

Cardiotocography Waveform Analysis Using Image Extraction Technique

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ABSTRACT

Cardiotocography (CTG) is one of the common tools used to monitor mother and fetus health status. CTG displays the continuous reading of fetal heart rate (FHR) and uterine contractions (UC) in graphical form. The common parameters used to analyze the signals are baseline, variability, accelerations, and decelerations of FHR. By using these parameters, the overall impression of the CTG waveform can be determined. Failure to accurately determine an abnormal condition might lead to a severe problem for the mother or fetus. This paper describes a CTG waveform analysis tool for easier monitoring of the fetal heart rate and uterine contractions. MATLAB is used to create the Graphical User Interface (GUI) to help users in using the developed algorithm more efficiently. The developed algorithm is used to extract the data from an image file of a CTG waveform printout to a useful signal. In this work, two methods are used to determine uterine contractions periods, acceleration, and deceleration. It is found that method 1 takes an average of 0.02786 seconds, while method 2 takes an average 0.01175 seconds to process the image files. The code length of method 1 in analyzing accelerations and decelerations is 10 rows, and method 2 only requires 4 and 2 rows for analyzing accelerations and decelerations, respectively. The accuracy of both methods is similar. Hence, it is concluded that method 2 with a built-in function is a better solution.

Keywords: Cardiotocogram, Fetal Heart Rate, Uterine Contractions, Matlab.

1. INTRODUCTION

Cardiotocography (CTG) has been used by doctors to monitor and record the fetal heart rate (FHR) and the mother's uterine contractions. It is widely used as a non-invasive solution to check the fetal conditions in the antepartum period [1]. The contractions of the uterus are linear correlations to the FHR [15]. FHR patterns are usually monitored manually by obstetricians or professional doctors during the process of cardiotocographs analysis. Failure to recognize an abnormal CTG pattern is a serious problem, and it will put the fetus in an uncertain condition.

The CTG machine provides a printout of data collected in the graphical form [3]. On the printout, there are two lines, which represent two CTG signals. The top line displays the FHR over time: the x-axis of the graph is the representative of the elapsed time of the readout, whereas the y-axis is the representative of the instantaneous fetal heart rate, which is in beat per minute (bpm). The bottom line displays the number of uterine contractions (UC), which is in mmHg. The two signals from the CTG printout can be monitored simultaneously [4].

It has been recorded that more than 60% of fetal deaths happen before the onset of delivery [5]. This has brought worries to certain parents to have babies. Over the year, many researchers came out with different methods and solutions. However, none of them has been adopted worldwide for everyday practice [6].

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Generally, image processing is a method that processes and analyses the data inside an image. This work, however, focuses only on image extraction and signal impression from the extracted data of an image. To the authors' knowledge, there is no similar work that deals with CTG signal impression or analysis. By using a few algorithms to analyze the CTG waveform, analyzed results will be determined and shown using the GUI, which is more convenient, and user-friendly to the users. Few algorithms are developed, such as baseline, variability, accelerations, and decelerations. These are used to estimate FHR and to determine the parameters of the FHR pattern.

The remainder of this paper is organized as follows. Section II presents the literature review, while Section III describes the methodology of extraction data from the image file and the CTG analysis system. Section IV provides the results and discussions. The conclusion is given in Section V.

2. LITERATURE REVIEW

The use of CTG is highly dependent on the FHR readings. Continuous monitoring of the fetal heart rate before and during labour is essential to evaluate fetal well-being during the delivery. CTG is important as the main purpose of CTG is to consistently check on the fetuses who may be short of oxygen or a condition known as hypoxia in order to guide an additional assessment of fetal wellbeing [7]. Work [8] presented a fetal state classification from cardiotocography based on feature extraction using hybrid K-Means and support vector machines in their research. K-Means Algorithm is used after extracting data from CTG and trained using Support Vector Machine (SVM). This method brings accuracy up to 90.64% using Cardiotocography Dataset obtained from the UCI Machine Learning Repository based on 10 cross-validations. The baseline is one of the fundamental features of FHR pattern recognition. Work in [9] has presented the cardiotocograph parameter estimation using MATLAB programming. The FHR baseline values are determined to act as bases for estimating another FHR parameter. The research developed an algorithm to process digital CTG for only FHR patterns.

