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Full Length Research Paper

A novel cardiotocography fetal heart rate baseline estimation algorithm

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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 during pregnancy and before delivery. FHR patterns are observed manually by obstetricians during the process of CTG analyses. For the last three decades, great interest has been paid to the fetal heart rate baseline and its frequency analysis, as a base for a more objective analysis of the CTG tracings. Changes in the fetal heart rate pattern relative to contractions provide an induction of fetal condition. This paper proposed new algorithm for FHR baseline calculation.In this work, we present an algorithm for estimating baseline as one of the most important features present in the FHR signal. An algorithm based on digital CTG using Mathlab programming to estimate FHR baseline, the work in this paper rely on detection of baseline values which gives an indication of the fetal status and health condition. The results were compared with the opinion of experts (obstetricians) baseline estimation and one researcher in the same field of study. The obtained results showed slight difference with the experts opinion as a first step for further work to estimate the other parameters of the CTG.

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).

INTRODUCTION

Optimization problems arise in a wide variety of scientific and engineering applications including signal processing, system identification, filter design, function approximation, regression analysis and so on (Erdogmus, 2010; Vatansever and Ozdemir, 2009). Electronic fetal monitoring (EFM) has been widely used for ante-partum (the period before labour) and intra-partum (the period during labour and delivery) fetal surveillance. The term EFM means the continuous recording and monitoring of fetal heart rate (FHR) and uterine contraction (UC), also known as cardiotocogram (CTG) Figure 1. (Susan et al., 2005) shows CTG segment with the FHR at the upper part and UC at the lower part as illustrated in Figure 1.

More than 60% of fetal deaths occur before the onset of delivery; hence it would be natural to extend the principles of intra-partum fetal heart rate (FHR) monitoring to the ante-partum period. A substantial number of ante-partum deaths occur in women who have risk factors for uteroplacental insufficiency (UPI). Cardiotocogram (CTG) consists of two distinct signals, its continuous recording of instantaneous fetal heart rate (FHR) and uterine activity (UC). These two biosignals are illustrated in Figure 1. 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 (Parer, 1997).

For the last three decades many researchers have employed different methods to help the doctors to interpret the CTG trace pattern from the field of computer programming and signal processing. They have supported and incorporated the doctors and interpretations in order to reach a satisfactory level of reliability so as to act as a decision support system in obstetrics. Up to now, none of them has been adopted worldwide for everyday

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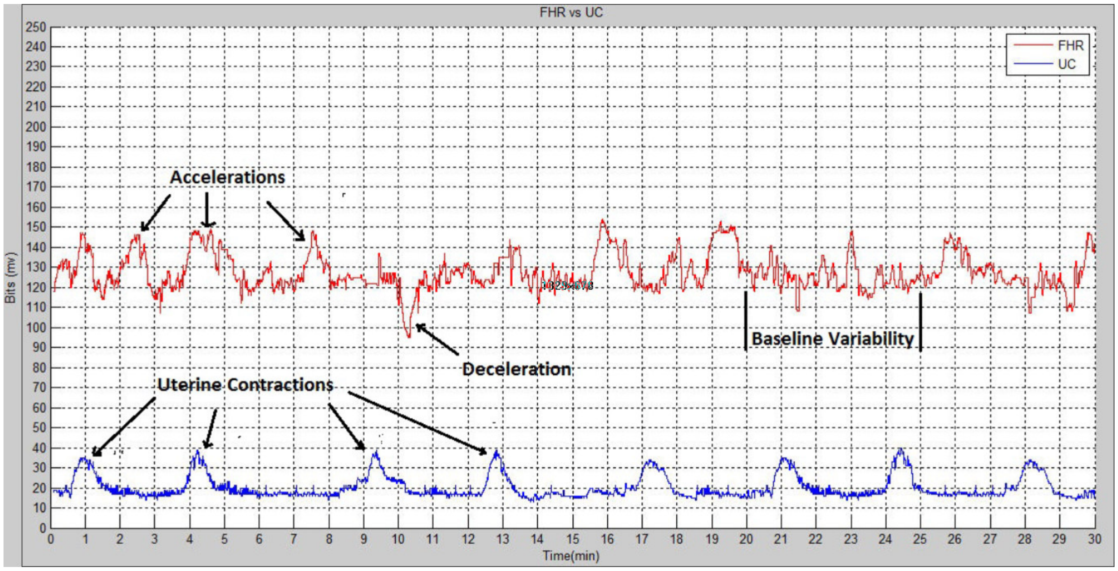

