An advanced software tool for analyzing and interpeting Gardiotocograms

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ABSTRACT: Labour is a stressed procedure for both the fetus and the mother and a key issue for fetus surveillance is the detection of fetal distress. This paper describes a software tool that has been developed in order to monitoring fetus status by acquiring and processing the Cardiotocogram (CTG). This software tool establishes a communication between PC and the cardiotocograph, the medical device that records and prints out the Fetal Heard Rate and the Uterine Activity. Then, the software tool pre-processes the signal from the cardiotocographic device, artifacts are removed and non-signal parts (gaps) are filled utilizing an interpolation method. The more advanced part of the software tool includes the processing of CTG signal, extracting the characteristics of the signal such as baseline, variability, accelerations and decelerations. According to these characteristics, CTG can be evaluated and comments on the physiological or not status of the fetus can be done and giving an objective estimation on the health of fetus to the doctor.

INTRODUCTION

The continuous recording of fetal heart rate (FHR) and uterine activity (UA) on a single paper strip is referred as a cardiotocogram (CTG). The medical device that is used for acquiring and printing out the corresponding signal is called cardiotocograph. The instantaneous FHR (beats/min) can either be obtained by Doppler ultrasound or directly from the fetal electrocardiogram via scalp electrodes. The uterine activity is measured using an external tocodynamometer or with the use of an intra-uterine pressure catheter (mmHg) [1]. Today, almost all cardiotocographs in use are operating using Doppler ultrasound and external tocodynamometer and this will be our base for recording and examining CTG.

The use of cardiotocography (also named electronic fetal monitoring), antenatally as well as during labor, is world wide regarded as an indispensable part of fetal surveillance. However the examination and interpretation of a cardiotocogram is far from easy. Inter- and intra-observer agreement regarding the classification and interpretation of cardiotocographic patterns is greatly disappointing [2,3,4]. In light of this observation and in combination with the advances in computational power of nowadays personal computers some automated or semi-automated systems have been introduced to clinical practice for the interpretation of the cardiotocogram and the extraction of the most important features that are contained in any particular graph [5,6,7].

Towards the development of a fully automated diagnostic and expert tool, that would become a Decision Support System for the obstetrician, the first step is the development of a software tool for the acquisition of the cardiotocographic data. This tool will have the advanced ability to operate in autonomous way for archiving and interpretation of CTG. Moreover the output of the system will be qualitative information on the classification of CTG that can be combined with clinical data from other sources that would lend towards the development of a complete expert system for the manipulation of fetal deliveries.

DATA ACQUISITION

Currently all cardiotocographic devices have an RS232 serial port that can be used directly for data acquisition and remote display of the CTG signal. Through this serial port a computer can have access to all the measured data and configuration settings. Thus, significant signal values such as the Fetal Heart Rate and the Uterine Activity can be recorded, displayed and processed remotely.

The software tool that has been developed is a Microsoft Windows based software, as Windows is a very popular operating system with many advantages, like data-sharing and user-friendly environment. The software tool has been developed with Microsoft Visual C++ version 6 [8].

The developed software tool has been tested and validated using the cardiotocograph Huntleigh's BD4000though its serial port. The communication protocol between the PC and the cardiotocographic device is based on the handshaking method using the settings for handshaking described in the Huntleigh's protocol manual [9]. During the communication procedure the software tool acts as a master and the cardiotocograph device as a slave. When the data acquisition

procedure starts, the software tool sends a command word to the device, through the communication port (COM1 or COM2) where the device is attached and waits for the answer word. The answer word is a string, which contains the requested information and a CRC word to insure the data integrity. Some example command words are shown in Table 1. Using this simple protocol, the software tool obtains the FHR, UA and other significant data and stores them in the computer's memory (buffer) as well as in a temporary file for further analysis.

Table 1. Some Commands for the Communication Protocol.

