Design of H-IoT Based Pregnancy Monitoring Device in Free-living Environment

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Research Article

Keywords: Electromyography (EMG), Fetal Electrocardiogram (FECG), Fetal Heart Rate (FHR), Handheld Pregnancy Monitoring Device (HPMD), Health-Internet of Things (H-IoT), Pregnancy Health Monitoring (PHM).

Posted Date: June 9th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1102515/v1

Abstract

The revolution of Internet of Things (IoT) technology has paved the way for designing modern health care systems. Among the various applications of IoT, health care monitoring is need of the hour. This paper deals with the design of a Handheld Pregnancy Monitoring Device (HPMD) that comprises of a wearable abdominal patch and mobile application (Pregnancy Health Monitoring app) interfaced with the analytical Health-Internet of Things (H-IoT) platform. This aids in non invasive measurement of the pregnant woman's uterine contractions, the Fetal Heart Rate (FHR) and the fetal presentation to detect true labor and to ensure fetal safety. Here, the abdominal patch includes the Electromyography (EMG) electrodes that capture the uterine contractile activity and the Fetal Electrocardiogram (FECG) electrodes that capture the fetal electrical activity for monitoring FHR and fetal presentation. Now, the data captured from these electrodes are analyzed using the H-IoT platform by using various methods. A Level crossing rate method is used in H-IoT to differentiate true labor from Braxton-Hicks (false labor). In addition, FHR is retrieved using Discrete Wavelet Transform (DWT) and fetal position is determined by cross correlating the obtained FECG with the existing FECG template. Further, decisions from the analyzed parameters are displayed in the Pregnancy Health Monitoring (PHM) mobile app which includes the live visualization plots of the EMG and FECG signals for monitoring the mother and fetus health condition in the free-living settings.

I. Introduction

The recent advances in microelectronics, sensor manufacturing, telecommunications, and data analysis techniques have opened up new possibilities for designing innovative pregnancy wearable devices in the smart healthcare systems. In the present condition, almost all pregnant women experience labor pain at an uncongenial environment like home, workplace etc., where they need to search for the final logistics to reach the hospital for a safe delivery. This situation causes more stress to the patient, their family members as well as the doctors and the hospital faculties involved in the treatment for the safety of the newborn. Thereby, pregnancy health monitoring is considered as vital process to avoid obstetric complications by providing just-in-time care during the needy hour.

The periodic tightening and relaxing of the uterine muscles lead to the labor contractions [1] in a woman's body. In the childbirth process, the progress of labor goes through a series of contractions. These contractions thicken the upper part of the uterus, while the cervix and lower portion of the uterus stretch and relax, which helps the baby to pass from inside of the uterus, into the birth canal for delivery. Contractions occurring during early pregnancy period are generally weak, irregular and often unfelt. No change occurs in the cervix during these pre-labor contractions, sometimes referred to as false labor or Braxton-Hicks contractions. Many pregnant women cannot differentiate between the true labor contractions and Braxton-Hicks contractions. At full term, beyond 37 weeks of gestation, more intense and regular contractions occur to assist the mother in the normal delivery of the baby. The contraction patterns vary in the three stages of labor.

1. Selection of Vital Parameters for Pregnancy Monitoring

Early labor is widely variable and can last anywhere between a few hours. In the early stage of labor, the duration and intensity of the contractions are very less, hence not painful. The time duration between the contractions can last from five to twenty minutes, and contractions last less than a minute. The active labor, the second phase of the first stage of labor, has an average duration of 12 hours where the contractions are very intense. The final phase of the first stage of labor is a transition. This phase can last for few minutes to few hours. In the second stage of labor, pushing of the baby progress is being made and the third stage of labor, during which the placenta is delivered, lasts about 10 minutes.

