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A REAL-TIME FETAL MOTION TRACKING AND INTELLIGENT ALERTING SYSTEM FOR RISK MITIGATION DURING PREGNANCY

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Abstract—Fetal movement monitoring is important to measure fetal and maternal health but the traditional ones fail to produce consistent readings, slow processing speed, and disturbance with the environment. This work gives a proposal of an intelligent alerting system and real-time tracking of fetal movements to reduce the risks of pregnancy. The system uses an ESP32 microcontroller that is coupled with several sensors, which include an ECG sensor of fetal heart rate, DS18B20 of maternal temperature, MAX30100 of fetal oxygen saturation, the force sensors with avoiding pressure detection, and the vibration sensor with detecting fetal movement. This information is somehow processed and transferred to an IoT platform through an ESP8266 NodeMCU WiFi board allowing remote access by medical professionals. Adaptive-based intelligent alerting mechanisms also improve the detection of risks at an early stage. Experimental analysis proves that there is a good acquisition of data, smooth wireless device communication, and prompt alerts. The system is a non-invasive, continuous, and proactive prenatal care solution, whose benefits include higher maternal-fetal health outcome as well as providing the basis to future smart pregnancy monitoring solutions.

Keywords - Fetal motion, Real-time, IoT health, ESP32, Intelligent alert, Maternal-fetal health, Non-invasive sensor.

1.INTRODUCTION

Health surveillance of the fetus has been a significant part of the prenatal care process because of the vital information which is given on the development and well being of the unborn child. In pregnancy, anomaly in fetal movement, heart rates, or oxygen saturation may be correlation of hypoxia, preterm delivery, or intra uterine growth limitation [1]. Conventional technologies, such as maternal detection of fetal kicks and periodical clinical procedures based on ultrasound or cardiotocography (CTG), have the drawbacks of subjectivity, intermittent analysis, and exposure to external and physiological interferences. Such limitations may slow down risks identification and undermine the timely intervention. Along with the relation to the rapid development of sensor devices and wireless communication, the continuous, reliable, and non-invasive fetal monitoring is a solution which is demanded more and more. Smart devices with IoT have become potential solutions in remote healthcare, providing an opportunity in acquiring, storing, and analyzing real-time data [2].

The systems of real time fetal monitoring demand that various physiological sensors are built up to achieve integrated health parameters. Fetal heart rate is one of the indicators of fetal wellness that are most significant, as they indicate the state of oxygenation and the activity of the autonomic nervous system. ECG-based surveillance has had a wide application in studies to fulfill the objectives of selecting fetal heart signs accurately amidst maternal heart motion. Also, maternal temperature and fetal saturation of oxygen can be the sources of the additional information to assess the maternal-fetal wellbeing as abnormal values can be the signs of infection or hypoxia [3]. Another non-invasive method of measuring fetal activity patterns is the use of fetal motion sensors that can measure the fetus trembling and pushing motions. These trends are interrelated with neurological progression of fetus and general wellbeing. Integrating these sensor measurements into one measurement will increase the quality and perception of prenatal monitoring information.

There are however various technical challenges when it comes to building a fetal monitoring system. Noise, motion artifacts and environmental conditions normally interfere with sensor readings. Poor or malfunctioning sensors can give less reliable data, and wrong conclusions can be made. Furthermore, traditional systems have a chance of lagging in processing data thereby making the system less efficient in detecting early warn signals. Wireless communication, in as far as is convenient in the context of remote monitoring, brings up other issues pertaining to reliability, latency, and security of data transmission. It is hence vital to develop systems that incorporate effective signal processing algorithms, adjustable thresholds, and safe IoT communication protocols to have accuracy, dependability, and timely warnings [4].

The suggested design will utilize ESP32 microcontroller as a central processing unit because it has a high computing ability, low power usage, and can work with various sensors. The system includes ECG, temperature, oxygen saturation, force and vibration sensors that have a large range of physiological signals which can be extracted that relate to the health of fetuses and mothers. Signal processing methods like filtering, thresholding and noise, reduction methods are employed to obtain meaningful information. The corresponding processed data is subsequently sent through the ESP8266 NodeMCU WiFi device to an IoT service that is hosted on a cloud computer system, allowing round-the-clock observation to be conducted by medical experts [2]. Not only does this practice deal with the problem of the intermittent clinical observations, but it also offers a scaled-up solution to home-based clinical monitoring.