Data	Command from Host	Answer word	Description
FHR	$10A<CR>	09830<Checksum><CR>	FHR=098bpm, Signal Quality=3 (good), Status=0, Checksum='0'+'9'+'8'+'3'+'0'+'A' modulo 256
TOCO	$10B<CR>	03071110<Checksum><CR>	TOCO value=0307, TOCO_zero_flag=1 (zero button has been pressed), Checksum='0'+'3'+'0'+'7'+'1' +'1' +'1' +'0'+'B'

The developed software tool uses regular (fixed) interval fetal heart rate sampling instead of recording and displaying each heartbeat. The advantage of using a constant sampling rate is the ease with which data can be handled by the software and/or hardware for further analysis. There are two options for the sampling rate at 4 Hz (default) and at 10 Hz, for special research needs. The rate of 4 Hz seems to be a reasonable option for the particular implementation and for the time being we use the default frequency of the 4 Hz for the acquisition of the FHR signal

The cardiotocographic device signal is also sampled every one second for the acquisition of the UA value. The use of an apparent slower sampling rate is preferred as this particular signal is a low frequency signal and the 1 Hz sampling rate is more than satisfactory. Technically, the sampling method is implemented using a timer mechanism provided by Windows OS. Using the timer configured at the desired frequency, the software tool sends periodically messages to the cardiotocographic device through the communication port (COM1/2). Once an answer word is received, a command parser is executed to identify the word and to gather the information available, also checking for CRC errors if it is enabled. If a CRC error found, the acquisition procedure stops and an error message is displaying to the user.

The communication procedure just described is concerned as the "On-line" mode where data are been acquired from the cardiotocographic device at the same time that cardiotocograph records the data from the pregnant. There is another mode the "Off-line" mode. In this mode the user can open a file, where CTG data are stored from a previous acquisition, and the signal processing procedure starts.
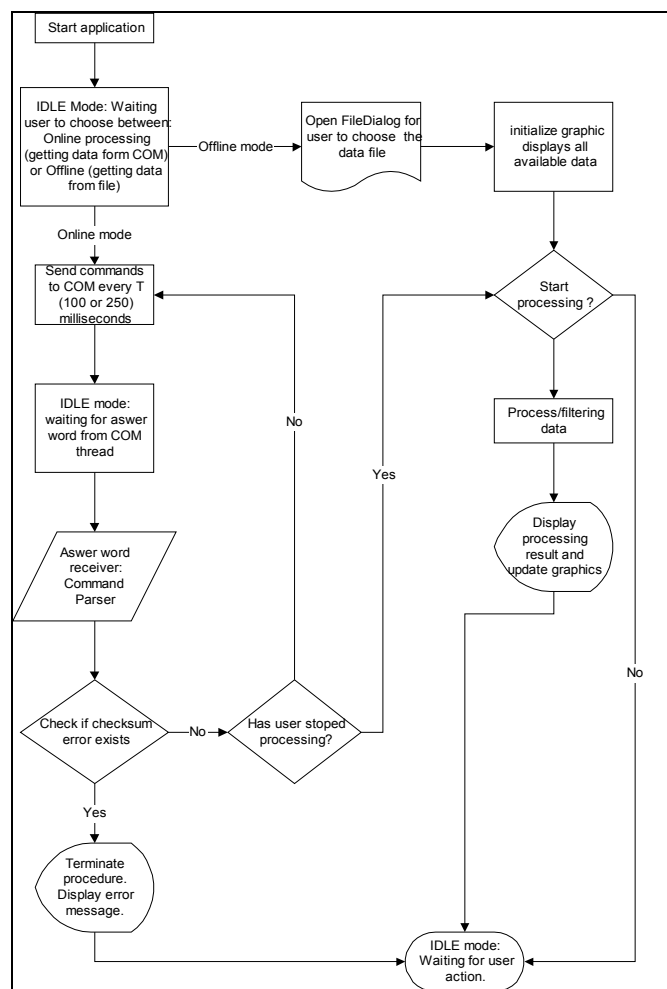

Figure 1- Application flowchart.

The signal processing part and results extraction is common in both modes (Figure 1).