Figure 1. Examples of CTG trace FHR (top) and uterine activity (bottom).

practice (Geijn, 1996). 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. Attitudes towards fetal monitoring have altered as more research findings are published and reviewed highlighting both the beneficial and detrimental effects of continuous electronic fetal heart rate monitoring (EFM) (Van Geijn, 1996). Researchers established a few methodologies for FHR estimation based on mathematical and computerized analysis programs (Mantel et al., 1990; Arduini et al., 1996).

Most proposed mathematical algorithms for computerized estimation of FHR baseline are satisfactory when the FHR tracings are regular with long and stable FHR segments. These kinds of tracings are found most commonly during the ante-partum and the early hours of delivery. Baseline estimation is more complex when the FHR tracings are irregular and any misinterpretation would affect the overall interpretation of the CTGs (RCOG, 2001).

When interpreting a CTG, there are four main parameters to be considered relating to the FHR and uterine contractions (UC) as shown in Figure 1:

1. Baseline heart rate (BL)
2. Baseline variability (V)
3. Accelerations (Acc)
4. Decelerations (Des)

In this work, we focus only on the estimation of FHR baseline as the most important parameter in CTG signal.

Fetal heart rate baseline, which is controlled mainly by the autonomic nervous system. Sympathetic activity results in tachycardia, while parasympathetic activity, mainly the vagus nerve, results in bradycardia. In normal circumstances, the vagal activity is dominant, exerting a constant slowing of the heart rate, stabilizing it at 110 to160 beat per min (b.p.m) the baseline fetal heart rate is also controlled by receptors in the aortic arch:

a. Chemoreceptors, which are stimulated by changes in oxygen levels. An acute fall in oxygen levels leads to an increase in parasympathetic activity, resulting in a slowing of heart rate.
b. Baroreceptors, which are stimulated by changes in arterial pressure. Hypertension leads to an increase parasympathetic activity, resulting in a slowing of heart rate. Hypotension leads to an increase in sympathetic activity, resulting in a rise in the heart rate.

The baseline heart rate is also related to gestational age and the maturity of vagus nerve. The more mature the fetus, the more evident the slowing effect the vagus nerve exerts upon the heart rate becomes. The baseline FHR is the heart rate during a 10 min segment rounded to the nearest 5 b.p.m increment excluding periods of marked FHR variability, periodic or episodic changes, and segments of baseline that differ by more than 25 b.p.m. The minimum baseline duration must be at least 2 min. If minimum baseline duration is less than 2 min then the baseline is indeterminate.

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 period of time of

Table 1. RCOG guidelines for baseline classification.

Reassuring	Non-reassuring	Abnormal
110-160 b.p.m	100-109 b.p.m 161-180 b.p.m	<100 b.p.m or > 180 b.p.m

5 or 10 min and expressed in b.p.m". Baseline is classified as reassuring, non-reassuring and abnormal based on the values given in Table 1 (RCOG, 2001).

MOTIVATION

Since 1970 many researchers have employed different methods to help the doctors to interpret the CTG trace pattern from the field of signal processing and computer programming. They have supported doctors with interpretations in order to reach a satisfactory level of reliability so as to act as a decision support system in obstetrics. Up to now, none of them has been adopted worldwide for everyday practice (Van Geijnt, 1996). There is currently no consensus on the best methodology for baseline estimation in computer analysis of cardiotocographs. The algorithm proposed in this paper will help and support the doctors with interpretations to make a good interpretation for all pregnancy cases before delivery and its application can be used in all hospitals as first computerized detection software for CTG pattern parameters analyzer.

RESEARCH OBJECTIVES

The main objective of this research is to develop effective algorithm for FHR baseline estimation using conventional programming. The major tasks involved are listed below:

a. Research on the CTG signals, its feature and analysis. Acquiring normal and abnormal CTG signals.
b. Design and development of conventional FHR estimation baseline based on RCOG guidelines and furthermore, validating the conventional process by comparing the results with those of expert's visual interpretation.