Another vital parameter is monitoring the fetal heartbeat, which determines the well-being of the fetus. The health care provider uses this procedure to assess the different rhythm and rate of the fetus heartbeat. Under normal conditions, a fetus heart rate ranges anywhere from 120 beats to 160 beats per minute [13]. This rate varies depending on the type of environment the fetus experiences in the uterus. If the fetus heart rate becomes abnormal, it could mean that the fetus is not getting sufficient amount of oxygen or there could be other labor-related problems. Monitoring the heartbeat allows the physician to ensure the newborn’s health during the pregnancy and labor.

During labor, many changes occur in the fetal attitude, position, and presentation. As the fetal grows during the pregnancy, they may move around in the womb. But in the last month of pregnancy, the baby becomes bigger and doesn’t have much space to move. At that time, the presentation of the fetal becomes very important, because the fetal gets into the best suitable position to prepare itself for delivery as the due date is nearing. The size of the baby and uterus determines the fetal head position. In the early pregnancy stage, fetal has plenty of room in the uterus, hence it is not necessary to be in the head down position. As the pregnancy progresses, the space in the womb starts decreasing and the bottom side of the fetal occupies the upper side of the uterus while the fetal head takes the lower side towards the birth canal. If the fetal does not adopt the head down position, then it leads to a complicated process due to abnormalities in the uterus. The conventional technique used for determination of the fetal presentation is ultrasound imaging, which is very expensive to use for long-time monitoring. Hence monitoring the fetal presentation during the labor is an important parameter for pregnancy monitoring.

2. State of Art

In the recent years, awareness about pregnancy health monitoring among people is increasing. With the fast growing technology, there are numerous ways for health monitoring among where non-invasive techniques are widely used. Research in [2] evaluates the capability to indicate the preterm delivery risk analyzing the spectral parameters and time domain features extracted from signals of electrical uterine activity. The electrohysterography (EHG) is a promising tool, as it indicates the symptoms of preterm labor. The sample entropy, the mean values over the contraction episodes were detected in each record and their statistical significance for distinguishing the full term and pre-term groups of recordings was provided.

The detection of labor [3] is done by the combination of the Heart Rate (HR) and EHG by the extraction of time and frequency domain features. It also showed the different physiological features obtained to recognize labor and non-labor records with the accuracy rate of 87%. A comparison of linear and non-linear signal-processing techniques was done in [4] using uterine EMG records. The linear techniques such as peak and median frequency of the signal power spectrum, root mean square value and autocorrelation zero crossing and the non-linear techniques were the estimations of the correlation dimension, maximal Lyapunov exponent and sample entropy. These techniques helped in classifying the term and pre-term deliveries. In [9] non-linear correlation co-efficient is used to predict pre-term labor, monitor pregnancy, and detect labor.

A 3-D model based on the single dipole of the electrical activity of the heart [5] is proposed. It relates to the body surface potentials considering the rotations and movements of the cardiac dipole, together with a realistic ECG noise model. The limitation of recording long-term ECG data is discussed. A multichannel fetal ECG signal extraction process [6] is done by Multivariate Empirical Mode Decomposition (MEMD). The signal is decomposed into p-variate IMFs and finally, Singular Value Decomposition (SVD) is done. An accuracy of 85.33% is achieved for Fetal Heart Rate. In [10] the presence of fetal QRS is determined using template and normalizing fetal ECG signal.

The existing works described herein are the techniques to monitor the patient only inside the hospital settings but are not accessible in the free-living environment. The work proposed here is used for monitoring labor conditions in a free-living state, by a Handheld Pregnancy Monitoring Device (HPMD) with the access of Internet of Things (IoT). This device helps the pregnant woman to monitor three vital parameters such as the uterine contractions by Level crossing rate, Fetal Heart Rate by fetal signal extraction and the fetal presentation by signal template matching non-invasively by characterizing various features. Hence healthcare experts can get access to large amounts of physiological data, analyze the healthcare trends and monitor the particular pregnant woman's health condition. The remainder of this paper is organized as follows. Section II describes the system model for Pregnancy Monitoring. The biosignal acquisition and estimation of the vital parameters are described in Section III and about the Pregnancy Health Monitoring (PHM) app is discussed in Section IV. Finally, this paper is concluded in Section V along with the future works.