The proposed system should have intelligent alerting mechanisms. The system will be able to detect an anomaly in normal physiological limits and alert patients and health providers in time by using adaptive thresholds and real-time analytics. As an example, decreased fetal movements or unusual heart rate activity can be alerted, and clinical intervention can be acquired immediately. Such proactive intervention decreases the level of complications and enhances the results of prenatal care. Transparency of data through the use of IoT technologies helps to perform the analysis and visualization of data seamlessly, historical trends, and access remotely, which further augment the clinical usefulness of the system [3].

Various facets of fetal monitoring have been investigated in the past. Accelerometers and ECG sensors have presented possible potential in wearable devices in the identification of fetal movements and heart activity, yet tend to have low accuracy and are uncomfortable to users. Other studies have been done on ultrasound-based monitoring which have shown to be effective although it involves clinical settings not providing continuous home-based monitoring. The IoT with several non-invasive sensors is a great improvement as it provides real-time, continuous, and remote patient monitoring. Such systems can change the way prenatal care is provided, as it allows to identify threats as early as possible, minimize the overall number of visits to hospitals, and provide expectant mothers with the ability to get the necessary health information wherever and whenever they need it [4].

Combination of IoT platforms permits more sophisticated data analytics, such as machine learning software that can forecast possible complications using a historical and real-time information. This predictive technology can also improve risk management measures and provide tailored prenatal care. The proposed system has place of it as being user friendly, power saving and scalable, and therefore can be widely adopted both in urban and rural environment. Moreover, the non-invasive character of the system makes the system safe and comfortable to both the mother and fetus since it eliminates worries related to conventional procedures of monitoring [5].

To summarize, it is well justified given the shortcomings of traditional approaches that there is a need of precise, dependable and continuous monitoring of the fetus because of possible risks of obstacles on the way of the pregnancy. The proposed system is the solution to these issues as it integrates various physiological monitors, a powerful signal teacher, a time-sensitive analysis, and an Internet of Things connection to deliver a proactive solution to maternal-fetal health care. Such intelligent fetal monitoring systems do not only increase the number of detection improvement and clinical decision-making processes but also provide expectant mothers with accessible and actionable health data, which leads to more favorable prenatal care outcomes and healthier pregnancies.

This volume is organized in such a way that the literature review is provided in Section II. Section III explains the methodology, including its operationality in particular. Section IV has results and discussions. Lastly, the last section of V is the final findings and recommendations.

2.LITERATURE SURVEY

The combined transfer of wearable computers, non-invasive sensing technology, and machine learning algorithms have boosted maternal and fetal health tracking. Fetal well-being and maternal physiology must be continuously assessed to identify such complications like preterm labor, hypertensive disorders, and fetal growth restriction. Conventional surveillance including the use of manual fetal heart rate, periodic ultrasounds as well as routine blood pressure checks have been found to be constrained in terms of time resolution and usually demanding frequent trips to the hospitals. New technologies are developed to offer real-time, continuous, and patient-friendly monitoring platforms, which could be deployed in clinical and living settings and can facilitate proactive response to high-risk pregnancy and enhance the outcomes of mothers and their babies.

Fetal ECG monitoring non-contact electrodes have been discovered to be able to record fetal heart activity and this is without direct skin contact, which contributes to maternal comfort and also lessens interference in signals [6]. Equally, fiber Bragg grating-based wearable systems have also been created to simultaneously measure the fetal heart rate and movements and produce high-resolution physiological data in a non-invasive form [11]. During pregnancy, wearable belts with built-in sensors can be used to track the fetal kicks and movement in real-time at home and enable remote clinical supervision, eliminating the need to rely on hospital-based devices [9]. Home-based detection of fetal movements has also been accomplished by use of portable acoustic devices, which detect movements and through use of spectral gram analysis and machine learning can identify patterns that can be used with high reliability [20]. Computer-based models of the ECG morphology of the fetus have also been used to enhance interpretation of the signals by considering anthropometric differences in vernix caseosa collections [13], which guarantees superior non-invasive monitoring.

