

Fetal heart rate baseline correction algorithm based on threshold control

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Abstract

Fetal heart rate (FHR) baseline calculation plays an important role in fetal heart rate analysis. In order to extract more accurate fetal heart rate (FHR) baseline, a new FHR baseline correction algorithm was presented in this paper, combined with the existing fetal heart rate baseline algorithm. Firstly, a region division based on threshold control was performed and the unstable region of FHR baseline was found and corrected. And then a new baseline was obtained finally after treatment with some smoothing methods. To assess the performance of FHR baseline correction algorithm, a new FHR baseline estimation algorithm that combined baseline estimation algorithm and the baseline correction algorithm was compared with two existing FHR baseline estimation algorithms. Experiment results showed that the new FHR baseline estimation algorithm did well in both accuracy and efficiency. What's more, the results also prove the effectiveness of the FHR baseline correction algorithm.

Keywords

FHR monitoring, Fetal care, baseline estimation.

1. Introduction

Nowadays, fetal heart monitoring as an important measure of maternity in hospital obstetric assessment of fetal health, can help to find fetal abnormalities in a timely manner to reduce the birth defects and infant mortality rate. [1]Cardiotocography (CTG) is a common and effective method of fetal monitoring today. Through the analysis of CTG information, we can understand the level of fetal physical signs.[2-3] The key to analyzing CTG information is to extract several features of CTG. In the extraction of these features, the calculation of fetal heart rate (FHR) baseline is particularly critical and other features rely on FHR baseline to judge. The errors in baseline evaluation can cause errors of other feature extraction.[4]In order to solve this problem, many researchers have proposed their own baseline algorithms. The existing baseline estimation algorithms fall into three categories: one is algorithm based on linear filtering, which removes the baseline variation by removing the baseline curve by filtering the fetal heart rate curve. This method is used by Dawes and Mantel. Dawes[5]selects a fetal heart rate value as the peak value, and performs low pass filtering to the curve forward and backward to obtain the baseline. Mantel[6]improve the method of Dawes, perform multiple forward and backward low-pass filtering and tailor the fetal heart rate curve based on the obtained quasi-baseline after each filtering to cut out the acceleration, deceleration and larger fetal heart rate variation in the fetal heart rate curve. Since accidents—accelerations or decelerations—are faster signals than baseline variations, a low-pass filter can remove most of them. However, the baseline rate will rise or fall when an accident occurs, and even on periods outside the accident, which produces a shift in the bounds of accidents[14]. The second one is algorithm based on the mode. This kind of method take the mode of FHR values in a sliding window to determine the baseline. The computation is done by taking the maximum of the smoothed probability density function in order to take into account the surrounding values. These principles are used in the methods of Mongelli[7], Ayres de Campos[8]and Maeda[9]. In most cases, the mode is efficient for computing the baseline. Unlike the filtering method, it is generally not affected by accidents. However, when stable accident periods are longer than the baseline period, the computed baseline would pass through stable accident

periods. Moreover, during transition periods between two base levels, the determined baseline make an erroneous discontinue step which have important consequences for the subsequent morphological analysis[14]. With the development of artificial intelligence, some researchers put forward the third kind of algorithm: Improve the first two methods by neural networks. Gelmetti[10] uses neural network filters to obtain baselines, which resulted in more accurate baselines than low-pass filters. Lu[11]uses empirical mode decomposition for noise reduction, then uses self-organizing neural network to find the points on the baseline and calculate the baseline from those points. Compared with the previous type of algorithms, this type of algorithms has more accuracy. However its computational cost is high, and the computational efficiency is low. In order to achieve the accuracy of the third type of correction algorithm and ensure the computational efficiency, Li[12] puts forward the idea of the correction algorithm: Obtain the baseline by the first two kinds of algorithm, and then use a specific correction algorithm to correct and smooth the baseline. In this paper, a new baseline correction algorithm for fetal heart rate was designed based on the previous baseline algorithms and Li's baseline correction algorithm, to improve the accuracy of baseline. After this correction algorithm, the resulting fetal heart rate baseline will become smoother, and more in line with the fetal heart rate curve with higher accuracy.

2. Baseline algorithm selected

The proposed baseline correction algorithm of fetal heart rate is designed to improve the existing baseline algorithms but not to calculate the baseline directly. Therefore, in order to test the algorithm, a FHR baseline algorithm will be used as the test object. The test object selected in this paper is Andersson's baseline estimation algorithm [13], which is based on the baseline algorithm of Mantel et al. In this baseline estimation algorithm, histogram analysis is first performed on the FHR curve, and the peak value is selected. Based on this value, the curve is filtered multiple times to obtain the baseline. The advantage of this algorithm is that the baseline obtained will fit the curve well, so that the stable curve can be handled well. However, if there are some large or long-lasting variations in the fetal heart rate curve, the results obtained by this algorithm are not satisfactory, for the baseline fluctuates greatly. Therefore, this paper chooses the algorithm as the test object of the correction algorithm.