Virtual imaginary baseline FHR,

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

The true baseline,

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

Equation 1 and Equation 2 show the virtual imaginary baseline FHR and the true baseline, where N is the total number of samples, y is the FHR, H is the highest limit for the wanted signal, and L is the lowest limit for the wanted signal.

Baseline FHR is the mean value of the heart rate estimated in 10 minutes. Normal baseline FHR is between 110-160 bpm. Fetal tachycardia (FT) is a baseline FHR higher than 160 bpm. It is caused by maternal fever, dehydration or anxiety, maternal ketosis, medications like anticholinergic medications, sympathomimetic medications like terbutaline, fetal movement, preterm fetus, maternal thyrotoxicosis, and maternal anaemia [10]. Fetal bradycardia (FB) is a baseline FHR of less than 100 bpm. It is common if postdate gestation or occiput posterior or transverse presentations. Severe prolonged bradycardia is defined as FHR less than 80 bpm, which caused by prolonged cord compression, cord prolapse, epidural and spinal anaesthesia,

maternal seizures, and rapid fetal descent. Immediate delivery is recommended if the cause cannot be identified and corrected.

Variation of FHR is caused by the interaction between the nervous system, chemoreceptors, baroreceptors, and cardiac responsiveness. It is one of the features to determine the healthiness of the fetus. Normal variability shows an intact neurological system in the fetus. Loss of or diminished beat-to-beat variability might be caused by fetal sleeping but not more than 40 minutes, fetal acidosis, fetal tachycardia, drugs, prematurity, and congenital heart abnormalities [10].

The presence of acceleration in FHR shows that the fetus is healthy. The decelerations in FHR bring different interpretations. Decelerations happen when the fetus reduces its heart rate to preserve myocardial oxygenation and perfusion in response to hypoxic stress. Early decelerations are considered not pathological [11]. It is caused by increased fetal intracranial pressure causing increased vagal tone and it does not indicate fetal hypoxia or acidosis. Late decelerations show a concerning situation as it represents insufficient blood flow to the uterus and placenta. It will cause fetal hypoxia and acidosis. These indicate a chemoreceptor-mediated response to fetal hypoxemia. Prolonged decelerations show the situation is dangerous, and actions such as fetal blood sampling and emergency C-section must be taken quickly. Nevertheless, CTG waveform analysis can only be used as a guideline and need to be assessed by professional doctors for further clinical decisions.

3. METHODOLOGY

3.1 Implementation Flow

A GUI is created using the MATLAB software to ease the implementation of the FHR, UC analysis, and the overall impression. The implementation is shown in Figure 1. At first, the FHR signals are transferred into MATLAB data, as well as the UC signals. After the signals are converted into digital signals, it is then ready to be analyzed. Few algorithms are created to identify the pattern of the signals. Then, all the data are collected and categorized. The data are then displayed for users' information.

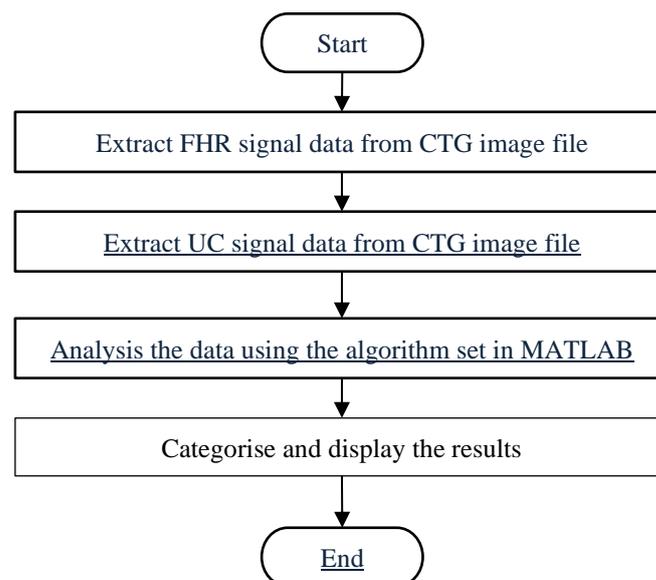


Figure 1. General Implementation Flow.

