Patricio Fuentealba*, Alfredo Illanes, Frank Ortmeier

Analysis of the foetal heart rate in cardiotocographic recordings through a progressive characterization of decelerations

Abstract: The main purpose of this work is to propose a new method for characterization and visualization of FHR deceleration episodes in terms of their depth, length and location. This is performed through the estimation of a progressive baseline computed using a median filter allowing to identify and track the evolution of decelerations in cardiotocographic CTG recordings. The proposed method has been analysed using three representative cases of normal and pathological CTG recordings extracted from the CTU-UHB database freely available on the PhysioNet Website. Results show that both the progressive baseline and the parameterized deceleration episodes can describe different time-variant behaviour, whose characteristics and progression can help the observer to discriminate between normal and pathological FHR signal patterns. This opens perspectives for classification of non-reassuring CTG recordings as a sign of foetal acidemia.

Keywords: Foetal monitoring, cardiotocograph, progressive and time-variant analysis, CTG decelerations, baseline, floating-line.

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1 Introduction

The main information for foetal surveillance during labour and delivery is based on data obtained from simultaneous recording of foetal heart rate (FHR) and uterine contraction (UC) signals, which are obtained through a non-invasive instrument known as Cardiotocograph (CTG). One important aim of foetal monitoring is to enable clinicians to identify potential hypoxic foetuses with risk of deterioration to an acidemia in order to prevent potential foetal adverse outcomes [1], and all this without excessive obstetric intervention. However, CTG interpretation is difficult since it involves the human visualization of highly complex signals that results from a non-evident relationship between the FHR and the UC signals. Moreover, CTG signals involve low signal-to-noise ratio and problems of missing data during the CTG signal acquisition. Therefore, a good interpretation of the CTG depends on the knowledge, skills and experience of healthcare practitioner. It is for this reason that the interpretation of CTG signals has been shown to suffer from wide intra- and inter-observer disagreement [1].

In order to improve CTG interpretation and visualization, several medical guidelines [2], [3], and Expert Systems (ES) [4] have been proposed. However, guidelines still lack consensus in many key aspects and are considered too complex and ES do not show concrete evidences on improving foetal welfare assessment [4]. This is why many works have been proposed for extracting hidden patterns from the FHR signal using signal processing techniques, based mainly on FFT, autoregressive modelling, time-varying analysis and wavelets [5]. However, traditional visual CTG analysis is still the primary method to predict foetal welfare in many delivery units. Baseline, variability, accelerations, and decelerations are the main assessed patterns in CTG recordings, being decelerations considered to be one of the most significant and difficult pattern to interpret in a CTG signal. The main aim of this work is to propose a parametrization based on a characterization of the baseline through a floating-line estimated by a progressive median filter computation. The main objective of that is to offer to the clinical staff additional simplified graphic information by providing them a parametrical option to visualize deceleration and baseline patterns.

Results show that both the floating-line trending and the parameterized deceleration episodes can describe different

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time-variant behaviour, whose characteristics and progression can help the observer to predict the foetal condition.

This paper is organized as follows; in Section 2 the proposed method is explained; it involves the steps of signal pre-processing, floating-line estimation and identification of deceleration episodes. Section 3 presents the results using three representative FHR cases. Finally, Section 4 concludes this work discussing about the results and future research.

2 Method

The main idea behind this method is to identify and parametrize every FHR deceleration episode according to its depth, length and location. For this purpose, it is indispensable to estimate a baseline as a reference level allowing the extraction of deceleration episodes in the FHR signal. According to the FIGO guidelines [1], [3] the FHR baseline is defined as “a mean level of the FHR when this is stable, in the absence of periodic events”. In this context, many works have been proposed for baseline estimation and a performance comparison of these methods has been presented in [6]. However, during a continuous succession of acceleration / deceleration events, the baseline is represented by an imaginary line describing the trending of the FHR values that would exist if those events did not occur. In this perspective, this work proposes a time variant baseline estimation based on the progressivity of the low-frequency FHR signal dynamics. In the sequel, this progressive baseline will be called as *floating-line*.

In this section, the proposed methodology is explained. First, the FHR signal is pre-processed in order to reduce the signal artefacts and extract the frequency bands of interest. Then, the floating-line is estimated to finally identify and characterise the deceleration episodes.

2.1 Foetal heart rate signal pre-processing

The first step consists on the interpolation and filtering of the FHR signal. CTG recordings usually involve several types of artefacts. The loss of sensor’s contact is one of the main source of artefacts and can temporarily interrupt the FHR signal as can be observed in **Figure 1**(a). Therefore, the main objective of this step is to obtain a reconstructed continuous signal, whose operation is performed using the artefact rejection method proposed in [7]. Firstly, the segments of the FHR signal that are considered abnormal in amplitude (less than *50 bpm* and more than *200 bpm*) are removed. And then those that are considered reliable data are interpolated using a Hermite spline interpolation.

