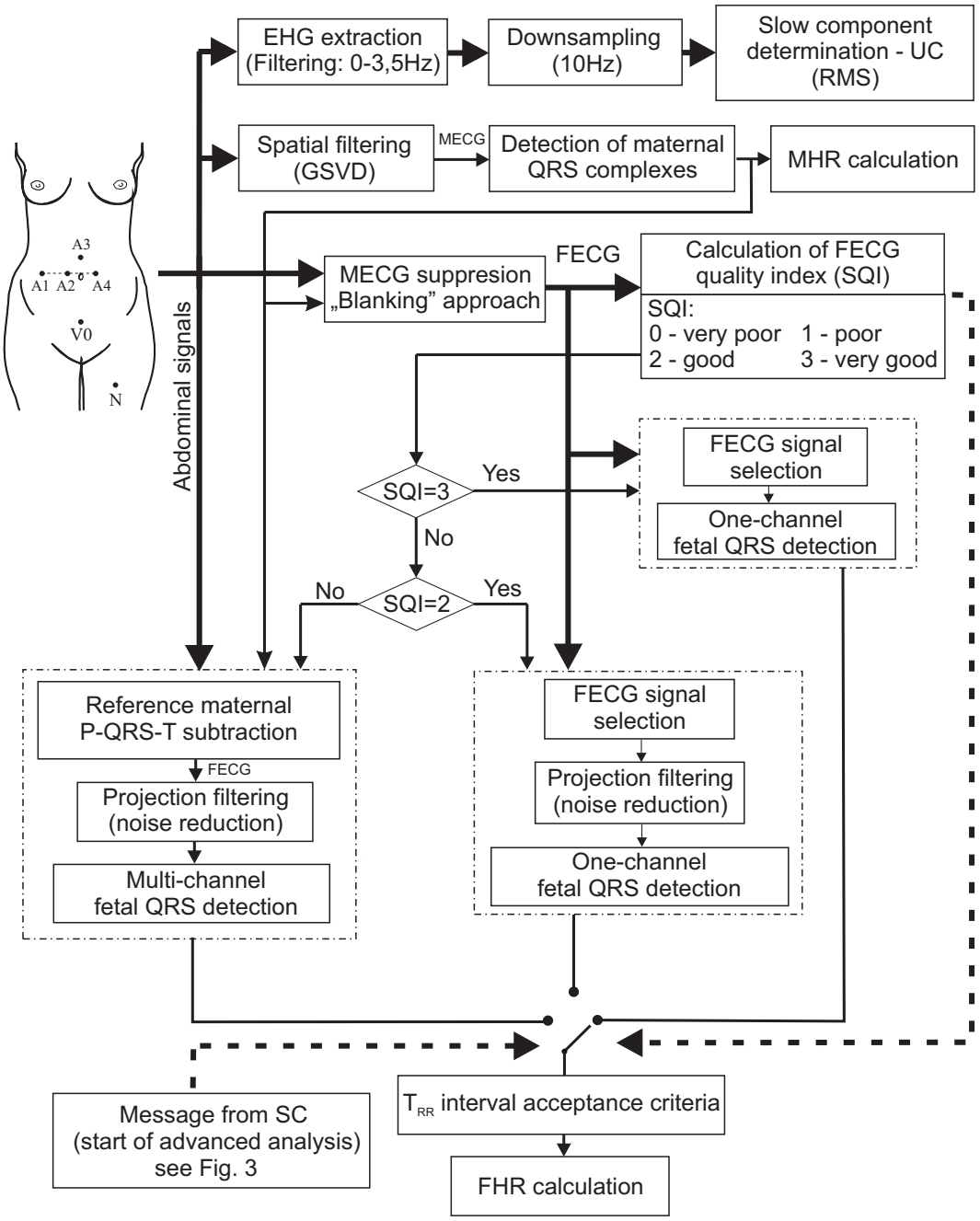

Fig. 2. Smart selection of biosignal analysis algorithms in the Mobile Instrumentation controlled directly by MI using the FECG quality index SQI.

basing on subtraction of the reference maternal P-QRS-T complex is involved automatically. The fetal P-QRS-T complexes obtained in such way undergo the weighted averaging and the relation of the amplitude of the T wave to the amplitude of QRS complex is calculated (the T/QRS ratio) [5]. Averaged complexes together with relating T/QRS values are sent to the SC, where their further analysis is carried out.