3.2 FHR and UC Waveform Extraction

The data extraction and conversion to digital signals from the 'jpg' file are firstly done by uploading the required image file in the developed GUI. Then, a minimum value and maximum value for each X and Y-axis are inserted. After that, the point of the signals is drawn or grabbed. Finally, the reproduced signal will be shown in the GUI system. The same procedures are applied to both FHR and UC signals. In this work, 15 minutes was chosen for the analysis of the CTG waveform.

3.3 Algorithm

Normal FHR is between 110 to 160 bpm. In this developed software, the data is extracted from the Y-axis of FHR signals. The mean of the data is equal to the baseline heart rate. It is calculated and shown at the GUI display. Normal heart rate variability is between 5 to 25 bpm. In this developed software, the Y-axis from the FHR graph is obtained first in order to find the variability of the FHR. Then, the difference between each point is searched and the difference found must be positive. Then, all the difference are sum up and divide with the total number of data in order to find the mean.

There are two methods in determining UC periods, acceleration and deceleration. The first method to calculate the UC period is by calculating the time difference between two consecutive peaks. In this developed software, the data for X-axis and Y-axis are taken from the UC graph. The major peak is defined when the Y-axis value is bigger than the left and the right value. It must exceed 30 mmHg to be counted as the major peak. The total number of peaks is counted every time it detects a peak. Then, the difference between the X-axis of the major peak is found. In addition, the mean of the value to show the average distance between the two peaks is obtained.

In the second method, a MATLAB built-in function is used, which is 'findpeaks' to search for peaks of the signals. Then, the peaks which are less than 30mmHg are filtered. Then, the x values of the peak location are found and the time distance between 2 consecutive peaks are calculated. The results are displayed in the GUI.

Accelerations are the transient increase of FHR of 15 bpm or more above the baseline and lasting for greater than 15 seconds are. Figure 2 shows the flowchart of method 1 in finding accelerations. In this proposed software, in order to find the accelerations in FHR, the Y-axis data is obtained from the FHR graph, and the difference between each point is found. If the difference is more than 15 bpm, it will be considered as an acceleration point. The number of acceleration point is counted and displayed.

Figure 3 shows the flowchart of method 2 in finding accelerations. The second method also used the built-in function 'findpeaks'. By using 'Threshold', it can find the increase of 15 bpm between two points. Then, by using 'numel', the total number of accelerations can be counted. Finally, the results are displayed in the GUI.

Decelerations are the abrupt decrease of FHR below the baseline of more than 15 bpm lasting at least 15 seconds. Figure 4 shows the flowchart of method 1 in finding decelerations. In this developed software, the decelerations in FHR is obtained by obtaining all the data of the X-axis and Y-axis of both FHR and UC graphs. Then, the difference between each point is found. If the difference is more than 15 bpm, it will be considered as a deceleration point. Next, a similar solution for UC contractions is used to find the major peaks. Figure 5 shows the flowchart of method 2 in finding decelerations. For the second method, 'findpeaks' is used. All values of the FHR Y-axis was inverted in order to find the deceleration. The x values of the deceleration point are also found.

The X location of the deceleration point is measured with the UC signals. The difference in the X-axis between the X-axis value of the decelerations and the X-axis value of UC peaks are found. If the difference is small less than 0.5, it is considered as Early Decelerations. If the difference is higher around more than 0.5 but less than 1.5, it is considered as Late Decelerations. To be considered as a Prolonged Decelerations, there are two conditions to be fulfilled. First, the decelerations must be more than 30 bpm. The same method is used to find the decelerations but changes to 30 bpm instead of 15 bpm. Second, the deceleration must be more than 3 minutes. Hence, the difference between the X-axis of FHR signals is searched. If both conditions are met, it shows 'YES' in the Prolonged Decelerations' box in the GUI.