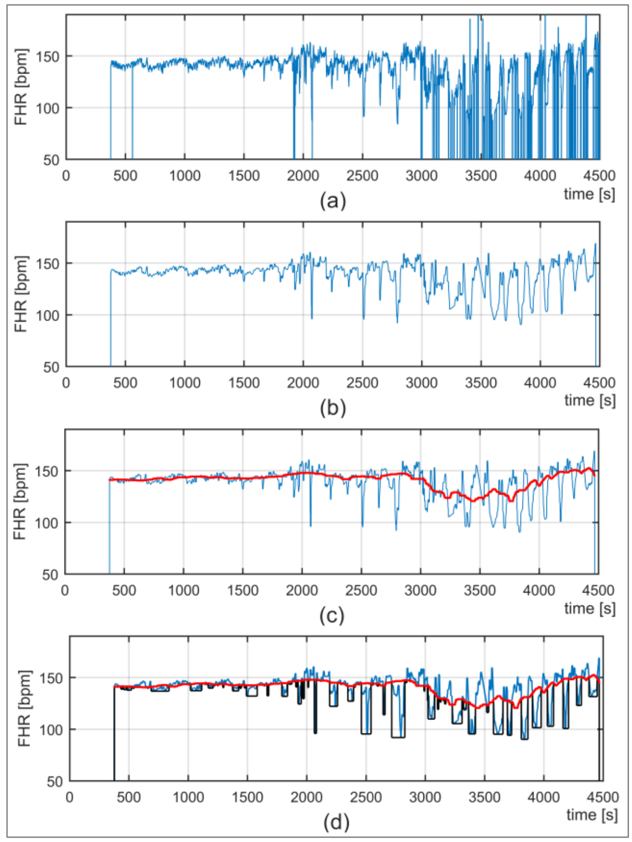

Figure 1: (a) FHR recording 1185m; (b) Filtered signal from (a); (c) Floating-line (red); (d) Acceleration /deceleration detection.

The proposed analysis involves the characterization of deceleration episodes. As described in the literature [8] such episodes present non-linear characteristics and lie in the frequency range between *0* and *0.05 Hz*, which corresponds to the very low frequency (VLF) band. According to this, for the filtering step it is adopted a non-linear median filter for baseline wander extraction [9]. The median statistical values are calculated over a sliding window of *10 s* length. The main advantage of this type of filters is that it not only acts attenuating higher frequency bands but also tracks the non-linear characteristics of the signal. As a result, deceleration episodes in the filtered FHR signal keep their morphologic characteristics as can be observed in **Figure 1**(b).

2.2 Floating-line estimation

For the floating-line estimation, the same non-linear median filter for baseline wander extraction described in Section 2.1 is used. For this new filtering step, the sliding window length parameter is adjusted empirically in *400 s* by testing different cut-off frequencies lower than the VLF band. The idea is to find a trending line describing the FHR signal evolution under the concept of a progressive floating-line defined at the beginning of Section 2. In **Figure 1**(c) the estimated floating-line (red colour) and the filtered FHR signal (blue colour) are shown. In this figure, it can be observed how the floating-line tracks the non-linear progression of the FHR giving a representation of a time-variant baseline.

2.3 Identification of FHR deceleration episodes

The identification of deceleration episodes involves the use of both the filtered signal and the floating-line which are described in Section 2.1 and 2.2, respectively. The floating-line is used as a threshold over the filtered signal which allows the extraction of deceleration episodes. The episodes showing values under the floating-line are considered as decelerations. The FHR deceleration episodes identification is shown in **Figure 1**(d), where every episode is plotted in black colour.

3 Results

The proposed method has been analysed in FHR signals extracted from the CTU-UHB Intrapartum Cardiotocography Database freely available on the PhysioNet Website [10].

In order to show the advantages of this method, the results will be presented through three representative cases, which were selected from the database by their pH value. This foetal outcome value is generally used as a gold standard for foetus acidemia assessment. The first two cases (**Figure 2** and **Figure 3**) correspond to signals that are considered to describe a high foetal distress (*pH≤7.05*) and the third case (**Figure 4**) corresponds to a normal foetus (*pH≥7.25*).

As explained in Section 1, the FHR decelerations are considered to be one of the most difficult patterns to interpret by the clinical staff. For that, the results analysis is focused mainly on decelerations episodes along with the estimated baseline. The main idea is to relate the deceleration patterns with cases of high foetal distress and normal foetuses.

As it can be observed in **Figure 2**, **Figure 3** and **Figure 4**, a simplified characterization of deceleration episodes is proposed. The FHR and UC signals are plotted in blue colour in the first and second graph, respectively. Superimposed to the FHR signal the progressive floating-line is plotted (red line). On the horizontal axis of the FHR signal graph, the red bars represent a parametrization of every deceleration episode in the FHR signal over time, thereby offering to the clinicians clear and accurate information about its depth, length and temporal position.

According to the FIGO guidelines [1], [3], deviations of FHR below the baseline level, of more than *15 bpm* and lasting *15* seconds are considered as decelerations. In addition, making use of the UC signal, these episodes can be classified as early, variable, late and prolonged decelerations.