Ii. System Model For Pregnancy Monitoring

Figure 1 represents the system comprises of wearable patch attached on the abdomen of the patient, an analytic IoT platform where the features are extracted in real time over a period of time and the analysis results are decided based on the thresholds provided and the final results are displayed in the Pregnancy Health Monitoring (PHM) Mobile application.

The wearable patch comprises of an EMG (Electromyogram) sensor and a FECG (Fetal Electrocardiogram) sensor attached on the abdomen of the pregnant woman using disposable electrodes. EMG signals are used in many clinical and biomedical applications that measure the electrical activity of uterine muscles at rest and during contraction. The FECG records the electrical activity of the baby's heart and the pattern of the heart beats over a period of time.

ThingSpeak is an Internet of Things (IoT) platform [8] for collecting and storing the sensor data in the cloud and which is used to develop IoT applications. Another attractive feature of ThingSpeak platform is that it provides apps for analyzing and visualizing the data, as well as acting on the data depending on the specified conditions.

The EMG data and FECG data are sent to the ThingSpeak platform wirelessly. The feature extraction is done in ThingSpeak, where the analysis is done on EMG and FECG signals. The uterine contractions are calculated by level crossing rate from the EMG signals. In FECG, the maternal noise suppression and extraction of the fetal signal is done. From the extracted fetal signal, Fetal Heart Rate (FHR) and the fetal presentation are estimated. Finally, the safety limits for the parameters are fixed as thresholds based on the analysis and mapped for monitoring the labor conditions to ensure a safe delivery.

Iii. Biosignal Acquisition And Estimation For Pregnancy Monitoring

1. Data Acquisition

The wearable patch consists of EMG electrodes which are represented as 2, 4, and 6 in a triangular configuration. The FECG electrodes are represented as 1, 3, and 5 in the patch for obtaining the FHR and fetal presentation from the maternal abdomen. The electrodes are adhesive and need to be placed properly for recording the required physiological data. The electrodes are placed near the navel to capture the signals. The electrical activities of the electrodes are captured and they are transferred to the analytic IoT platform for feature extraction.

2. Interfacing with Analytic H-Iot Platform

In the analytic IoT platform "ThingSpeak", a new channel is created which collects the physiological data wirelessly and sends it to the cloud for analysis by providing personal cloud for each user to store measurements giving API for easy access. The electrical activities of the electrodes are captured and the EMG and FECG data are sunk with the ThingSpeak. The channel specifications include the author's name, channel ID and the access provided for the channel. The channel status includes the time duration of the created data, latest updates, and the last entry is done. The channel view can be shared with the family members and medical services for knowing the status of the patient.

3. Pre-Processing of Signals

The EMG signal is digitized at 100 samples per second and is digitally filtered using different 4-pole digital Butterworth filter from 0.3Hz to 4Hz in the IoT analyzer. The FECG signal obtained has a wandering baseline which may be due to the maternal motion artifacts, any electrical noises or even breathing movements that contributes to lower frequencies. Hence to avoid these effects, the mean value of the signal is subtracted from the signal itself. The power line interference is removed by using a notch filter with 50 Hz frequency. A Butterworth band pass filter of 4-80Hz is used to remove the DC components.

4. Number of Uterine Contractions Estimation

The uterine EMG signals measure the action potential changes associated with the uterine contractions of the pregnant woman. The uterine contractions depend on the intensity of the EMG signal as well as the duration of the event that occurs. Uterine contraction is a vital sign of labor. Hence monitoring the number of contractions is an essential parameter.

The average number of contractions for each stage is estimated as below. During the first stage, i.e. at the early labor contraction period, 4 contractions per hour will occur. Further, during the active labor contraction period, first stage, and 15 contractions per hour will occur. Finally, at the first stage, i.e. transition contraction period, 24 contractions per hour will occur. As the labor progresses, the second stage leads to 12 contractions per hour and the third stage have 2 contractions per hour. Hence the contractions increase as the delivery approaches and then it gradually decreases when the baby is delivered.