2.1 Pretreatment of original FHR curve

Because of the presence of breakpoints and high-frequency glitches in the original FHR curve, a method for preprocessing of the signal, proposed by Ayres-de-Campos et al. (2000) was utilized for artifact removal. Differences between two adjacent samples of 25 bpm or more were detected, and linear interpolation was applied between the first of the two samples and the first sample of the next stable fetal heart rate segment. A stable segment was defined as five adjacent samples which do not differ more than 10 bpm. If, in rare cases, short segments of actual heart rate variations are removed by this algorithm, it does not significantly affect estimation of the events of interest for this thesis. For simplified processing and faster analysis, the signal was reduced by resampling it at finite time intervals by replacing the heart rate samples in the original signal by one sample containing the average of the fetal heart rates. A sampling duration of 1.25 seconds, 0.8 Hz, was chosen, according to the thesis of Ayres-de-Campos et al. This compromises yields acceptable processing time but also adequate signal quality not seriously distorting the acceleration and deceleration flanks. After the averaging, periods of signal loss were identified, and segments shorter than 15 seconds in between these were removed.

3. Baseline correction

3.1 Region division

The method of finding the stable part of the fetal heart rate baseline is based on the principles of threshold control and time search. First, the average deviations of the baseline are calculated with a segment time window of 12 seconds. The lower the average deviation value, the more stable the

baseline in the current time window. The formula for calculating the average deviation value D is as follows:

$$D = \frac{1}{N} \sum_{i=k}^N (BSL_i - W_i)^2$$

N is the amount of FHR data in the segment, which is determined by the FHR sampling rate and k is the position of the start data of the current segment. BSL is the array of baseline data calculated by Andersson's algorithm and W is the array of fetal heart rate data after preprocessing.

After calculating the average deviation value of each segment, the stable part of the fetal heart rate baseline can be found according to the average deviation value of each segment. The stable part of the curve is defined as the area which has little difference between the curve and the baseline. If there is a set of adjacent deviation values satisfying the starting deviation value and the ending deviation value are both less than 5 and the deviation value of the middle part is less than 10, then the corresponding area of FHR curve can be considered as a stable part. The curve outside the stable part of the curve can be considered unstable.

3.2 Correct the unstable part of the baseline fetal heart rate

Baseline calculated by Andersson's algorithm is easily affected by the unstable part of FHR curve. So this method is mainly for correcting unstable part of the baseline. The correction is divided into three steps: first calculate the base value of the entire region to be corrected, and then segment the region to be corrected and obtain the local base values of each segment, finally draw the baseline of the region to be corrected according to the local base values of each segment.

3.3 Calculate the base value

The method of calculating the main base value is to sort the data in the region and to get the average and middle value of the whole region. If the average value is greater than the median, the maximum data in the region is deleted; if the mean value is less than the median, the data in the area with the smallest value is deleted. After deleting the value, the average value and the median value are recalculated. The absolute value of the difference between the average and the median is less than the specific value ϵ . The last average will be the main base value BV . In this paper, ϵ takes 0.1.

After the main base value is obtained, the local base value of each segment should be calculated. The method of calculating the local base value is to traverse the data in the segment, and replace the data that is larger than $BV + U$ and the data less than $BV - L$ as BV . After the ergodicity is completed, the average value is the local base value of the segment. In this paper, U takes 10 and L takes 10.

3.4 Re-calculate the baseline in unstable part

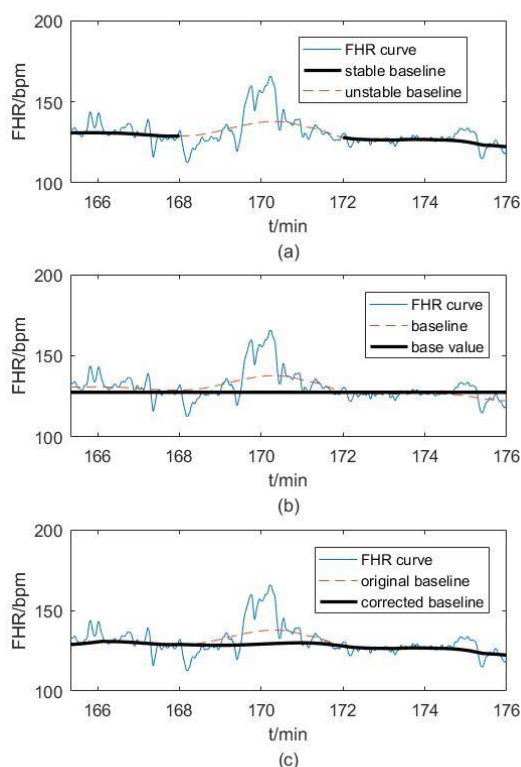
After calculating the datum values of each segment, the baseline of the part is drawn according to the local base values. First, dichotomy is used to determine where the local base value should be in the segment: for each segment, the absolute difference between the average value of the left half part and the reference value D -left is calculated, and so is the absolute difference between the average value and the reference value of the right half part D -right. If the difference between D -left and D -right is less than that of a specific value ϵ , the base value can be considered to be placed to the middle point of the segment. Otherwise, if the times of division is less than a specific value k , the part which has larger absolute difference value is divided, and the comparison is made again. In this method, ϵ takes 0.2, and k takes 3.