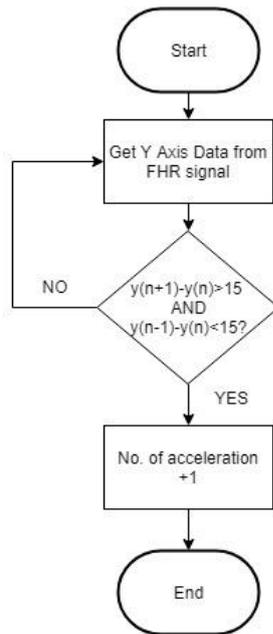


Figure 2. Method 1 for accelerations.

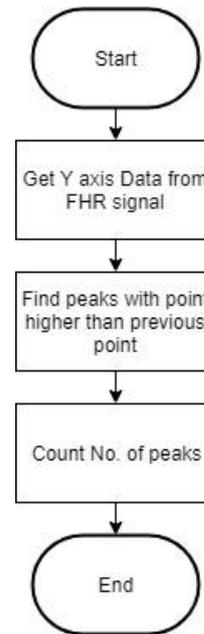


Figure 3. Method 2 for accelerations.

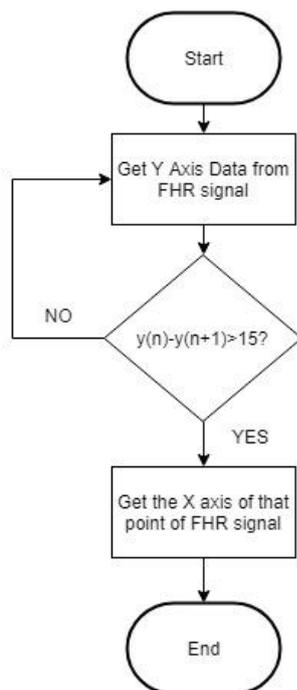


Figure 4. Method 1 for decelerations

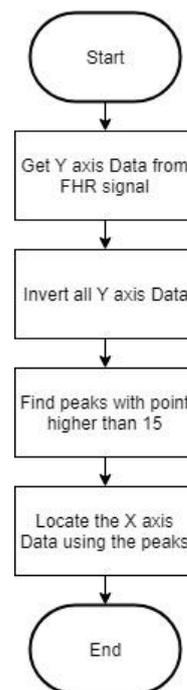


Figure 5. Method 2 for decelerations

3.4 Overall Impression and Displayed Results

Once all the aspects of the CTG are assessed, the overall impression can be given. It is divided into Reassuring, Suspicious or Non-reassuring and Abnormal, or Pathological. There are different definitions for each category and actions to be taken.

The determination of the number of accelerations for FHR, the variability of FHR, the baseline of FHR, FT or FB, number of peaks for UC, and the types of deceleration are important. If all categories are assessed to be normal, then the overall impression will display to be normal. If at least one category is assessed to be suspicious and other categories are normal, then the overall impression will be suspicious. The method in this developed software is to count when a suspicious category is detected. If more than one category is assessed to be suspicious or at least one category is assessed to be pathological, then the overall impression will be pathological.

3.5 Execution Time

There are few measurements used to investigate which method is better for CTG tracing. The measurements include code length, accuracy, and execution time. In the developed software, *tic* and *toc* function are used to measure elapsed time. *Tic* starts the stopwatch timer, while *toc* stops the stopwatch timer.

3.6 Limitation

There are a few limitations to this work. Due to the data obtained are from the graph signal of the image file, there are only limited data can be obtained at a time. 15 minutes period is used for analysis. Few parameters, such as variable decelerations, could not be detected, as it needs at least 30 minutes or 90 minutes for further analysis. This might lead to some problems that could not be detected by CTG Reader.

Besides, prior to method 1 or 2, the extraction data from an image file is done by hand manually. This might lead to errors when users did not draw the signal accordingly. As a result, it might give a wrong interpretation of the analyzed signal.

4. RESULTS AND DISCUSSION

4.1 Image File to Digital Signal using a Drawing Method

A few test cases (see Appendix) have been conducted in this work. Some of CTG printouts are taken from the internet. Those images are different types of test cases. Those images are processed in MATLAB. Figure 6 shows an example of an image file CTG printout, and Figure 7 shows an example of a newly created signal of CTG after using the image extraction technique.