The average number of times the EMG signal crosses a particular threshold is denoted as Level Crossing Rate reflects the uterine contractile activity. The EMG signals produce bursts of action potential spikes, which provide information during the pregnancy and labor. The estimation of the threshold levels is calculated by overlaying the labor EMG signals and the non-labor EMG signals. Hence at the onset of labor, continuous burst of EMG signals is found to occur. The threshold is fixed as 1500 which contributes to a strong uterine contraction.

The uterine contractions are determined by detection of the peaks of the EMG signal. The minimum peak height is specified based on the intensity of the EMG signal, which denotes the signal crossing the fixed threshold levels. The location of the peaks is found by finding the maxima and ties of the peaks. The peaks are detected for the time-series which exceed the minimum peak height which represents the strong uterine contractions. On analysis, the thresholds are fixed based on certain criteria to differentiate between the contractions for true labor and Braxton-Hicks accordingly. The Fig. 2 shows an example in which the Level crossing rate is determined for the uterine EMG time series data and the contractions are estimated as 3 contractions which are denoted in red circles. Hence the 3 contractions represent the first stage of early labor.

5. Fetal Heart Rate Estimation

The FHR will normally accelerate during a uterine contraction, and then gradually slows as the mother and baby recovers. If the FHR fails to recover adequately, medical attention needs to be provided. The normal heart rate of the fetus ranges from 120 (bpm) to 160 (bpm) [13]. Hence the safety margin is fixed as: 100 (bpm) < FHR (bpm) < 160 (bpm). If the FHR deviates from the safety margin then the fetal is prone to high risk of labor.

FECG signal provides valuable information about the fetal heart growth, fetal maturity, and health condition which is obtained by FECG electrodes on the surface of the abdomen. Maternal electrocardiogram (MECG) is a dominant noise mixed in FECG [7] and the amplitude, the magnitude, and the strength of MECG are greater than that of the FECG. Moreover, the baseline drift, the power-line interference, the gestational age, position of the electrodes, skin impedance and random electrical noise caused by human movement, baseline drift due to poor contact of measurement electrode are some external noises that can affect the FECG separation. The Essential problem is the efficient suppression of maternal electrocardiogram since its amplitude exceeds the level of the required signal. As the FECG signals are non-stationary and non-linear in nature, the noise suppression has to be done from the FECG signals. Suppression of maternal peaks for proper fetal signal extraction is required without losing the useful information.

In the wearable patch, the fetal electrical activity of the FECG electrodes placed on the abdomen is captured and sent to the ThingSpeak IoT platform wirelessly. The process of the FECG extraction is done as below.

A Discrete Wavelet Transform (DWT) is used in the ThingSpeak analysis to decompose the abdominal ECG signal which gives adaptive size window with maximum time-frequency resolution. DWT uses shorter windows at high frequencies (HF) and longer windows at low frequencies (LF) by applying a high pass filter and low pass filter. Hence a Daubechies wavelet is used as it is similar to the shape of the heartbeat. Then the data rate is reduced by a down sampling process.

The output of this down sampled data provides the detail and the approximate coefficients which analyze the HF and LF components respectively. The maternal QRS complexes are found from the approximate values of the obtained signal and the exact positions of the complexes are analyzed [6]. From the analyzed positions, the maternal template is created. This template is cross-correlated with the maternal signal obtained from the clinical data provided. The best match which is correlated with the maternal signal is selected. The FECG signal is obtained after the MECG subtraction of the best correlating template. Now the IoT analyzer detects the fetal R wave peaks (fetal ECG wave peak) and it is denoted as R [10]. The fetal R wave peak detection is done to calculate the RR interval (distance between successive R) [11]. The calculated RR intervals are used for estimating the FHR as shown in Fig. 3.