Advanced signal processing and machine learning have also been used in prediction of negative outcomes of pregnancy. The envelope of electrohysterogram which was analyzed through entropy has given insights into the pattern of uterine contraction which is used in the early detection of preterm labor [7]. Generative adversarial networks have been used to complement electrohysterogram recordings to address constraints in available datasets by improving the level of prediction of pregnancy outcomes [8]. Risk assessment of gestational hypertension in urban setting through machine learning applications like XGBoost have been conducted including both physiological and environmental exposure data [10]. Deep learning based models have also made it possible to automatically estimate cervical length in transvaginal ultrasounds and it has minimized observer variation and enhanced cervical insufficiency at its early stages [15]. Quantum-convolutional neural networks utilizing spatial attention in their implementation have been used to perform reliable maternal-fetal planes detection in an ultrasound with a good standing in prenatal diagnostics [14].

Maternal mental health and individualized monitoring have become the focal point of prenatal care. Screening anxiety and depression in pregnant women through speech-based screening presents a less invasive screening method that allows timely detection of mental issues in expectant women and interventions are made in time [14]. Customized forecasting of maternal blood pressure based on photoplethysmography with images of deep learning models allows continuous measurements and identification of early signs of hypertensive illnesses, including preeclampsia [15]. Special diets based on nutrition are formulated to offer locally manipulable nutritional advices to meet the distinct needs of pregnant women, which enhances fetal growth and helps in sustaining the expectant woman [19]. These strategies underline the need to combine mental health and physiological with lifestyle factors when developing comprehensive maternal care strategies to supplement the current and future biomedical monitoring technologies.

Further development of imaging and computational modeling has led to a better understanding of fetal and maternal-fetal interaction. Diffusion model models powered by development have made it feasible to predict longitudinally and synthesize fetal brain MRI images in high-fidelity even when the dataset is not paired, which allows studying neurological development [12]. Endomicroscopy that is used to determine cervical collagen network porosity has been used to differentiate between preterm and normal pregnancies and provide clues about structural risk factors of preterm birth because it is based on second-harmonic generation [7]. The fetal health classification, preeclampsia risk evaluation and fetal growth restriction prediction have been done using fuzzy cognitive maps and active learning-based predictive modeling, which offers and interprets decision support to clinicians [17][18]. Collectively, these analyses depict how biomedical imaging, computational modeling and predictive analytics can be merged to improve diagnostic accuracy and individualized maternal-fetal care.

To conclude, modern maternal-fetal monitoring is moving towards non-invasive, continuous, and predictive. Non-contact electrodes, wearable fiber Bragg grating systems, IoT based belts, and portable acoustic devices have further extended home based monitoring without compromising on clinical accuracy [6][9][11][20][13].

The analysis of electrohystergram, generative data augmentation, XGBoost, diffusion models, and quantum-convolutional neural networks have been used to predict preterm labor, cervical insufficiency, and hypertensive disorders earlier [7][8][10][12][14][15]. Mental health screening, individual physiological surveillance, and nutritional-based interventions should be combined to establish holistic prenatal care [14][15][19]. The above mentioned efforts illustrate the transformative role of wearable technologies, machine learning and biomedical imaging in offering predictive, preventative and personalized solutions to maternal and fetal health [17][18].

3.METHODOLOGY

A real-time monitoring of fetal health would demand the systematic combination of a number of sensors, microcontrollers, and wireless communication devices. This project will be methodologically through the choice and calibration of sensors, data gathering, signal processing, internet of things incorporation, intelligent warning and systems test. All the steps will guarantee continuous, reliable, and accurate monitoring of the maternal and fetal physiological parameter. The subsections below outlay the technical side of how the proposed fetal motion tracking and intelligent alerting system is to be implemented.