The contractile activity signal is determined basing on electrical uterine muscle activity. For this task, the abdominal signals are fed to low-pass filter with cut-off frequency of 3.5 Hz, which corresponds to electrohysterogram frequency band. The signals are then resampled from 500 Hz to 10 Hz, and the resulting signal of the contractile activity is obtained by composition of the signals from four leads. After that the RMS values are calculated in one-minute windows

shifted with 3 seconds to obtain the consecutive values of the UC signal [9].

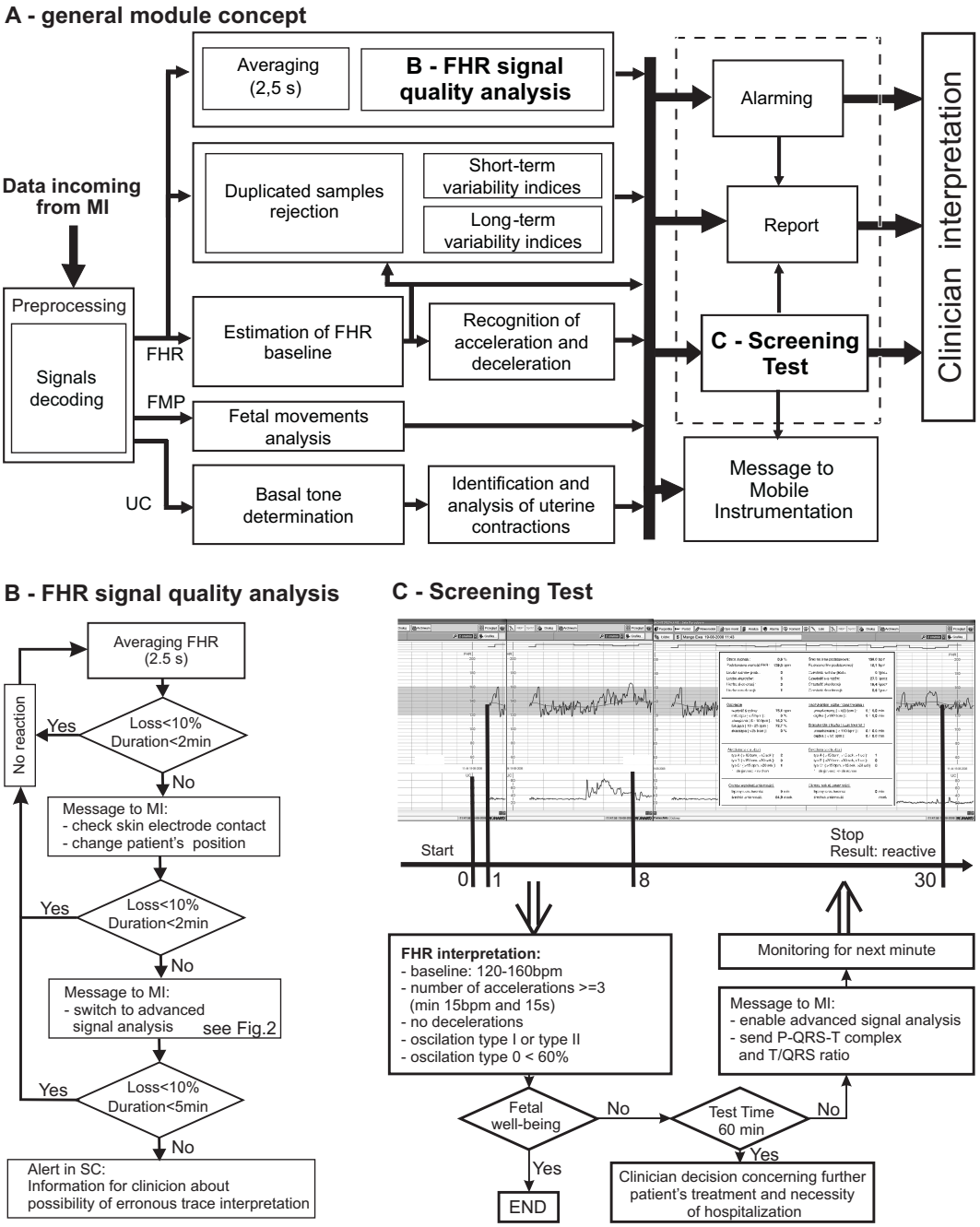

Fig. 3. Basic components of the Surveillance Center module responsible for analysis of signals obtained from MIs: A general module concept, B smart selection of the analysis algorithms for MI using the FHR signal quality data, C Screening test for fetal well-being during pregnancy.