The decision handler in the H-IoT platform checks for the safety margin of the Fetal Heart Rate (FHR) as follows

- 100<FHR<160: FHR normal.
- FHR>160: FHR is too high.
- FHR<100: FHR is too Low.

If it lies within the normal range, then the baby is in good health condition otherwise, medical attention should be given at the right time.

6. Determination of Fetal Presentation

The typical ECG adult heart using electrodes placed on the chest gives the QRS complex. If the positions of the adult chest electrodes reversed, their positions are rotated through 180°, the ECG becomes an inverse copy of the previous ECG. The method of rotating the electrode positions is similar to the context of the fetal ECG, to the fetus rotating through 180° within the maternal uterus. The FECG will register the intermediate shapes when the fetus undergoes an angular rotation of 90° within the maternal uterus.

The presentation of the fetus depends on the abdominal FECG waveforms [10]. There are four types of FECG characteristic waveforms, where each one corresponds to a fetal presentation as Cephalic, Breech, Shoulder dorsoanterior and Shoulder dorsoposterior. The four types of FECG characteristic templates are generated and updated in the ThingSpeak IoT platform. The captured abdominal FECG signal is fed into another channel. Each template is cross-correlated with the captured signal and the maximum correlation with the templates is determined. The best-correlated template represents the fetal presentation accordingly as in Fig. 4 and Fig. 5 shows that type 1 ECG complex represents the Cephalic (Head down) presentation.

The decision handler in the IoT analyzer fixes safety limits for the three parameters. For EMG signals, the limits are fixed to differentiate between the contractions for true labor and Braxton-Hicks accordingly. For FECG signals, FHR normal range is fixed at 100 (bpm) < FHR (bpm) < 160 (bpm). For the fetal presentation, the signal template matching is done and presentations are found based on the highly correlated results.

Iv. Pregnancy Health Monitoring (Phm) App

The APP is created using an online development platform by parsing the URL of the ThingSpeak plots. The required blocks are designed like a puzzle on the graphical block development and the URL's of the required plots are called in the blocks to view the plots in the mobile phone.

The EMG and FECG plots of the ThingSpeak channel can be easily viewed in the PHM mobile application as in Fig 6. This Pregnancy Health Monitoring (PHM) app helps the family members to monitor the pregnant mother and the fetal health condition and alerts them if the labor progress deviates so that medical attention can be provided at the right time thereby reducing risks and complications in pregnancy.

V. Conclusion

A Handheld Pregnancy Monitoring device (HPMD) to monitor the pregnant woman health status by characterizing various parameters such as uterine contractions, the Fetal Heart Rate (FHR), and the fetal presentation non-invasively is designed with the help of Internet of Things.

The average number of uterine contractions by Electromyography signals estimated from the Level crossing rate by fixing thresholds based on certain criteria to differentiate between the contractions for true labor and Braxton-hicks accordingly. The FECG data obtained from the maternal abdomen is used for monitoring fetal health development. The fetal signal is extracted by maternal noise suppression and the FHR is calculated. Hence the decision handler in the H-IoT platform checks for the safety margin of the FHR as 100<FHR<160: FHR is normal; FHR > 160: FHR is too high; FHR < 100: FHR is too Low. Further, the fetal presentation is determined from the fetal signal by the signal template matching, where the abdominal FECG waveforms depend on the presentation of the fetus, the four types of FECG characteristic waveforms correspond to a fetal presentation are Cephalic, Breech, Shoulder dorsoanterior, and Shoulder dorsoposterior and the best-correlated template with the captured abdominal signal represents the fetal presentation accordingly.

Declarations

Funding

No funds, grants, or other support was received.

Conflicts of interest:

The authors have no relevant financial or non-financial interests to disclose.

Availability of data and material:

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

All the results of our work are crosschecked with real-time data obtained from the hospital. Also, the threshold values used in our project are carefully selected by doing field trip and interviewing more than one gynecologist and pediatricians.