RESEARCH QUESTIONS

Over the last decade many researchers have employed various methods from the field of signal processing and computer programming, and have incorporated the doctors' expertise, in order to reach a satisfactory level of reliability so as to act as a decision support system in obstetrics. Up to now, none of them has been adopted worldwide for everyday practice (Georgoulas et al., 2006). This research paper tries to answer the following questions:

a. Is the algorithm able to overcome the problems of estimation regular and irregular FHR signals?
b. What is the major problem on FHR estimation?
c. Is this proposed new method is enough?
d. What are the differences between this method and other method?

The answers of the above questions will be discussed in the results and discussion section.

RELATED WORKS

There is currently no consensus on the best methodology for baseline estimation in computer analysis of cardiotocographs. For example, in the Toitu system, FHR values are divided into 20 categories, each comprising 10 b.p.m intervals ranging from 0 to 200 b.p.m, and the baseline in each 5 min period corresponds to the mean value of the group having the largest amount of samples. In the Nottingham/Hong Kong system, baseline corresponds to the average FHR value in a sliding window 6 mins wide. In the Montreal system, baseline is defined as the mean FHR in 1 in segments after exclusion of accelerations, decelerations, periods of artifact and signal loss. It is considered inexistent when less than 5% of values coincide with this average value (Diogo et al., 2004). In system Sonicaid 8000/8002, baseline is determined using a low pass digital filter with forward and backward propagation, excluding values that differ for more than 60 ms from the preceding ones, and starting from the mean of FHR values in the first 2 min. The 2CTG system uses a low-pass digital system that crosses the tracing five times, starting from a value determined by histogram analysis of the FHR distribution (Mantel et al., 1990; Arduini et al., 1993). Nearly all the proposed mathematical algorithms for computerized estimation of FHR baseline are satisfactory when the FHR tracings are regular with long and stable FHR segments. These kinds of tracings' are found most commonly during the ante-partum and the initial stages delivery. Baseline estimation is more complex when the FHR tracings are irregular and any misinterpretation would affect the overall interpretation of the carditocographs. In Sisporto 2.0 system, 5% of the FHR values were considered along with the abnormal short term variability to estimate the baseline (Ayres-de-Campos et al., 2000).

Other method of "baseline estimation based on number and continuity of occurrences" have taken 5% or more of the number of occurrences of the FHR values and the percentage of the consecutive occurrence of each one of them along with the number of occurrences in calculating

Table 2. CTG classification.

Cardiotocograph (CTG) classification				
Normal	A CTG where all four features fall into the reassuring category			
Suspicious	A CTG whose features fall into one of the non-reassuring categories and the reassuring category and the remainder of features are reassuring			
Pathological	A CTG whose features fall into two or more of the Non-reassuring the reassuring category or two or more abnormal categories			
	Fetal heart rate features classification			
	Baseline (bpm)	**Variability (bpm)**	**Deceleration**	**Acceleration**
Reassuring	110-160	>=5	Non	Present
Non-reassuring	100-109 161-180	<5 for >= 40 but < 90 min	Early deceleration Variable deceleration Single prolong Deceleration up to 3 min	The absence of acceleration with an otherwise normal CTG is of uncertain significant
Abnormal	<100 >180 Sinusoidal pattern For >= 10 min	< 5 for >= 90 min	A typical variable deceleration Late deceleration Single prolong Deceleration greater than 3 minute	

the baseline (Krupa et al., 2008).

CTG CLASSIFICATION

CTG is classified as normal, suspicious and pathological and the baseline is classified as reassuring, non-reassuring and abnormal based on the values given in Table 2 (RCOG, 2001).

MATERIALS AND METHOD

In our work, we have assumed a virtual imaginary baseline which is equal to the mean value of the whole FHR signal of 30 min segment. This virtual baseline is our reference to calculate the true baseline. 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). The algorithm is implemented entirely using MATLAB 7.4 functions using CTG data stored in excel files in the windows XP file system. Two types of CTG data samples were used in this research used to test the algorithm. The first sample is fifteen CTG data used by (Krupa et al., 2008), and the second sample is twenty two semi-synthetic CTG signals derived from the first sample. The reason behind using modified signals (semi-synthetic) is to cover all types of baselines (Reassuring, non-reassuring and abnormal). Those two groups of CTG signals were handed over to two obstetricians. Obstetricians were asked to estimate the CTG samples parameters baseline; the obtained computerized results are compared with the estimated results made by the two experts.