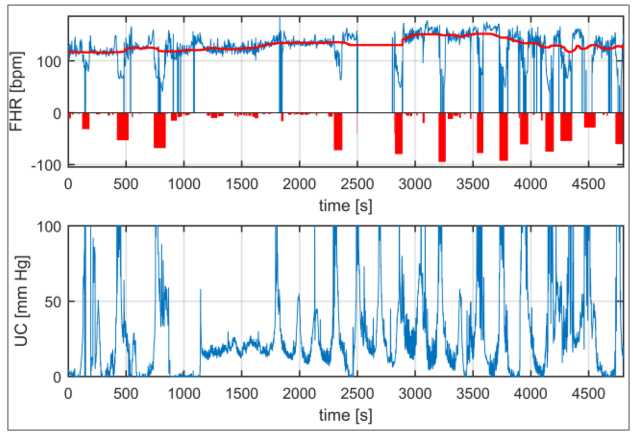

Figure 2: CTG recording 1418m; pH = 6.98; pathological.

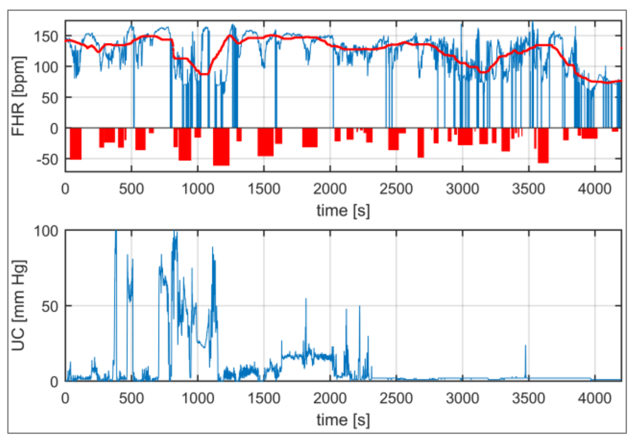

Figure 3: CTG recording 1359m; pH = 6.95; pathological.

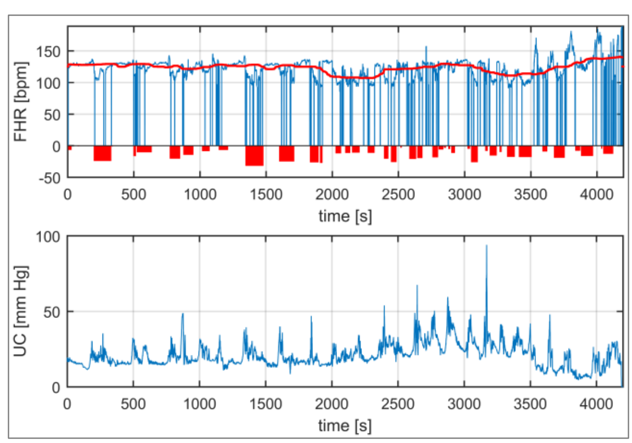

Figure 4: CTG recording 1008m; pH = 7.36; normal.

Results show that different types of behaviour can be observed in both deceleration episodes and floating-line, whose characteristics can be easily visually identified. For example, in **Figure 2** on the last *1500* seconds of the CTG recording it can be distinguish a repetitive set of UC events. These stimuli produce consecutive deceleration episodes involving a significant depth and duration. According to the guidelines, those characteristics can be associated with a pathological foetus which coincides with this case since this FHR signal is labelled by a *pH=6.98*. As another example (**Figure 3)**, besides the significant deceleration episodes, the floating-line segments located roughly at *1000*, *3150* and *4000* seconds involve levels considered pathological (values of FHR lower than *100 bpm*). The described characteristics coincide with the real foetal condition since this signal is labelled by a *pH=6.95*. On the other hand, **Figure 4** shows mild deceleration episodes and their depth is decreasing towards the end of the FHR signal. In addition, this case illustrates a more stable floating-line compared with the previous example, whose trending describes values considered normal (values of FHR between *110* and *150 bpm*). This evaluation indicates a normal foetal condition which coincides with this case since the analysed signal is labelled by a *pH=7.36*, which is considered normal.

It is important to note that the proposed method for parametrization of decelerations and floating-line, analysed according to the guidelines, allows the prediction of the real foetal conditions in the three representative cases.

4 Conclusion

The presented work proposed the use of a progressive baseline for the identification and characterization of deceleration episodes in FHR signal. The main idea is to offer to clinicians simplified graphic information about the depth, length and location of those episodes in order to make the deceleration patterns assessment an easier task for medical staff.

Results show that both the progressive floating-line and the parametrized deceleration episodes can undergo different responses whose behaviour is time-variant. The characteristics and progression of such episodes can help the observer to discriminate between normal and pathological FHR signal patterns in order to predict the foetal condition.

According to the analysis applied to three representative cases of CTG signals, the proposed method together with the use of guidelines allows the identification of pathological and normal foetuses making use of the graphic deceleration characterization and the floating-line. This opens perspectives for classification of non-reassuring CTG recordings as a sign of foetal acidemia.

A further step would be to estimate the FHR signal variability in every identified deceleration episode using digital signal processing techniques. The hypothesis is that it is possible to classify CTG recordings by tracking the evolution of the decelerations' response making use of the signal variability as a sign of the foetal welfare.

Author's Statement

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