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Figures

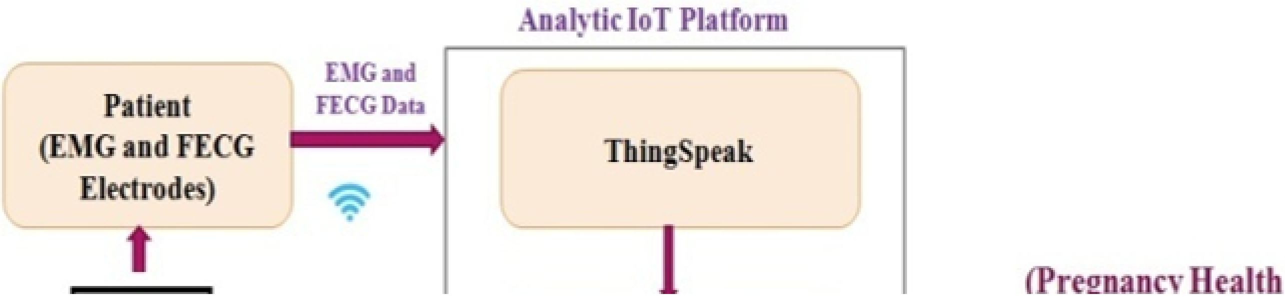
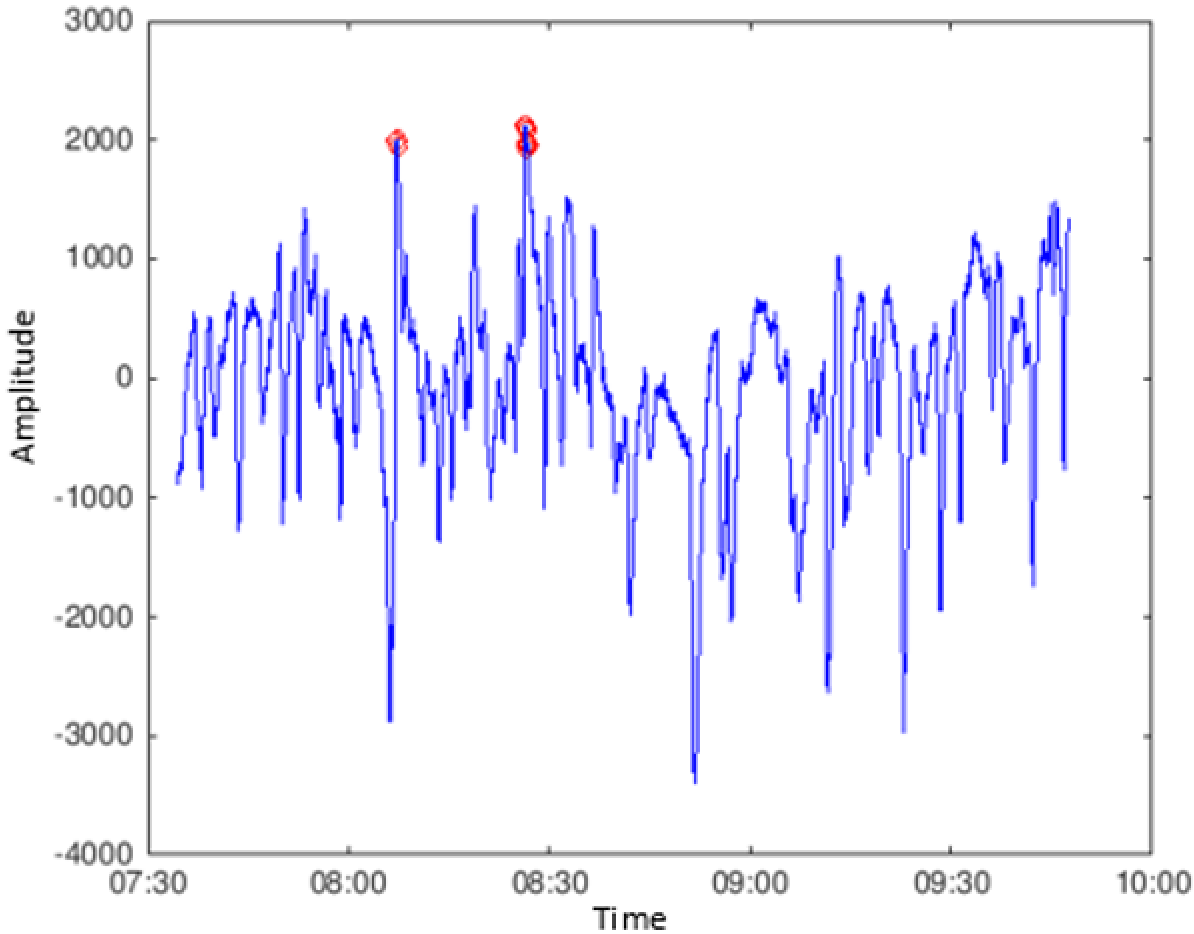