A-Features measurement in time domain

Since we are dealing with a time series signal, the following set of time domain features are extracted (Magenes et al., 2000; Magenes et al., 2001).

Virtual imaginary baseline FHR,

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

The true baseline,

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

Where:

N is the total number of samples,
y is the FHR signal data,
H is the highest limit for the wanted signal,
L is the lowest limit for the wanted signal,
BL is the true baseline for the wanted signal.

B- Baseline estimation algorithm

Baseline is an imaginary line that is drawn across the FHR tracing signal. The algorithm we have implemented calculates the baseline

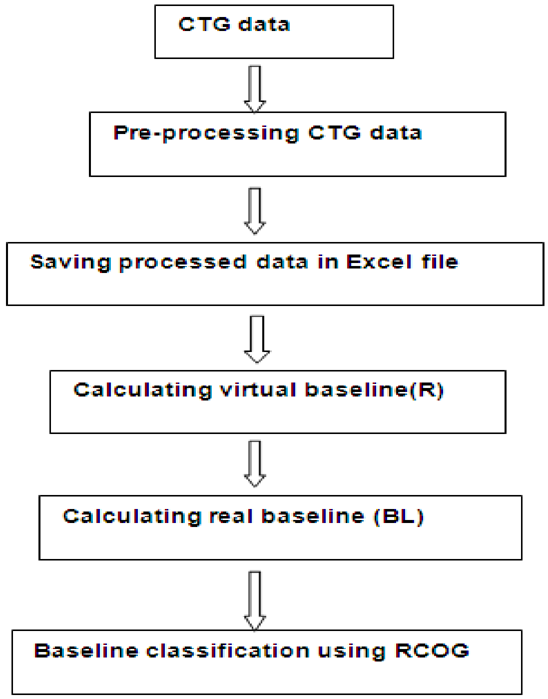

Figure 2. Full program structure.

Table 3. comparisons between the computerized estimation of baseline and the experts' estimation.

Signals	Interpreted baseline (b.p.m)			
	Expert 1	Expert 2	Krupa work	This work
S1	130	130	132	129
S2	130	130	131	132
S3	130	130	128	128
S4	120	120-125	125	124
S5	120	120	125	125
S6	130	130	133	132
S7	140	140	140	138
S8	145	145	152	145
S9	145	145	147	145
S10	130	130	132	132
S11	140	140	138	141
S12	130	130	128	129
S13	130	130-132	134	133
S14	130	130	133	130
S15	140	140	140	142

and classified whether it is reassuring, non-reassuring or abnormal. The decision is made according to the RCOG guideline. The details are provided in Table 2. Figure 2 shows the overall procedure employed to calculate the true baseline.

The first part of the measurement is based on finding the value of virtual imaginary baseline (R) and its value is the mean of whole FHR signal. Second part of measurement is done by evaluating the minimum and maximum limits of FHR signal (H&L) to be taken in our measurement according to RCOG baseline definition. As mentioned before the FHR signal is a noisy with spiky artifacts, which occur due to fetal movements or displacement of the transducer. In the preprocessing stage the biosignals are conditioned, where the spiky artifacts are removed using a method described in (Ayres-de-Campos et al., 2000). Figure (3a and b)

Table 4. Computerized and visual estimation of Baseline FHR results for Semi-synthetic CTG signals.

	Interpreted baseline (b.p.m)		
	Expert1	**Expert2**	**This work**
M1	120	125	127
M2	200	195	199
M3	120	125	126
M4	80	75	77
M5	140	145	149
M6	130	130	130
M7	200	205	211
M8	60	65	65
M9	140	135	141
M10	130	130	133
M11	130	130	129
M12	130	135	134
M13	120	125	126
M14	120	120	126
M15	120	135	126
M16	70	70	76
M17	140	140	148
M18	130	135	134
M19	140	130	142
M20	160	160	164
M21	80	85	84
M22	80	90	82

show the signal before and after pre-processing.

