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Cardiotocography Trace Pattern Evaluation Using MATLAB Program

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Abstract. Cardiotocography (CTG) is a simultaneous recording of fetal heart rate (FHR) and uterine contractions (UC) and it is one of the most common diagnostic techniques to evaluate maternal and fetal well-being. An algorithm is developed to process digital CTG using MATLAB programming to estimate the parameters of the FHR pattern (baseline, baseline variability and FHR acceleration. The results of FHR baseline are compared with the estimations of two experts (obstetricians).

Key words: Cardiotocogram (CTG), fetal heart rate (FHR), baseline (BL), uterine contraction (UC), electronic fetal heart rate monitoring (EFM), Royal College of Obstetricians and Gynecologists (RCOG).

1. Introduction

More than 60 percent of fetal deaths occur before the onset of delivery [1], hence it would be natural to extend the principles of intrapartum fetal heart rate (FHR) monitoring to the antepartum period. A substantial number of antepartum deaths occur in women who have risk factors for uteroplacental insufficiency (UPI) [2].). Fig.1 shows typical CTG segment with the FHR at the upper part of the figure and UC at the lower part.

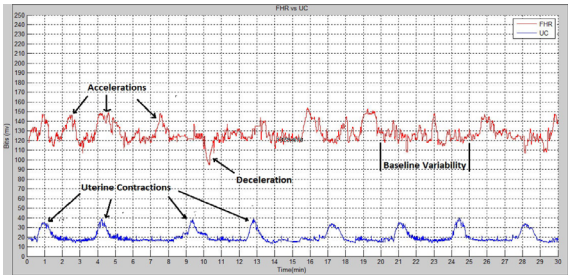

Fig 1: Examples of CTG trace FHR (top) and uterine activity (bottom)

Cardiotocogram (CTG) consists of two distinct signals, the continuous recording of instantaneous fetal heart rate (FHR) and uterine activity (UC)[4]. These two biosignals are illustrated in Fig.1 with FHR at the upper part and UC at the lower part. FHR variability is believed to reflect the interactions between the sympathetic nervous system (SNS) and the parasympathetic nervous system (PSNS) of the fetus. Stimulation of the PSNS results in a decrease in heart rate of the normal fetus while stimulation of the SNS results in an increase in heart rate. During stressful situations for the fetus, such as the uterine contractions at the time of delivery, the sympathetic nerves may act as a compensatory mechanism to improve the fetal heart pumping activity, which is reflected in the FHR signal variations [3]. Baseline is considered as one of the fundamental features of the FHR pattern recognition, as most of the other features rely on its value. It can also be called as the resting level of the fetal heart rate. Up to present days there is no consensus on the best methodology for baseline estimation in computer analysis of Cardiotocogram. Researchers established a few methodologies

for FHR estimation based on mathematical and computerized analysis programs [5]. According to the Royal College of Obstetricians and Gynecologists (RCOG), "The mean level of the FHR when this is stable, excluding accelerations and decelerations. It is determined over a time period of 5 or 10 minutes and expressed in bpm". Baseline is classified as normal, suspicious and pathological based on the values given in Table 1 [6].

Table1: RCOG guidelines for baseline classification

Reassuring	***Suspicious***	***Pathological***
110-160 bpm	100-109 bpm 161-180 bpm	<100 bpm or > 180 bpm

Baseline variability is defined as minor fluctuation in baseline FHR. It is assessed by estimating the difference in bpm between the highest peak and lowest trough of fluctuation in one minute segments of the trace. Table 2 below shows the different types of baseline variability.

Table 2: Baseline variability classification

Normal Variability	>= 5 b.p.m Between contractions
Non-Reassuring Variability	< 5 b.p.m for > 40 min or more but <90 min
Abnormal Variability	< 5 b.p.m for 90 min or more

Fetal heart rate variability (FHRv) is an important measure that can provide early information about fetal's wellbeing and identify those at risk of diseases such as sudden infant death syndrome (SIDS) [7]. Previous studies of FHRv signals obtained using cardiotocography (CTG) have shown that fetal acidosis and fetal hypoxia are directly associated with reduced (FHRv), which is directly related to increasing risk of prenatal mortality [8-11]**.** Acceleration is a transient increases in FHR of 15 bpm or more and lasting 15 seconds or more. The significance of no accelerations on an otherwise normal CTG is unclear. The duration of the acceleration is defined as the time from the initial change in heart rate from the baseline to the time of return to the FHR to baseline [7].

2. Materials and methods

When interpreting a CTG, there are four main parameters to consider relating to the FHR and uterine contractions (UC) Baseline heart rate (BL), Baseline Variability (V), Accelerations (Acc) and Decelerations (Dec) [6]. In our work, we have assumed a virtual imaginary baseline which is equal to the mean value of the whole FHR signal of 30 minute segment. This virtual baseline is our reference to calculate the true baseline, and additional work on calculation of baseline variability and FHR acceleration periods. All this work is based on software program analyzing through the limitation of virtual imaginary baseline of the FHR signal and limiting minimum and maximum values of the wanted signal to be taken in the evaluation in certain periods of time according to the definitions of (RCOG) [6]. The algorithm is implemented entirely using MATLAB 7.4 functions using CTG data stored in excel files in the windows XP file system. Twenty two semi-synthetic CTG signals were used to test the algorithm. The same semi-synthetic CTG (22)[12] signals were handed over to two obstetricians. Obstetricians were asked to estimate the CTG samples parameters (baseline, variability, number of acceleration) the computerized results are compared with the estimated results made by the two experts.

