BIOCYBERNETICS AND BIOMEDICAL ENGINEERING 33 (2013) 211–221

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/bbe

Original Research Article

Improving fetal heart rate signal interpretation by application of myriad filtering

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ARTICLE INFO

Article history:
Received 31 January 2013
Accepted 3 June 2013
Available online 10 September 2013

Keywords:
Electronic fetal monitoring
Fetal heart rate analysis
Baseline estimation
Signal processing

ABSTRACT

Analysis of the fetal heart rate (FHR) signal is aimed at detection of clinically important patterns like bradycardia or tachycardia, accelerations and decelerations, as well as quantification of instantaneous FHR variability. Automated pattern recognition methods are based on estimation of so-called FHR baseline. It is a common opinion that the baseline estimation algorithm determines the efficiency of an entire process of quantitative signal analysis. Automated methods for baseline determination have been continuously improved for many years since there are still new classes of FHR signals being identified, for which the previous methods fail. The new method proposed for the baseline estimation is based on the weighted myriad filtering. The application of this method required filter parameter selection ensuring its operation according to clinical guidelines for baseline estimation. A very important feature of the myriad filtering is that there is no need for preliminary interpolation of signal loss segments. Our new algorithm was tested against two other methods. Thirty one-hour FHR recordings were selected for the analysis. Quantitative inconsistency was measured using differences between corresponding baseline samples. Additionally, the baselines were evaluated as regards their influence on identification of the acceleration and deceleration patterns. Obtained results allow us to conclude that the new algorithm delivers more reliable baselines particularly for signals with specific changes of the basal FHR level which has been recognized as difficult for baseline estimation.

1. Introduction

Biophysical monitoring is a basis for a fetal state assessment that has been used since the sixties. Commonly used cardiotocography is a monitoring method which relies mainly on recording and analysis of the fetal heart activity signal. A noticeable breakthrough in cardiotocography was the introduction of computer-aided fetal monitoring systems in the middle 80s. Automated analysis has aided visual interpretation, ensuring higher objectivity and repeatability of the evaluation of the recorded fetal heart rate (FHR) signals.

Analysis of the FHR signal is aimed at detection of clinically important patterns like bradycardia or tachycardia,

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0208-5216/$ – see front matter
http://dx.doi.org/10.1016/j.bbe.2013.09.004

accelerations and decelerations, as well as quantification of instantaneous FHR variability. Automated pattern recognition methods are based on estimation of so-called FHR baseline. Therefore, even subtle errors in the baseline estimation may significantly distort detection of other signal patterns, and thus may lead to a false assessment of the fetal condition.

Linguistic description providing guidelines to help clinicians in visual estimation of the FHR baseline is very difficult to transform into numerical algorithms. This is caused by the fact that the baseline is an imaginary pattern only, whose shape comes directly from its definition. The baseline definitions that has been included in the FIGO guidelines [41] says: ''Baseline is the mean level of the FHR when this is stable, accelerations and decelerations being absent. It is determined over a time period of 5 or 10 min and expressed in beats per minute – bpm''. According to this definition, the baseline should be insensitive to FHR changes caused by external excitations: the accelerations (a temporary increase of the fetal heart rate) demonstrating a reaction of fetus to its own movement and decelerations (temporary decrease) being a response to temporary hypoxia [11]. So, during the acceleration and deceleration episodes the baseline represents an imaginary line along which the fetal heart rate values would be placed if those patterns (accelerations and decelerations) did not occur [23]. Outside these episodes, the baseline is a kind of mean FHR value. However, the guidelines do not give any details about a way of values averaging outside the segments that might turn into acceleration or deceleration patterns. They also do not define how to recognize and reject these patterns during averaging, but refer only to the baseline being in fact the final effect. In other words, the definition of baseline is circular, so that one cannot define accelerations and decelerations without defining the baseline first.

Guidelines published later [40] did not include anything new for the baseline definition. The other recommendations provided only slight modifications concerning additional criteria for rejection of the signal segments during the averaging process [33]. According to [5], for the last 25 years the guidelines have not become more simple or more objective, which could guarantee their wide application. To cope with circularity of the baseline definition, authors of [8] proposed to use additional information obtained from uterine contraction or fetal movement activity signals for removal particular signal segments from baseline calculation. However, significant subjectivity and high dependency on a signal recordings quality (using popular bedside monitors) are limiting this approach. Complex baseline definition as well as the diversity of FHR signal characteristics cause problems for correct algorithmization of the signal assessment process applied in the computerized fetal monitoring system [7,14,27].

The disagreement reported between clinical experts and automated algorithms for the baselines estimation [10,15] is not surprising as even the experts differ each other regarding their interpretations [3,21]. It was noted that for some signal segments the baseline cannot be assigned reliably by eye or numerically. Identification of such segments can improve the automated baseline estimation, as well as provides an additional clinical information useful for the fetal state assessment [16].

Many various algorithms have been developed and most of them are based on filtering approach. The nonlinear low-pass filtering is usually applied, where the most crucial step is an exclusion of segments being accelerations or decelerations. That reflects the idea of the clinical guidelines for the baseline estimation [5]. This process can be driven by amplitude thresholds determined in relation to current signal level [1], or to the selected signal segments [4,12,34]. Another approach is based on thresholds connected with the instantaneous speed of FHR signal changes [28]. Besides the classical filtering the application of neural network has been proposed by [35], where the inputs are fed with class quantities of frequency distribution of the FHR values for the twenty-minute signal. In the statistical approach described by [36], the true baseline value is obtained from the FHR values kept within established limits in reference to an imaginary baseline representing a mean value in a thirty-minute signal. However, those two methods provide the constant baseline value for the analyzed signal, that enables only its clinical classification according to [40] as abnormal, non-reassuring or reassuring. While the filtering methods follow the baseline variation point by point, which is required for correct detection of the acceleration and deceleration patterns.

Automated methods for baseline estimation have been continuously improved for many years since a new classes of FHR signals are still identified, for which the previous methods fail [13,28]. Analyzing various baseline estimation algorithms, it is rather obvious that the classical low-pass filtering methods are not able to correctly estimate the baseline for some signal classes [6]. Most often such difficult signals are expected to comprise the following features: unstable baseline level in the beginning of recording, an abrupt signal change or variations exceeding 20 bpm, too short signal (less than 10 min) to be analyzed, and the episodes of large accelerations or decelerations occurring one after another in a short distance.

The authors revealed that accelerations and decelerations can be considered as some kind of impulse noise when they are related to the low frequency signal component being the FHR baseline. As a consequence, an attention was paid to methods that have been successfully applied in other fields of science where immunity to such impulse noise is required. The robust filters are used in many different fields of digital signal processing, particularly in the impulsive noise environment which can appear in radar clutter, ocean acoustic noise, fast Internet access technologies such as digital cable modems and DSL, wireless communication systems in urban and cluttered (in-door) environments, industrial process control, etc. [37]. The robust filters are defined by using a wide class of maximum likelihood type estimators (M-estimators) of location, which are developed in the theory of robust statistics. The representative of a group of robust filters is the myriad filter which demonstrates to be robust countermeasure against negative effect that impulsive noise has over electronic systems [37]. The myriad filters have been successfully used in numerous applications [2,18,19,37]. One of the possible areas of myriad filtering application is biomedical signal analysis, particularly suppressing muscle noise in electrocardiographic signal processing [38].

The optimal selection of the myriad filter parameters during the baseline estimation process should ensure a