THE SOFTWARE TOOL-USER INTERFACE

The software tool can be characterized as a user-friendly and easy-to-use application. When the software tool runs a main window appears which is divided into 3 visual parts. The graph window, where FHR, UA values and other processing data are being displayed graphically, the results part, where the results after the processing of the acquired data are being displayed and the command part where the user can insert patient's information and control the entire application (Figure 2).

Once the program has been installed and executed, the necessary operational settings must be configured. The first thing that user has to determine is the communication port of the PC where the cardiotocograph is connected through the options menu (Figure 3).
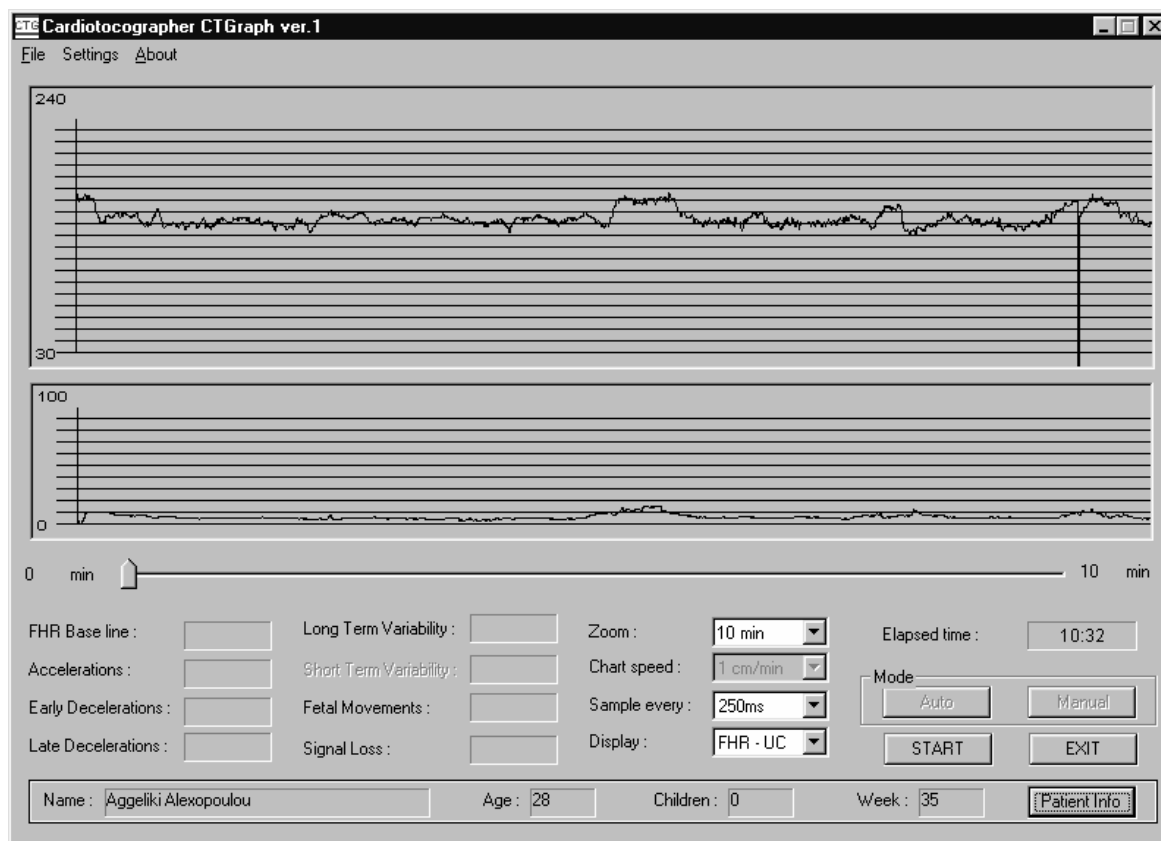
Figure 2. The application main window.