Figure 1

Schematic block diagram which shows interfacing of analytic H-IoT platform with wearable patch.

MATLAB Plot Output



Output

```
Number of uterine contractions:3
```

Figure 2

Uterine contractile activity measurement using Level crossing rate.

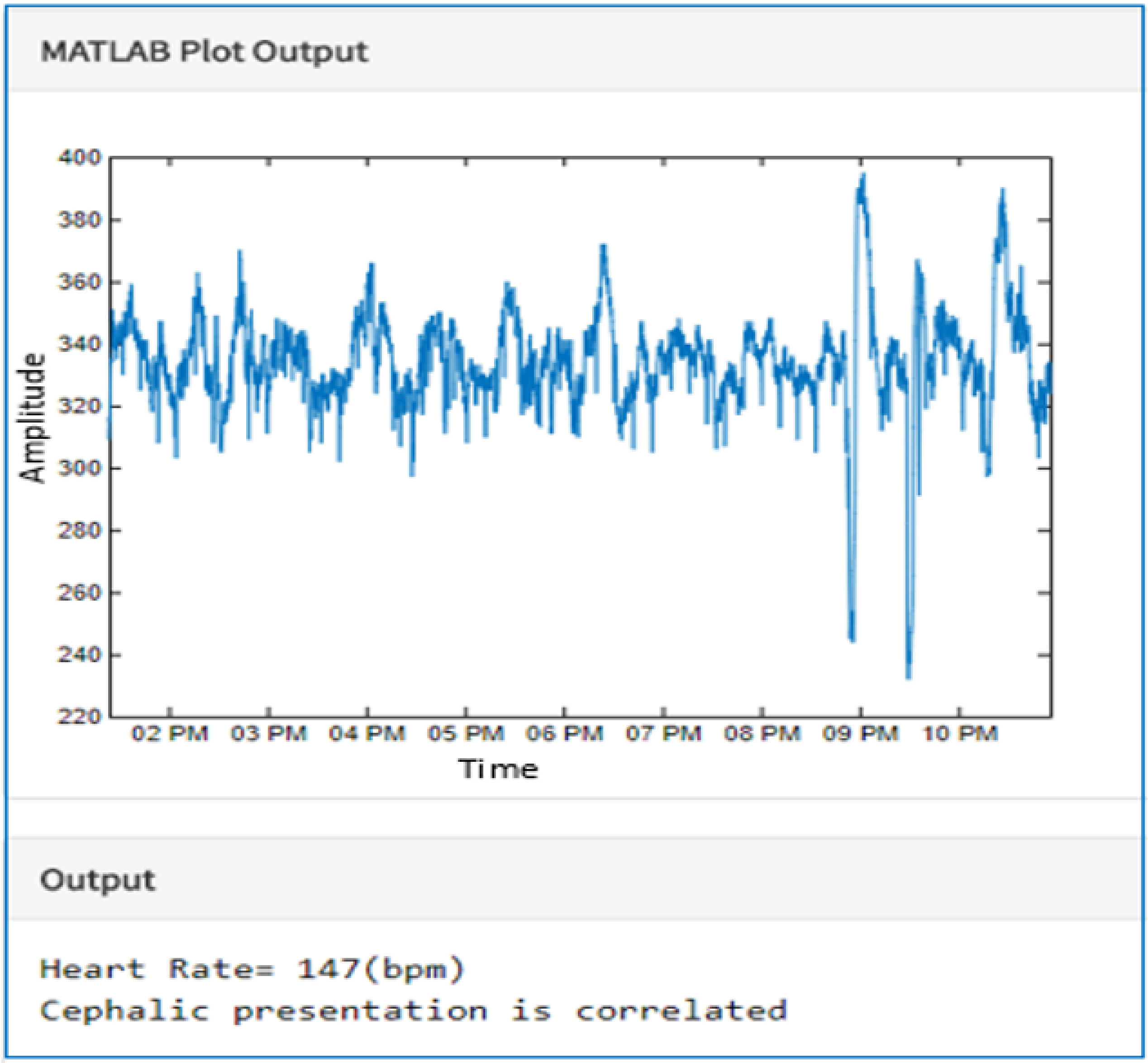


Figure 3