After all the positions of each segment's base value are calculated, they are put into an array with the position and baseline value of start point of the unstable area and the position and baseline value of the end point. After performing Hermite interpolation to the array, the corrected baseline in the unstable area is obtained.

3.5 Smoothing of the corrected baseline

After correcting the fetal heart rate baseline, there is a non-smooth part between the stable area and the unstable area. A mean-filter will be utilized for smoothing.

Overall, the workflow of the baseline correction algorithm for fetal heart rate presented in this paper is shown in Fig.1. The baseline of fetal heart rate before correction is the baseline obtained by Andersson's method. It can be seen that the baseline obtained in the stable part of baseline is more accurate, but there was a significant shift in the baseline in the mutational zone. After the baseline correction, the baseline migration in the unstable region is corrected, while the baseline in the stable region is basically unchanged.



(a) the baseline estimated by the algorithm of Andersson and its stable part and unstable part;(b) the base value of the unstable part;(c) the original baseline and the corrected baseline

Figure 1 Figure 1 Sequence of signal processing to correct the baseline

4. Experiment

4.1 Description of the experiment

During the study, a non-stress test (NST) on 70 pregnant women was performed to record the corresponding fetal heart rate signal. Before the fetal heart monitoring, pregnant women were informed of the contents of custody. Only with the consent of pregnant women can the fetal heart monitoring and signal acquisition be carried out.

The experiment used three methods to analyze 70 cases of fetal heart rate signal analysis: Andersson's baseline estimation algorithm (denoted as Algorithm 1), the combination algorithm of Andersson's algorithm and Li's baseline correction algorithm (denoted as Algorithm 2), the combination algorithm of Andersson's algorithm and the baseline correction algorithm in this paper (denoted as Algorithm 3). At the same time, two experts with rich experience in obstetrics (experts-one as an obstetrician and expert-two as a midwife) were invited to evaluate the results of the analysis by grading them into five categories: Very good, Good, Medium, Poor and Very poor: "Very good" indicates that the calculated baseline is in good agreement with the ideal baseline in the expert's mind; "Good" means

that while there are some minor fluctuations in the resulting baseline, these fluctuations have no effect on subsequent parameter identification; "Medium" indicates that the general trend of the baseline is correct, but this baseline will have some adverse effects on the accuracy of the parameter identification; "Poor" means that most of the obtained baseline do not match the baseline expected by the expert; "Very poor" means that the baseline obtained is completely wrong, and it has one or more error of more than 10 bpm with the experts' judgment.

In addition, in order to avoid the impact of computer analysis on expert judgment, experts should first estimate the fetal heart rate (baseline rate) of the fetal heart rate curve before rating the results. According to the related definition, the basic fetal heart rate refers to the average fetal heart rate excluding fetal heart rate acceleration, deceleration and significant variation within 10 min, and the basic fetal heart rate is generally a multiple of 5 bpm.

4.2 Comparison of the accuracy of these three methods

The analysis results of these three methods is shown in Figure 2. The baseline calculated by algorithm one drifts obviously in the acceleration zone, while the baselines calculated by algorithm 2 and algorithm 3 are more stable. As shown in Fig. 2, if the deviation of the original baseline (Algorithm 1) is large, the corrected baseline through Li's algorithm (Algorithm 2) cannot completely eliminate the drift phenomenon. In addition, the results of the algorithm will be affected by the selected reference value, even in the stable area. It means that the baseline in stable area will be forced to approach to the reference value, even if it does not match the FHR data. In contrast, the method of this paper first defines the stable and unstable areas and then only fixes the baseline in the unstable area, so it does not affect the baseline of the stable area. Moreover, the correction method of this algorithm is to recalculate the baseline, which is independent of the baseline values of the neighboring stable areas. Therefore, the corrected baseline (through Algorithm 3) will not be affected by the curve drift, and a more accurate baseline of FHR can be calculated.