Moreover, in settings menu at submenu options, the user can determine some special functions:

- What cardiotocographic device is connected to the PC (currently only Huntleigh's BD4000 choice is available),
- what kind of data will be stored in the file,
- whether or not the Doctor's Comment Window will be shown after every acquisition and
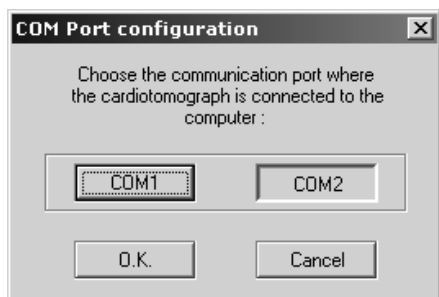- whether or not the CRC word will be checked during communication (Figure 4)

Figure 3. The COM port configuration window.

Once the settings have been configured the program is ready for data acquisition and/or analysis. At any time later the user can change these settings.

Prior to every CTG data recording the operator of the system, usually an obstetrician has to fill in the patient's personal information form. This form gathers necessary information, for the obstetrician and the monitoring of woman's pregnancy. Thus a data record is created containing: woman's age, the week of pregnancy, the number of children that this woman delivered (parity). Moreover, the obstetrician can add any other useful information or comment. This form simplifies the doctor's task of archiving and storing the information related to the particular pregnant (Figure 5).
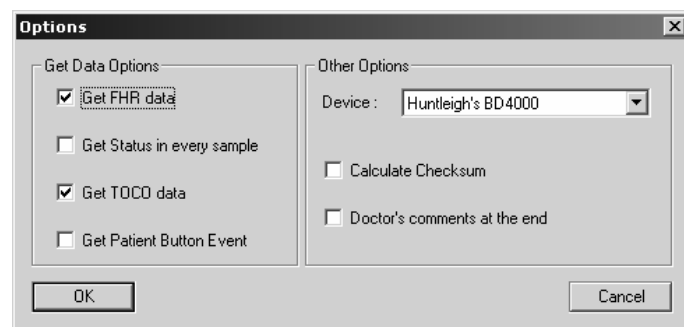

Figure 4. Configuration window.

During the data acquisition from the cardiotocographic device the user can observe the raw data on line, enabling the correspond choice from the control part of the application.

The system stores the patient's personal information and recorded data, including the starting and stopping time, in an ASCII format file. It is assumed a general way on naming every file; the filename is based on the patient's name, the hour and date of the CTG acquisition.
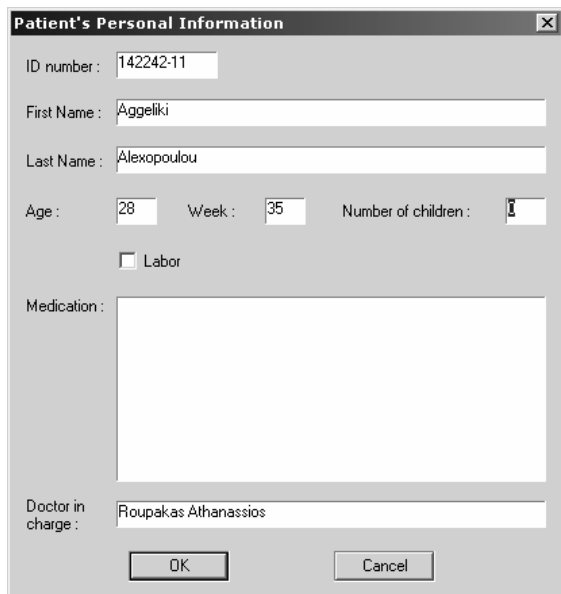
Figure 5. Patient Personal Information application window.