Estimation of Fetal Heart Rate and fetal presentation

Figure 4

A process flow of detecting fetal presentation using signal template.

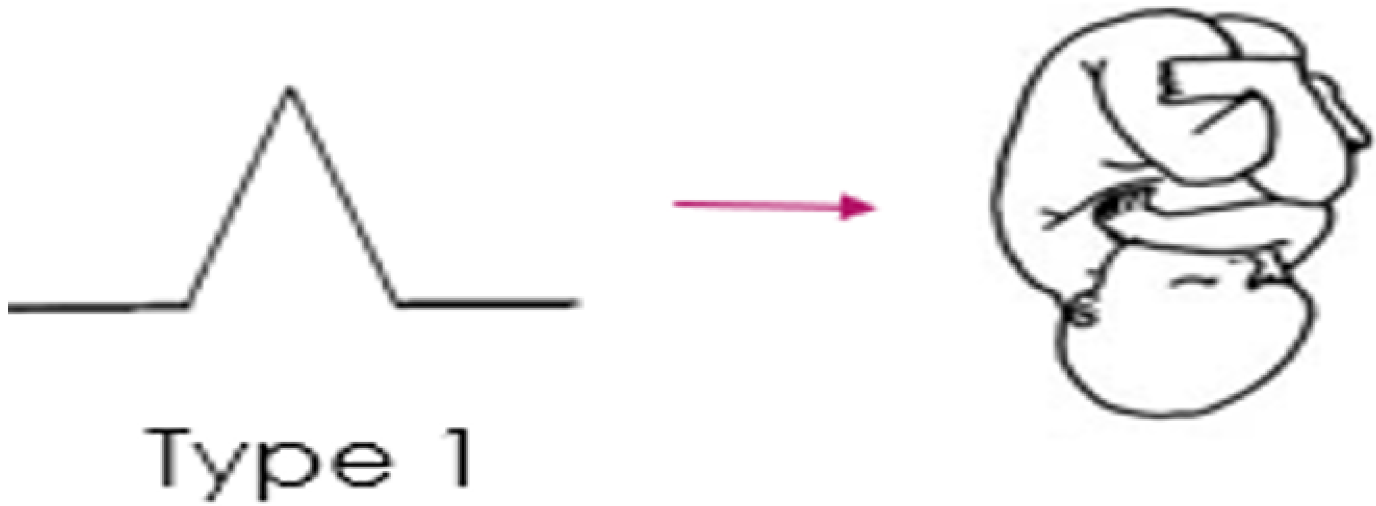


Figure 5

Determination of the fetal presentation

Figure 6

Screenshot of Pregnancy Health Monitoring (PHM) Mobile Application