The processing of CTG signals is to remove the spiky unwanted signal by using the low-pass filter and compensating the missing data during the process of measuring the data from the pregnant mother using the linear-interpolation method for missing data compensation. Figure 3b shows the FHR signal after the pre-processing.

The maximum and minimum limits (H&L) limits are taken so that any value above H and below L will be omitted, where H = R + α (b.p.m) and L = R – α (b.p.m). The remaining FHR signal within the boundaries of H and L will be taken in the calculation of the real baseline (BL). After long experiment to choose the best value of (α) to be added and subtracted from the imaginary virtual baseline (R) to calculate the maximum and minimum limits (H&L),and comparing the obtained results with the experts opinion, we found α= 8 b.p.m gives better results and best accuracy about 95% as shown in Figure 4.

Figure 5 shows the limited boundaries for calculation of baseline, and Figure 6 shows the remains of the FHR signal after the process used in the algorithm to calculate the true base line (BL). Figure 6 shows clear signal without acceleration and deceleration changes, and it well be used to calculate the best FHR baseline according to RCOG definition.

RESULTS AND DISCUSSION

FHR estimation algorithm is tested with two different types of CTG signals, the first one is 15 set of signal (S1 to S15) used before in one research in the same field of study (Krupa et al., 2008). The baseline results in Table 3 shows a slight deference between the obtained results and the results of both researcher and the two experts'. The output results are all different within (+/-2) b.p.m and almost similar to the experts estimated results.

The second used data is 22 set of data signals (M1 to M22) are modified signals (semi-synthetic) signals were used to test the algorithm. The same sample signals were handed over to two different obstetricians. Obstetricians were asked to estimate the FHR samples baseline; the computerized results were compared with the estimated results made by the two experts as shown in Table 4. The output results are all within (+/-6) b.p.m difference and almost similar to the experts estimated results, except signal M7 and M17, where the two signals are irregular CTG signal.

The obtained results shows the baseline of the 22 CTG signals were all reassuring category (RCOG, 2001) except signals (M2, M4, M7, M8, M16S and M22) were considered in the non-reassuring category and M20 where considered in abnormal category.

Conclusion

In this method, the difference with other proposed methods is based on calculation of imaginary baseline as a reference to find the other FHR parameters and real baseline (BL) which is within the signal limits (boundaries H and L) according to RCOG baseline definition. The outcome of the baseline estimation using the above