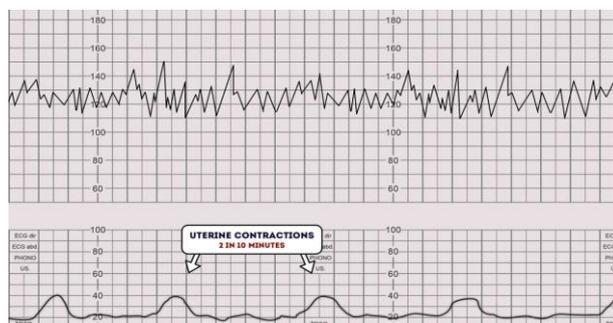


Figure 6. Test case 1.

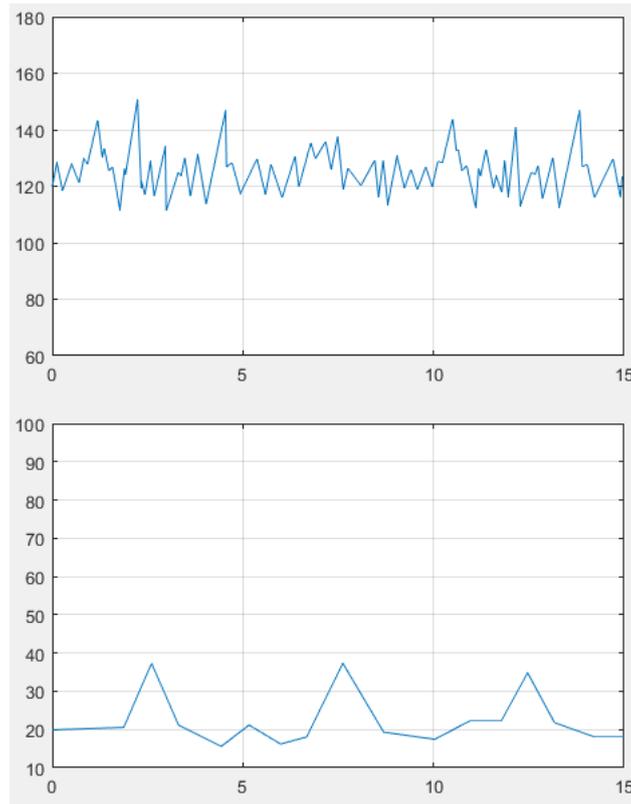


Figure 7. Reproduced Signal using MATLAB program.

4.2 Method 1 Results

There are 5 test cases for this method. All the results using method 1 are tabulated in Table 1. Figure 8 shows an example of the GUI result for a test case. Test case 1 shows the baseline is 125.557 bpm, and the variability is 11.2433 bpm. The number of accelerations is 6, the number of peaks of uterine contraction is 3, and the period between the peaks is 4.931 seconds. There is no deceleration for this CTG analysis. Therefore, all conditions are normal; hence, the overall impression is normal.

Test case 2 is to test the major acceleration in the signal. There are 3 acceleration detected. The FHR baseline and variability are 124.511 bpm and 8.1749 bpm, respectively, which are in the normal criteria. The number of peaks and periods for UC is 3 and 4.7564 seconds. Since there is no deceleration, it is considered as a normal overall impression.

Test case 3 shows the FHR baseline and variability are normal, which are 139.3636 bpm and 7.0909 bpm. The uterine contractions detected are 2, and the period is 5.4072 seconds. There is no acceleration in test case 3, which leads to 1 suspicious criterion. The deceleration detected is early deceleration since the difference in location between the deceleration and UC peaks is not more than 0.5. Hence, the overall impression is suspicious.

For test case 4, the FHR baseline is 136.2153 bpm, and the variability is 137.0619 bpm. While the number of UC peaks is 2, and the period is 6.042 seconds. Besides, there is also no acceleration detected in test case 4. Late deceleration is found for this case since the UC peaks are present between 0.5 and 1.5 after the deceleration point. Therefore, it is considered as pathological because of the absence of acceleration and late deceleration.