2.1. features measurement in time domain

Since we are dealing with a time series signal, the following set of time domain features are extracted [13-14].

- Virtual imaginary baseline FHR,

$$R = \frac{1}{N}\sum_{i=1}^{N} y(i) \quad \text{..... (1)}$$

- The true baseline,

$$BL = \frac{1}{N}\left[\int_{L}^{H} y dy\right] \quad \text{..... (2)}$$

2.2. Baseline estimation algorithm

Fig. 2 shows the overall procedure employed to calculate the true base line. The first part of the measurement is based on finding the value of virtual imaginary baseline and its value is the mean of FHR signal (R)[13]. Second part of measurement is done by evaluating the minimum and maximum limits of FHR signal to be taken in our measurement according to RCOG baseline definition. Figure (3) shows the CTG signal after the pre-processing procedure using MATLAB program.

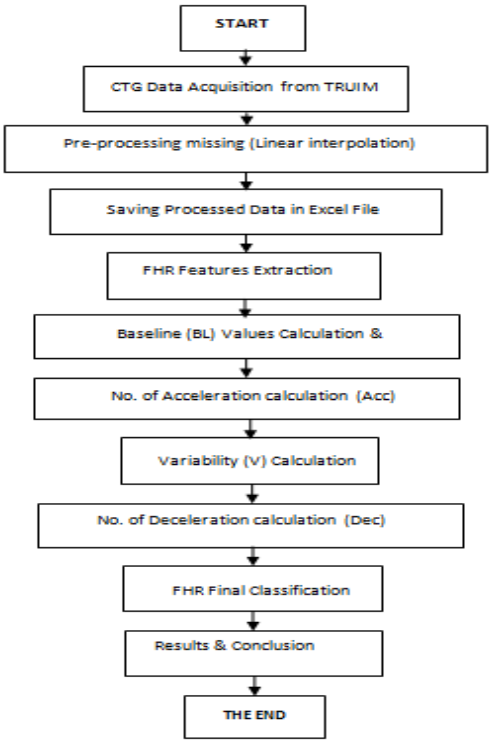

Fig 2: Full program structure

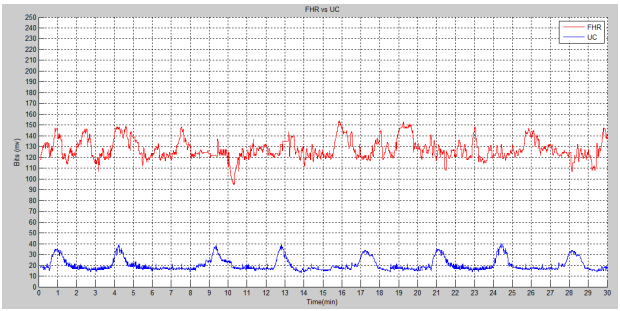

Figure 3: FHR & UC processed signal

The maximum (H) and minimum (L) limits are taken so that any value above H and below L will be omitted, where H = R + 10 and L = R – 10. The remaining FHR signal within the boundaries of H and L will be taken in the calculation of the real baseline (BL).figure (4) shows the limited boundaries for calculation of baseline. Figure (5) shows the remains of the FHR signal after the process used in the algorithm to calculate the true base line (RL).

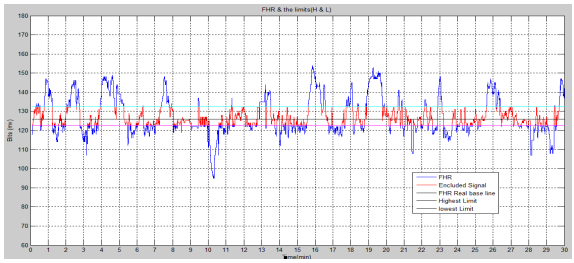

Figure 4: Algorithm limits

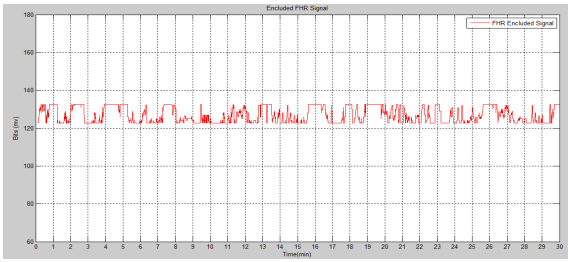

Figure 5: Signal included in real baseline calculation

2.3. Acceleration estimation algorithm

This part of the algorithm designed to calculates FHR acceleration by subtracting the signal in Fig (5) from the signal in fig (4), the remained signal is shown in fig (6) below.