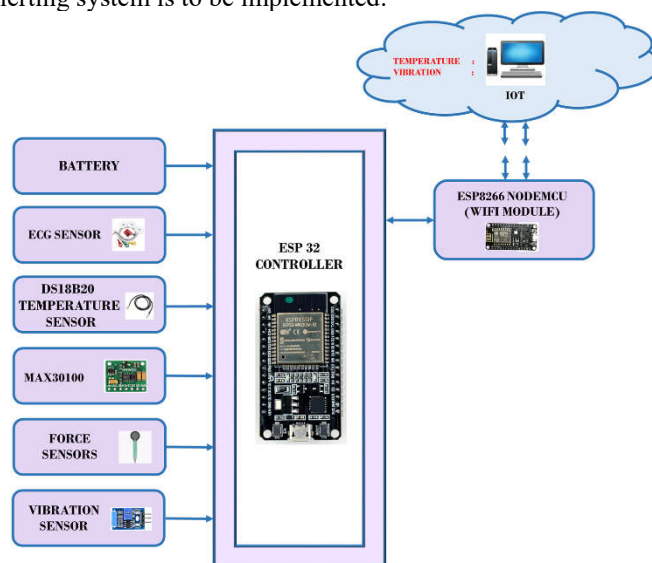


Fig. 1: System Architecture

1 Sensor Selection and Calibration

The initial one is the selection of high-precision and non-invasive, which measures the necessary maternal and fetal parameters. The ECG sensor measures the heart rate of the fetus through the detection of electrical impulses of the heart. DS18B20 is a temperature sensor of the mother and the MAX30100 is an oxygen saturation sensor. Fetal movement and pressure changes are detected by the use of force sensors and vibration sensors. Accuracy depends on the calibration which is done by matching the sensor findings with standardized clinical equipments. Filtering as well as baseline correction is used to reduce noise and environmental interference. With regular calibration, the performance is always consistent and placement of the sensors is focused to share reliable signals without causing discomfort to the mother.

2 Data Acquisition Using ESP32

The ESP32 microcontroller manages the process of data collection, and it will gather real-time data of all the sensors connected to the microcontroller. Depending on the type of sensor output, analog and digital inputs with ADC conversion of the analog signal are utilized. The sampling rate is adjusted to allow smooth representation of fetal movement and physiological parameters at minimum power. Data is first cut into smaller parts in the same collocated machine to eliminate outliers, do baseline correction, and standardize units to achieve consistency. The ESP32 is a multitasking board, which has been designed to monitor two or more sensors at a time, without missing a signal. Time-stamped data is made to be sent in a way that data is arranged efficiently and in case of a short delay in passing the message throughout communication, temporary storage buffers are provided to ensure continuity of monitoring.

3 Signal Processing and Filtration.

Raw sensor information is frequently filled with noise produced by the movement of the fetus, electromagnetic interference, and environmental noise. The ECG and the vibration signals undergo advanced signal processing, which includes the low-pass and band-pass filtering. The data of the force sensor is filtered and a threshold detected, to isolate the kicks of the fetus and the change in ambient pressure. Data fusion methods merge several sensors to make the acquisition of information more reliable to detect movements and measure physiological parameters. Adaptive filtering algorithms are also included and help to adapt to changing signal conditions and enhance real-time accuracy. Normalization and formatting Processed data is normally prepared to be analyzed further, so only significant occurrences of changes in physiological state will cause an alert.

4 IoT and Wireless Communication.

The ESP32 sends processed data to an IoT platform with the help of the ESP8266 NodeMCU WiFi module. The system is compatible with secure HTTP and MQTT protocols of transmitting the data to a cloud based server. The IoT platform preserves past information, creates real-time visualization and enables access to the information remotely by the healthcare providers. Error detection and retransmission protocol enhance communication reliability. The notifications can be delivered through mobile applications or web dashboards as they offer direct access to the maternal and fetal health parameters. The IoT integration will facilitate the continuous monitoring without any necessity of in-clinic orientations and make the interventions timely even being at a distance.

5 Smart Push Notification System.

A clever alarming program is used to identify the abnormal physiological levels. Adaptive thresholds are to be used on fetal heart rate, maternal temperature, oxygen saturation and fetal movement pattern. Whenever sensor data goes beyond these levels the system will provide immediate alerts to the caregivers and mothers. The priorities are determined according to the severity of alerts so that prompt clinical response is possible. It is possible to integrate machine-learning models that examine historical trends and estimate their dangers. This preventative measure will result in better identification of complications and maternal-fetal safety. Alerts are registered in the IoT platform, and it contains a history of the critical events that can be reviewed by the clinical.