In addition to the patient's information that is filled at the beginning of the recording, the clinician in charge can add more comments, suggestion**s** and other medical important information after the recording of CTG (Figure 6). The clinician can retrieve the CTG data any time later to use them for retrospective analysis enabling the Off-line mode.
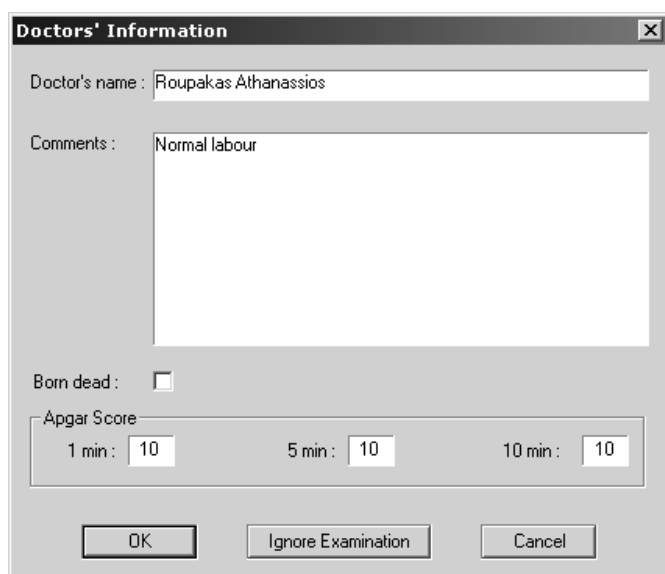

Figure 6. Doctor's comments application window.

When the data acquisition procedure from the cardiotocographic device has been completed, a question-form appears asking the user whether or not the software tool will continue with processing the received data. If the user's answer is positive a graphic initialization takes place and the processing of the measured data starts displaying on the graphic part the calculated baseline, accelerations and other values. In the same time the result part of the software tool will be updated with the new results and it is going to idle mode.

PREPROCESSING OF DATA AND REMOVAL OF ARTIFACTS.

During the antepartum period of pregnancy the continuous recording of the fetal heart rate is based on the ultrasound signal. The autocorrelation of the signal has improved the FHR trace, but there are a number of disadvantages. The autocorrelated signal has spiky "artifacts" (abrupt changes by more than 35 bpm) [20] and also sometimes the rate is halved or doubled [21].

Whenever a difference between adjacent beats is higher than 25 bpm, simple linear interpolation is implemented. The interpolating algorithm is used between the first of those two samples of the signal and the first new "valid" sample of the FHR signal.

Moreover the same interpolating algorithm is used for the case of missing beats. The proportion of the signal that is replaced by linear interpolated values and the proportion of the signal with very low quality is used as a measure for the acceptance or not of the trace as valid to be submitted for further processing. In the latter case the software tool informs the clinician with a warning message to rearrange the relative position of the transducer.

The Uterine Activity signal also needs to be processed for the removal of the high frequency components using a low pass filter. Tocodynamometer measurements cannot be quantified accurately and therefore calibration marks have little meaning [1]. Therefore the uterine resting tone has to be estimated and it is estimated as the mode of the low-pass filtered UA signal. Then the Uterine Contractions are calculated as an increase of the UA signal 10 (relative) units above the resting tone and lasting more than 40 secs [13]

PROCESSING OF CTG

The software tool do not only archive and preprocess CTG but it operate in an autonomous manner. When the "on line" mode is selected the clinician has access to the preprocessed data that results from the removal of the artifacts and the filling of the missing beats. In the "off line" mode the clinician can retrieve any previously recorded cardiotocogram file that has been stored.

The next step is the processing of CTG. The software tool is used to process the CTG signal and extract the characteristics and other useful information from the data. The baseline and the periods of accelerative and decelerative patterns can be calculated. The quantitative measurements of the cardiotocographic features are primarily based on FIGO guidelines [10] and are calculated using special developed routines incorporated into our system. Results of the processing are illustrated on the software tool and are marked on the processed cardiotocographic tracing

Baseline

The baseline is "the mean level of the fetal heart rate when this is stable, and accelerations and decelerations being absent" according to the FIGO guidelines [10]. A consequent and reproducible estimation of baseline is an essential prerequisite for any objective description of fetal heart rate

recordings. Nevertheless, baseline of FHR has a hypothetical nature, because there is no experimental way to verify whether or not the estimation of baseline is valid [14].