Test case 5 shows the FHR baseline is 97.2099 bpm, which is also Fetal Bradycardia, which means baseline less than 100 bpm. The variability of FHR is 9.0637 bpm. The UC peaks detected is 4, the period is 1.8876 seconds, and no acceleration is found. It is shown from the FHR signal that the deceleration is up to 30 bpm decrease and 3 minutes long. Hence, it is a prolonged deceleration, and the overall impression is pathological.

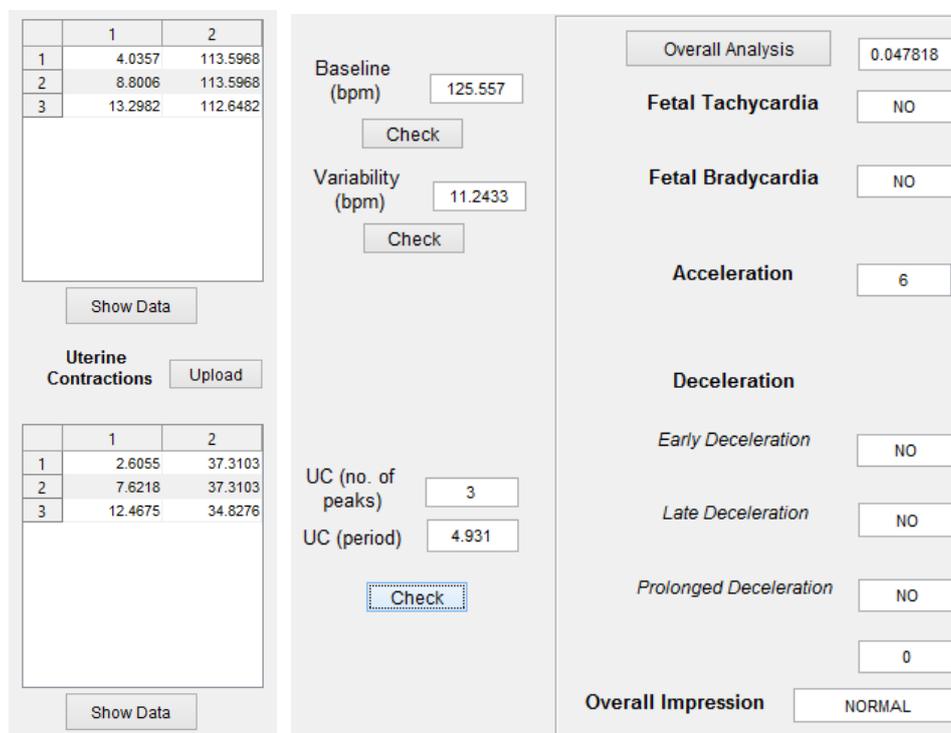


Figure 8. GUI result (for test case 1).

Table 1 Method 1 Performance Summary

Test Case	Baseline (bpm)	Variability(bpm)	UC		Accelerations	Decelerations
			No. of Peaks	Periods (Seconds)		
1	125.557	11.2433	3	4.931	6	Absent
2	124.5111	8.1749	3	4.7564	3	Absent
3	139.3636	7.0909	2	5.4072	0	Early
4	137.0619	13.3665	2	6.042	0	Late
5	97.2099	9.0637	4	1.8876	0	Prolonged

4.3 Method 2 Results

Method 2 used the built-in function for MATLAB for both acceleration and deceleration detection, which are explained in the methodology section. All the results using method 2 are tabulated in Table 2. Test case 1 shows that the baseline is 125.1131 bpm, and the variability is 10.1724 bpm. The acceleration found in the FHR signal is 3, and there is no deceleration spotted. The number of UC peaks is 3, and the period is 5.0608 seconds.

In test case 2, the FHR baseline and variability are 124.374 bpm and 9.5325 bpm, respectively. The acceleration detected is 3, and no deceleration found in the signal. The UC peaks are 4, and the period is 4.3493 seconds. Method 2 can search for the major peak in acceleration too.