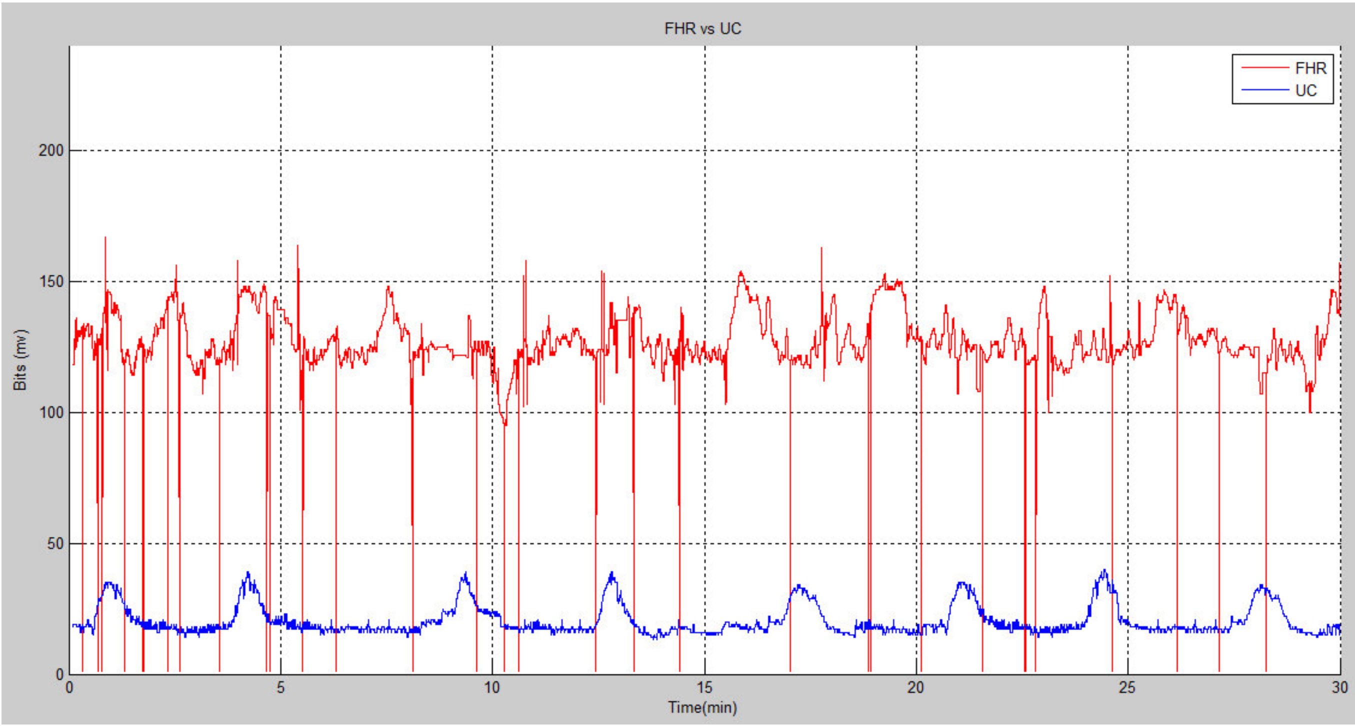

Figure 3a. CTG signal before pre-processing. The processing of CTG signals is to remove the spiky unwanted signal by using the low-pass filter and compensating the missing data during the process of measuring the data from the pregnant mother using the linear-interpolation method for missing data compensation. Figure 3b shows the FHR signal after the pre-processing.