For the determination and calculation of baseline numerous algorithms have been proposed [13,14,15,16]. In our system, a new algorithm is proposed and implemented: The preprocessed data (the data after the removal of the artifacts and the filling of the missing beats) are passed through a low pass fourth order zero-phase (two pass) Butterworth filter with a cut off frequency of 0.008Hz. By heavy low passing the FHR data a rough estimation of the so-called "running" baseline is calculated.

The preprocessed data are also passed through a low pass fourth order zero-phase (two pass) Butterworth filter but with a much higher cut off frequency than that of the first stage (of

0.4Hz.). By doing so, a rough approximation of the original signal is created after removing the high frequency components but leaving the accelerations and decelerations that give rise to low frequency components and thus can easily pass the filter [14]. Subsequently the product of the second stage is subtracted from the output of the first stage and if the absolute difference is above FHR the original beats are considered as part of a deceleration or acceleration and that particular segment is replaced by linear interpolated values. Finally the data (after the filtering the "pruning" and the linear interpolation) are passed through a low pass fourth order zero-phase (two pass) Butterworth filter but with a cut off frequency of 0.004Hz and their mode is considered to be the baseline of the trace.
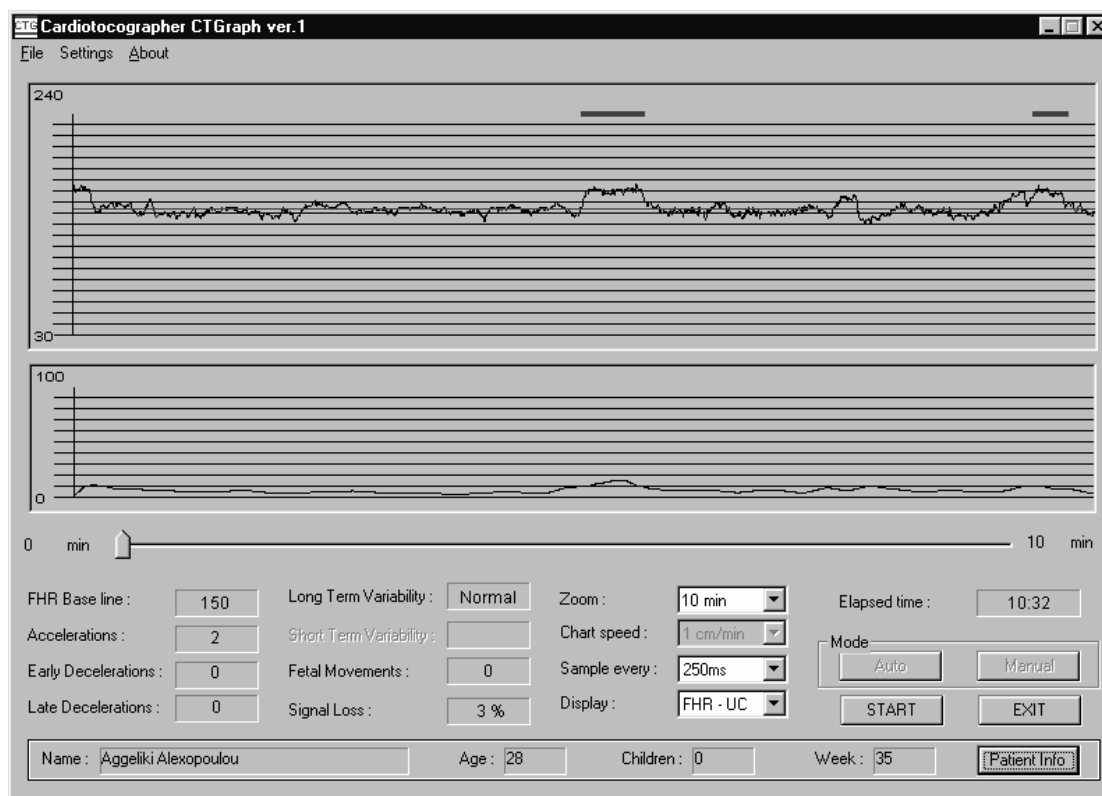

Figure 7 The CTG signal and the results of the processing (Baseline, variability etc) are depicted in the main window.