For test case 3, the FHR baseline is 139.6007 bpm, and the FHR variability is 6.3108 bpm. The UC peaks are 2, and the period is 5.4525 seconds. There is no acceleration detected for this test case. The deceleration detected for this test case is early deceleration since the location of the deceleration point and peak point is approximately the same. Hence, the overall impression is suspicious since there is only no acceleration as one of the suspicious criteria.

Test case 4 shows the overall impression of CTG as pathological. This is due to no acceleration detected, and late deceleration detected as the location of the UC peak is after the location of the deceleration point. The FHR baseline and variability are 134.7588 bpm and 21.3379 bpm, respectively. The UC peaks detected are 2, and the period is 6.042 seconds.

Test case 5 is pathological for the overall impression. The baseline is 99.2313 bpm, which is Fetal Bradycardia when the baseline is lower than 100 bpm, and the variability is 7.8995 bpm. There are 6 UC peaks detected, and the period is 1.996 seconds. There is none acceleration detected while prolonged deceleration is detected, which leads the overall impression to pathological.

Table 2 Method 2 Performance Summary

Test Case	Baseline (bpm)	Variability (bpm)	UC		Accelerations	Decelerations
			No. of Peaks	Periods (Seconds)		
1	125.1131	10.1724	3	5.0284	4	Absent
2	124.374	9.5325	4	4.3493	3	Absent
3	139.6007	6.3108	2	5.4525	0	Early
4	134.7588	21.3379	2	6.042	1	Late
5	99.2313	7.8995	6	1.996	0	Prolonged

4.4 Comparison of Method 1 and Method 2 Results

To investigate which methods are better in analyzing the CTG tracings, we have recorded a few aspects to compare with, which are the execution time, accuracy, and the code length for both methods. Table 3 shows the execution time for both methods. It is shown that method 2 has a shorter execution time than method 1 in all test cases, but the differences are insignificant. The longest time taken is in test case 4, using method 1, which is 0.047766 seconds, while the shortest time taken is only 0.0038683 seconds, which is in test case 5. It is found that method 1 takes an average 0.02786 seconds, and method 2 takes an average 0.01175 seconds to run the process. This may be due to the built-in function are compiled code as opposed to m-files, which are interpreted.

In addition, Table 4 shows the obtained results for both methods. We can see that almost all the obtained results from both methods are similar. The difference is the detected accelerations of test case 1 are 6 for method 1 and 4 for method 2 and test case 4, which has 0 acceleration but 1 acceleration in method 2. This small difference could due to human error and does not affect the final overall impression. Decelerations and overall impressions results are the same for both methods. The achievement shows high accuracy for both methods can be achieved.

Table 5 shows the code length for both methods. The table shows that method 1 requires 10 rows for both accelerations and decelerations. On the other hand, method 2 only uses 4 rows for accelerations and 2 rows for decelerations. This shows that the programming code for method 2 is shorter than method 1 and, therefore, more efficient.

Table 3 Execution time for both methods

Test Case	Method 1 (second)	Method 2 (second)
1	0.047616	0.012023
2	0.01796	0.010205
3	0.022076	0.014992
4	0.047766	0.010863
5	0.0038683	0.010656

Table 4 Results obtained for both methods

Test Case	Accelerations		Decelerations		Overall Impression	
	Method 1	Method 2	Method 1	Method 2	Method 1	Method 2
1	6	4	Absent	Absent	Normal	Normal
2	3	3	Absent	Absent	Normal	Normal
3	Absent	Absent	Early	Early	Suspicious	Suspicious
4	Absent	1	Late	Late	Pathological	Pathological
5	Absent	Absent	Prolonged	Prolonged	Pathological	Pathological

Table 5 Code length for both methods

Type of code	Code length (rows)	
	Method 1	Method 2
Accelerations	10	4
Decelerations	10	2