Signal analysis in SC: The analysis of the data received from fetal monitors is consistent with guidelines of the FIGO Subcommittee on Standards in Perinatal Medicine [19]. The signal analysis is accomplished in a number of stages (Fig.3). In the first stage the FHR signal is verified basing on identification and extraction of artifacts. Then the analysis of signal loss and averaging over 2.5s periods with interpolation of the lost values are carried out. It is crucial for estimation of the FHR baseline a basis for recognition of the acceleration and deceleration patterns as well as tachycardia and bradycardia episodes. In addition, a set of indices is determined to estimate the instantaneous FHR variability [2]. These indices are

calculated for each one-minute segment basing on the heart beat events obtained from the FECG. Analysis of the uterine contraction activity is aimed at recognition of the contraction patterns in relation to the so called basal tone, and then calculation of quantitative parameters describing contractions. These data are very important for recognition and classification of the FHR deceleration patterns, whereas information on fetal movement activity is crucial for acceleration patterns.

The FHR signal loss evaluated in the SC is key element for smart selection of algorithms for analysis of the signals recorded in MI (Fig.3B). But, preliminary decision is made automatically in MI on a basis of the FECG quality index. Depending on SQI value, less or more advanced algorithm is selected to analyze the bioelectrical signals recorded from maternal abdomen. In the SC the level of the FHR signal loss is continuously measured and evaluated. When the FHR loss exceeds 10% for at least two minutes, the message is sent to MI to inform the operator to check the contact between electrodes and patient skin, current position of the patient (lying on a left side is recommended during monitoring session) as well as other measurement conditions. If the FHR loss signal remains above 10% for the next five minutes the message is sent automatically to MI in order to start more advanced analysis of the recorded biosignals. If despite this action the FHR loss level is still not lower than 10% for the next five minutes, then an alerting message is displayed in SC. Alert should be taken into account by clinician during assessment of the recorded signals since significant FHR signal loss may strongly affect the final interpretation. As long as the FHR loss is below 10% the selection of signal processing algorithms is controlled in MI by continuous measuring the FECG quality index.

Apart from procedures of smart selection of algorithms for signal processing, a smart control of the monitoring session has been implemented in SC (Fig.3C), according to the monitoring trace interpretation. It is based on a set of decision rules applied to parameters of quantitative signal analysis used for qualitative assessment of the fetal state [6]. Usually, it is carried out for at least 30 minutes of recording. If fetal well-being criteria has been confirmed the monitoring is finished. In the other case, the recording can be prolonged by next 30 minutes, however that decision is made by doctor on call. This is due to the fact that fetal activity can be significantly lower during fetal sleep phase.

The more advanced approach relies on analysis of the averaged fetal P-QRS-T complex and T/QRS ratio that are sent from MI on a request from SC. The aim of this additional information is to help a clinician in decision concerning further patients treatment and necessity of her hospitalization [5].

3. CONCLUSIONS

The distributed system for fetal monitoring proposed in this paper will certainly improve a patients comfort and reduce the cost of medical care, keeping a full functionality of the hospital surveillance system [3], [16]. Additionally, the instant access to the database will make the communication between the patient and her attending doctor much easier. Automated smart adjusting of signal analysis software in Mobile Instrumentation as well as the smart control of the fetal monitoring session enable considerable reduction of amount of data that have to be sent to the Surveillance Center from particular MIs. This task sharing has been established taking into account that SC has to manage many patients simultaneously. In most cases, the simplest algorithms the thirty-minute monitoring session are sufficient. It is important taking into account the limited battery operating time in the MI. The measurement instrumentation based on the bioelectrical signals recorder enables additional information on the fetal state to be obtained. It is based on analysis of the averaged fetal P-QRS-T complex, and particularly on the T/QRS value changes. This information should enable verification of the suspicious

recordings.

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