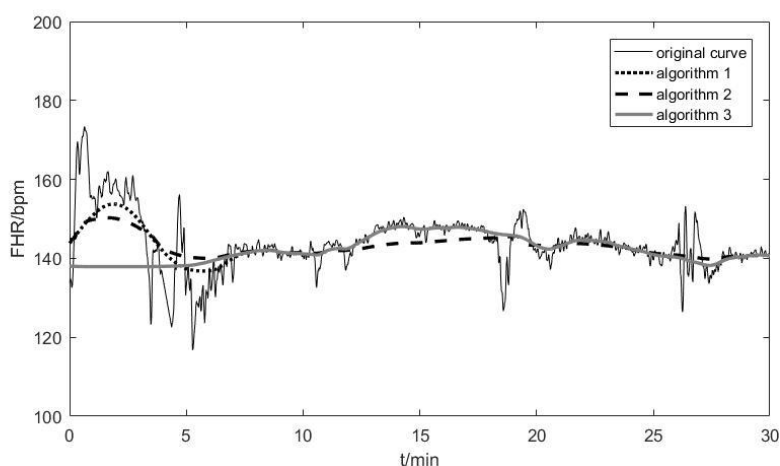


Figure 2 The Analysis result of 3 FHR baseline Algorithms on a FHR tracing

The frequency statistics for the rating results of 70 case of FHR curves by two experts is shown in Figure 3. Overall, in the two expert's judgment results, the performance of algorithm 2 and algorithm 3 are roughly the same, which is better than algorithm one. Among the 70 signals, experts think that the ratio of "Very good" in the first algorithm is 47.06%, the second is 63.52% and the third is 69.41%; while in the second expert's evaluation, the first one is 44.71%, the second is 62.35% and the third is 67.06%. By comparing the results of the expert evaluation of algorithm 1 and algorithm 2, it can be seen that the accuracy of the corrected baseline is obviously improved. In the overall analysis accuracy, algorithm 3 is more accurate than algorithm 2.

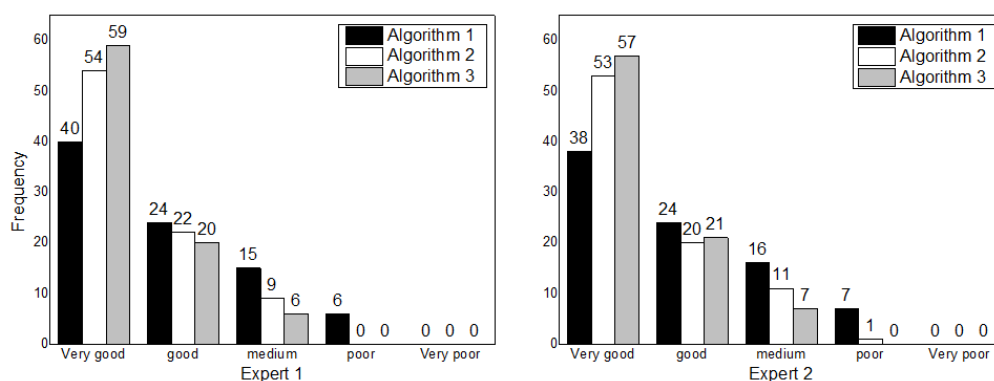


Figure 3 the assessment results by two expert on three algorithms

5. Conclusion

This paper presents a correction algorithm for FHR baseline. Fixing the baseline obtained directly from the existing baseline estimation algorithm by the correction algorithm can make the original baseline more accurate and smooth. In this algorithm, we first find out the unstable part of the original baseline by calculating the deviation value and calculate the base value of the unstable part, and then re-estimate the baseline of the deviation part with the base value, and finally smooth it to obtain a new baseline.

The visual evaluation of obstetric experts and the corresponding quantitative analysis results show that the proposed algorithm is effective and feasible. Experiments show that: using this method can help improve the accuracy of Andersson's algorithm significantly. And that the calculation efficiencies of this method and Li's algorithm similar, while this algorithm do better in the variation of the part of the baseline than Li's algorithm. In addition, the algorithm can adapt to the larger fluctuation of fetal heart rate curve. What's more, this baseline correction algorithm is not designed specifically for Andersson's or Mantel's baseline estimation algorithms and can be used as part of any baseline estimation algorithm. Of course, the premise of this algorithm is that the base line estimated by the baseline estimation algorithm is not a straight line.

However, the baseline correction algorithm is not a panacea. It is only applicable to those baseline which have significant fluctuations. When the fetal heart rate baseline fluctuates violently and frequently, the accuracy of the correction algorithm will decline. For some completely wrong baselines, it is difficult to improve the accuracy of the final result. Therefore, the baseline correction algorithm can only be used as a supplement to the baseline assessment algorithm. To get an accurate baseline at all, a new kind of baseline estimation algorithm is needed. An accurate and widely applicable baseline estimation algorithm is the common goal pursued by the researchers concerned.

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