5. CONCLUSION

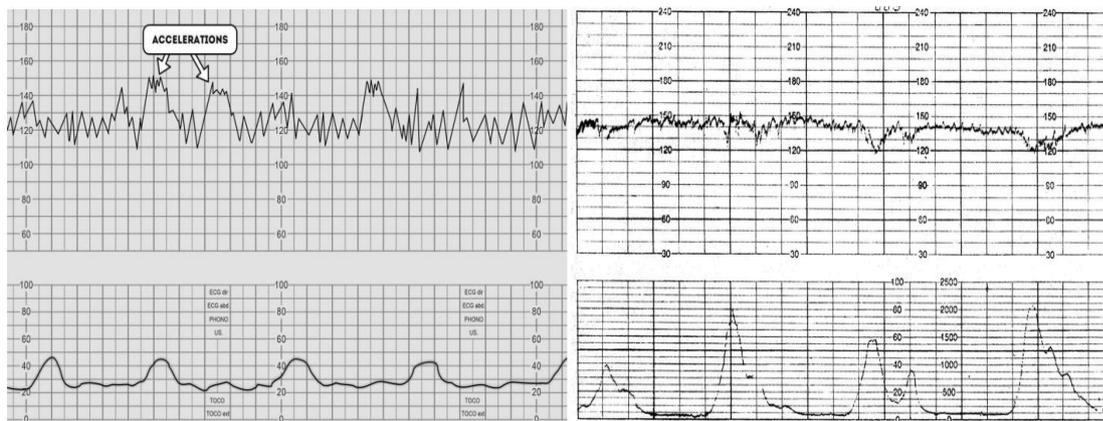
This paper has described a MATLAB-based software of cardiotocography waveform analysis using the proposed image-extraction technique. Initially, a drawing technique has been used to draw the line of the signal and convert it into useful data. 5 different test cases are successfully converted into the digital signal from image files for further analysis. In this work, 5 parameters have been used to analyze the CTG, which are the FHR baseline, FHR variability, number of UC, accelerations, and decelerations. By using these parameters, the overall impression of the CTG can be concluded. In addition, a GUI has been developed to ease the users. Users do not need to access to MATLAB or know anything about the software programming. Two methods are used to find out the faster algorithms to display the result fast and efficient. Both methods show high accuracy, short execution time, and method 2 has a shorter code length.

The future work can include adding more parameters to have a better interpretation of the CTG waveform. Some parameters require a longer time frame, such as variable decelerations. Therefore, a longer time frame might be a good way to improve the work. Besides, the 'image-processing' technique can be improved by extracting the data automatically. Thus, the users would not need to point for every data to extract them.

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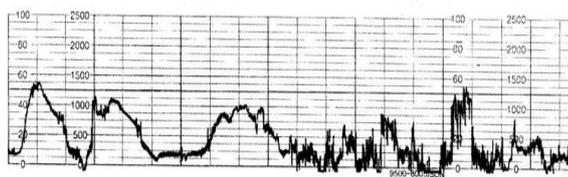
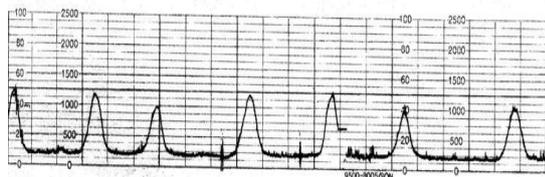
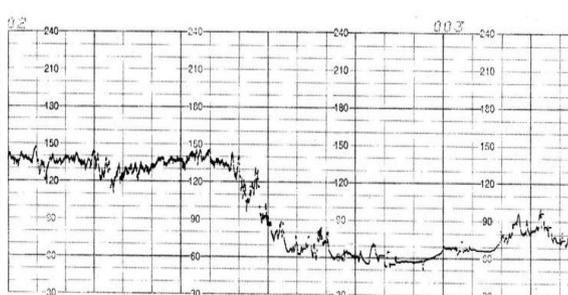
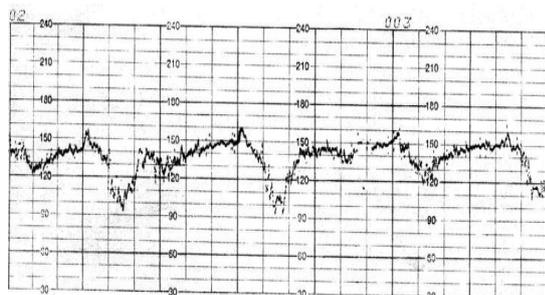
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APPENDIX



Test Case 2

Test Case 3



Test Case 4

Test Case 5