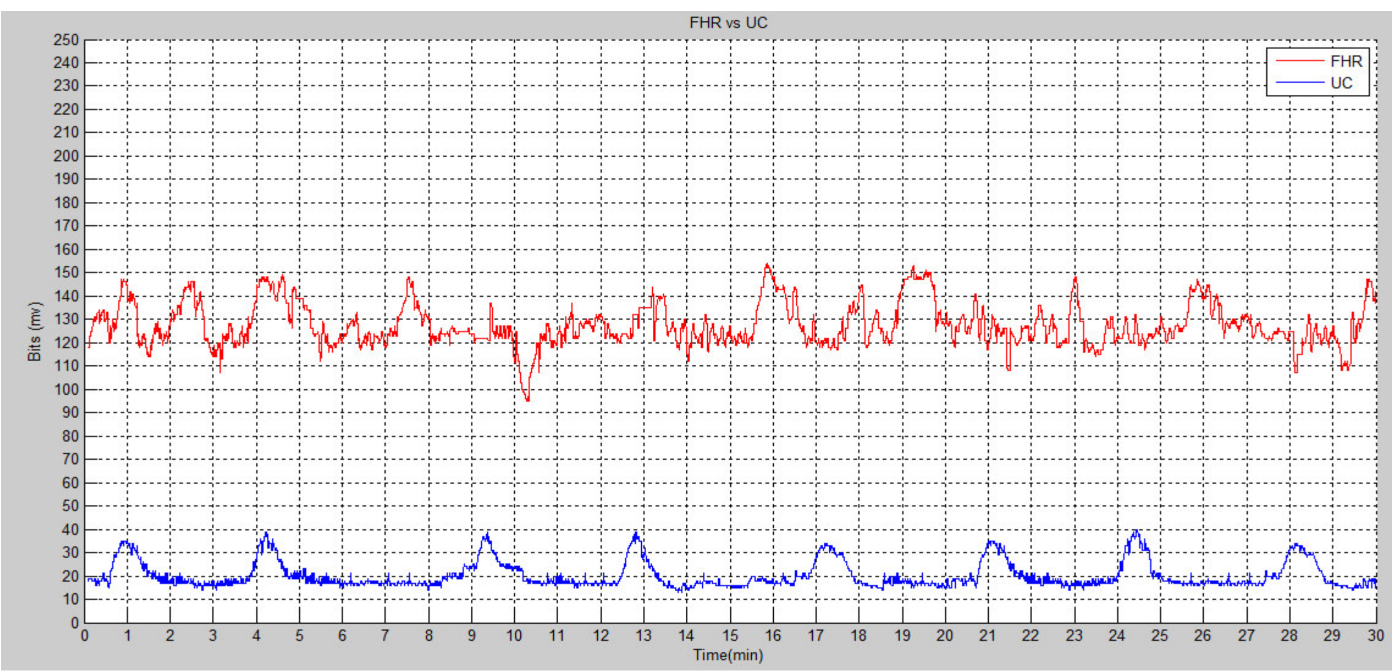

Figure 3b. CTG signal after processing. The maximum and minimum limits (H and L) limits are taken so that any value above H and below L will be omitted, where H = R + α (b.p.m) and L = R – α (b.p.m). The remaining FHR signal within the boundaries of H and L will be taken in the calculation of the real baseline (BL). After long experiment to choose the best value of (α) to be added and subtracted from the imaginary virtual baseline (R) to calculate the maximum and minimum limits (H and L),and comparing the obtained results with the experts opinion, we found α= 8 b.p.m gives better results and best accuracy about 95% as shown in Figure 4.

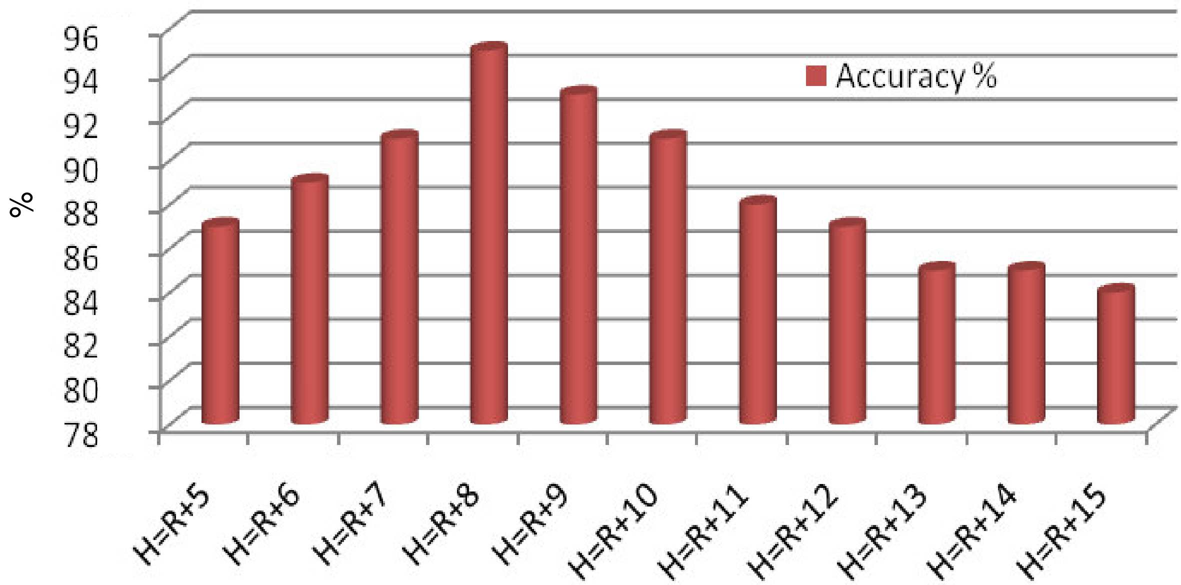

Figure 4. Accuracy of new signal limitations, where α=1, 2... 15. Figure 5 shows the limited boundaries for calculation of baseline, and Figure 6 shows the remains of the FHR signal after the process used in the algorithm to calculate the true base line (BL).