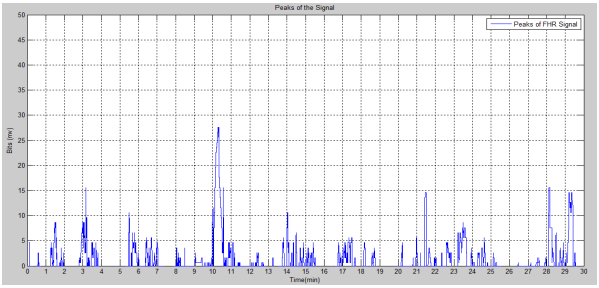

Figure 6: remained signal for FHR acceleration calculation

The remains of the FHR signal in fig (6) shows the convexities (transient period) in FHR signal due to the effect of uterine activities, which represents the acceleration detection values. Figure (7) below shows the gaps periods which represents the length in seconds of the FHR acceleration periods. If the transient period increases in FHR lasting for 15 seconds or more and increases in 15 b.p.m or more, this transient period is considered as acceleration period. The significance of no accelerations on an otherwise normal CTG is unclear. The same procedure is used to calculate the deceleration values in the FHR signal.

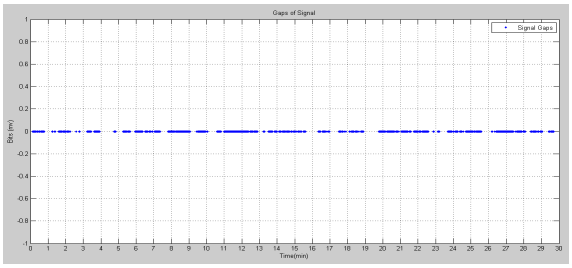

Figure 7: Gaps of transient periods

2.4. Variability estimation algorithm

The last part of the algorithm is to calculate the value of FHR variability which is calculated according to (RCOG) definition of baseline variability. After the first occurrence of FHR acceleration and for a period of two minutes, the calculation of estimated baseline variability based on the calculation the maximum and minimum values of the FHR signal during the two minutes and the baseline variability will be calculated according to the formula (3) below [14].

Baseline Variability: $V = Y_{Max} - Y_{Min}$ ……..…....(3)

Where Y is the CTG Data signal.

3. Results and discussion

The CTG pattern parameters estimation algorithm is tested with 22 sets of data signals (S1-S22). Twenty two semi-synthetic CTG signals were used to test the algorithm. The same sample signals were handed over to two obstetricians. Obstetricians were asked to estimate the CTG samples parameters (baseline, variability, number of acceleration) the computerized results are compared with the estimated results made by the two experts. The outcome of the estimation algorithm is as shown in table 3. The obtained results shows the baseline of the 22 CTG signals were all in reassuring category [6] except signals (S2, S4, S7, S8, S16S and S22) were considered in the non-reassuring category and S20 where considered in abnormal category. Baseline variability obtained results were all in the reassuring category.

TABLE 3: Computerized and visual estimation of Baseline FHR, Variability Baseline and acceleration results

S/N	Expert 1 Interpretation	Expert 2 Interpretation	Computer Results

	Baseline	Variability	No of Acceleration	Baseline	Variability	No of Acceleration	Baseline	Variability	No of Acceleration
S1	120	5	9	125	6-25	8	127	10	10
S2	200	5	9	195	6-25	9	199	14	11
S3	120	10	10	125	6-25	9	126	10	9
S4	80	5	6	75	6-15	6	77	11	6
S5	140	5	5	145	6-20	4	149	7	5
S6	130	7-10	6	130	6-15	6	130	11	3
S7	200	10-15	9	205	6-20	6	211	14	11
S8	60	5	13	65	6-15	11	65	18	16
S9	140	7	3	135	6-20	3	151	8	4
S10	130	10	3	130	6-25	1	133	8	11
S11	130	2-5	0	130	6-10	0	129	9	3
S12	130	2-5	0	135	6-10	0	134	8	2
S13	120	10	10	125	6-25	8	126	9	6
S14	120	10	9	120	6-20	8	126	10	9
S15	120	10	7	135	6-20	5	126	17	7
S16	70	10	6	70	6-10	5	76	11	5
S17	140	7-10	5	140	6-25	4	148	7	5
S18	130	2-5	1	135	6-10	1	134	8	2
S19	140	7	3	130	6-25	2	142	4	0
S20	160	10	2	160	6-25	2	164	15	8
S21	80	10	2	85	6-20	2	84	15	8
S22	80	10	0	90	6-20	2	82	9	9

4. Conclusion

The outcome of the baseline estimation, baseline variability and acceleration using the discussed algorithm is more convincing when the cardiotocography signals are regular. With an irregular FHR signal it shows noticeable differences when compared with experts baseline estimation. Research is still in progress and many significant features in time and frequency domains would be extracted along with the morphological features. Uterine activity and deceleration signals would be considered in the future work to support the feature extraction. Advanced classification techniques and improved features analyses procedures would be employed to enhance the outcome of the project.

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