Accelerations And Decelerations

Accelerations are determined according to the FIGO guidelines as increases from FHR baseline greater than 15 beats per minute and lasting more than 15s. Nevertheless after the observation that the obstetricians tend to classify as accelerations elevations that are near the acceptable limit but without fulfilling the criteria of the 15 beats, another classification was attempted using as threshold an elevation of 10 beats. This comparison is made between the calculated Baseline and the signal after passing through the filter with the cutoff frequency at 0.4 Hz. The number of accelerations and "mild" accelerations [16] is computed and their temporal positions also marked on the display of the tool.

Decelerations are determined as decrease from FHR baseline greater than 15 beats per minute lasting at least 15s. Again the

number of decelerations is computed comparing the Baseline and the low passed version of the FHR signal and there is also a graphical indication on the display window of the software tool.

The system classifies the decelerations as early, late or variable in accordance to their position considering the peak of the more approach uterine contraction (even though this is not probably the best way to classify decelerations [GGG]

Variability

Long-term variability is calculated as the difference between the highest and the lowest FHR during one-minute using the algorithm presented in [13] (amplitude of variability). The Long Term Variability is considered reduced/absent if it is less

than 5 beats per minute, normal if it s in the range [5,25] beats per minute and increase if exceeds 25 beats per minute.

Taking into consideration that because of the use of autocorrelation there can be up to 30% reduction in the measured beat-to-beat variation compared with that determined simultaneously using the fetal ECG the system does not calculate short term variability [17].

Figure 7 illustrates in the graph window the cardiotocogram signal after preprocessing, in the middle part the results and calculations on the CTG characteristics are depicted and also the patient information is depicted.

CLASSIFICATION OF CTG

The importance of CTG is for evaluating the Fetus health status according to findings and features of CTG. Some scoring systems have been proposed that take under consideration all the CTG characteristics and classify it as normal, suspicious or pathological. The scoring systems have aimed to limit the variation in the reading and classification by providing some general guidelines [18] Scoring systems remain in use in many European countries [4] but there remains general concern about the degree of observer variation with regard to interpretation of CTG records.

Scoring systems were developed to classify fetal heart tracings as normal, suspicious or ominous. Following these scoring systems, guidelines were supplied for obstetric management. The criteria for the classification of the fetal heart rate patterns were however mainly based upon empiricism. The current version of the system is capable of classifying the tracings as normal, suspicious and pathological utilizing a number of fixed criteria in accordance to FIGO's guidelines for the antepartum period [10]. These criteria are summarized in Table 2.

Table2. Scoring system for classifiacation of CTG

	Normal	Suspicious	Pathological
Baseline (beats/min)	110-150	100-110 or 150-170	<100 or >170
Variability (beats/min)	5-25	5-10>40 min or >25	<5 >40 min or sinusoidal
Accelerations (n/10 mins)	2+	absent >40 min	absent
Decelerations	absent	occasional and small	any recurrent or large, long or late

CONCLUSIONS

This paper described the development of a new software tool for recording, analyzing and interpreting Cardiotograms. The use of the software tool is very friendly and easy and but it is very useful because helps obstetrician to store easily information for his/her patients, to store the CTG data and process the CTG. Moreover the software tool provides the "knowledge" engineer with a vast amount of information.

The most important part of the described software tool is the pre-processing and processing part. New algorithms and methods have developed for improving the CTG signal and calculation the CTG characteristics and the corresponding routines were developed. This part is very helpful to obstetrician because it is an objective calculation of the CTG quantities and characteristics far more advantage and automated than estimating them by him as the obstetrician does today.

At this point, it must be mentioned that the precise calculation of the CTG quantities and so the extraction of CTG features and characteristics is very tough task that is still under investigation from the scientific community worldwide. This means that the whole issue is still under investigation and the software tool is going to be expanded incorporated the new methods for processing CTG that are developed. Moreover, further development and validation of the system is currently in progress.

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