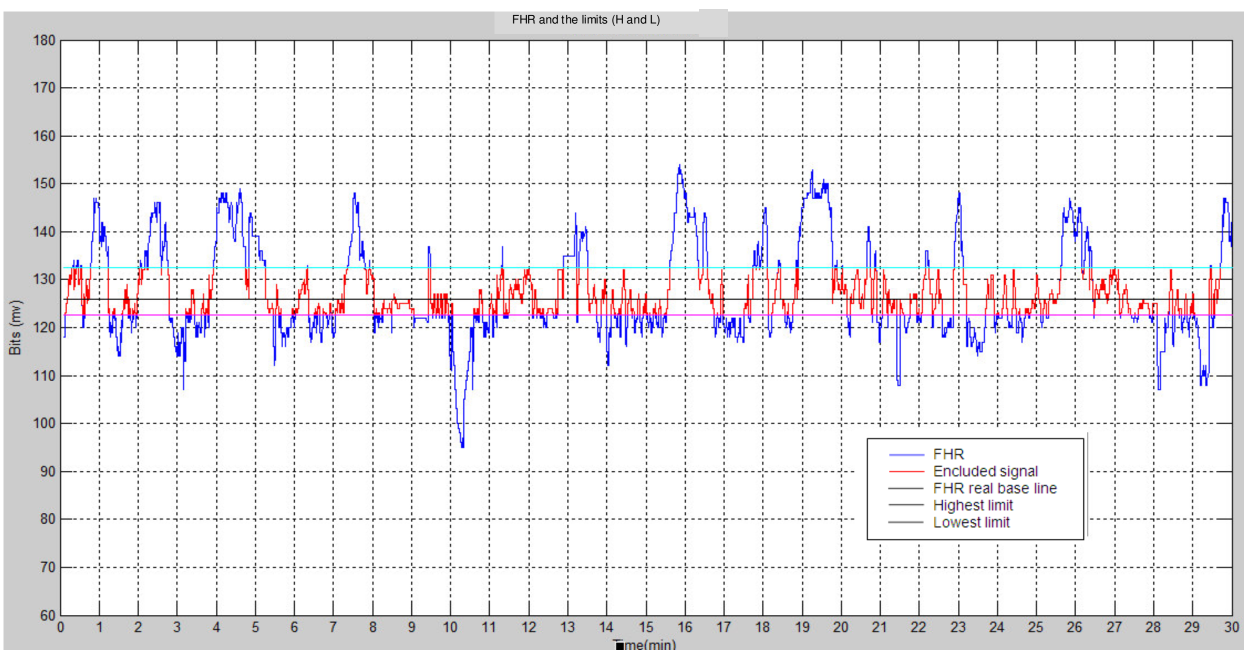

Figure 5. Algorithm limits.

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. The major problem in all CTG analysis and classification researches is how to establish full CTG parameters estimation and classification method. Research is still in progress and many significant features in time and frequency domains would be extracted along with the morphological features. Variability, acceleration deceleration and uterine activity would be considered in the future work to support the feature extraction. Advanced classification techniques

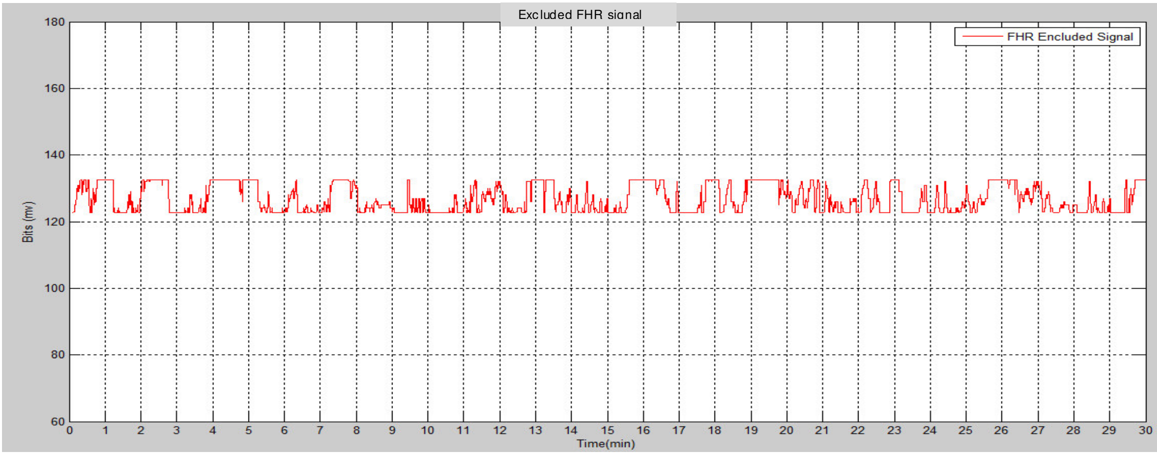

Figure 6. Signal included in real baseline calculation .It shows clear signal without acceleration and deceleration changes, and it well be used to calculate the best FHR baseline according to RCOG definition.

and improved features analyses procedures would be employed to enhance the outcome of the project.

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