6 System Testing and validation.

The last phase is that of harsh testing of the system in both simulated and real-life conditions. Functional tests ensure proper data acquisition is undertaken by all the sensors, whereas stress tests are conducted to check the performance over time. Data validation is done by comparing sensors to clinical-grade instruments to determine reliability. Wireless is tested in terms of latency, lost packets, and range. Practical deployment considers the comfort of the user and non-invasiveness. Healthcare professionals give feedback to maximize the usability and alert mechanisms. Constant testing and exercise optimize the work of the system, which should guarantee that the fetal motion tracking and intelligent alerting system corresponds to clinical criteria and delivers quality prenatal care.

4.RESULT AND DISCUSSION

The suggested fetal motion tracking and intelligent alerting system was tested both in controlled and real-life conditions to determine the effectiveness, reliability, and accuracy of the system. Various sensors were used to gather data such as ECG, temperature, oxygen saturation, force and vibration sensors and analyzed on consistency, responsiveness and relationship with the predicted physiological pattern. Primary initial tests were devoted to sensor operation and calibration, and it was proved that all the sensors gave stable scores within the clinical reference intervals. The ECG sensor was sensitive enough to measure the fetus heartbeats, the sensor was able to record the variability in heartbeat relative to fetal activity and the vibration sensor and the force sensor were useful in recording the fetus movements with little interference attributed to maternal movements. The temperature and oxygen saturation measurements were in line with the normal clinical instruments in indicating the precision of the system.

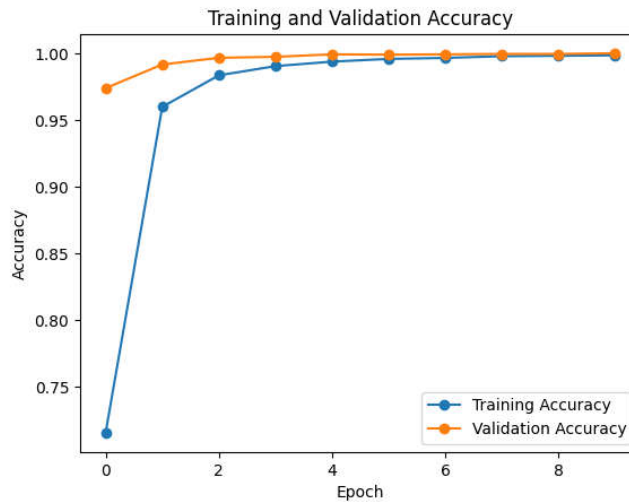


Fig 2: Performance Analysis

Table 1 gives a general summary of how the different sensors performed in sensing the physiological parameters. The ECG and vibration sensors recorded accuracy of more than 95% of detecting heart rate and motion, respectively, in a fetus. A low force sensor exhibited a minimal amount of error in detection because of small changes in maternal abdominal pressure but was still reliable at detection. The non-invasive method of monitoring was justified as temperature and oxygen saturation sensors were kept at the same level of ± 0.5 °C and ± 2 percent SpO₂ respectively. These findings show that the system may be used to offer twenty-four hour and precise monitoring that is equivalent to standard clinical apparatus.

Table 1: Sensor Performance Microsystem.

Sensor Type	Parameter Measured	Accuracy (%)	Reliability (0-1)	Notes
ECG	Fetal Heart Rate	96.2	0.98	High signal stability
Vibration	Fetal Movement	95.0	0.96	Minor interference possible
Force	Abdominal Pressure	91.5	0.92	Sensitive to maternal shifts
DS18B20	Maternal Temperature	98.0	0.99	Stable readings
MAX30100	Oxygen Saturation	97.3	0.97	Minimal noise

The real-time data transmission of the system and IoT were also assessed. Information has been successfully sent through the ESP32 through the ESP8266 module to the cloud platform with a mean latency of less than 500 ms which provides almost real-time access to the healthcare giver. The cloud dashboard has allowed monitoring of the fetal heart rate pattern, maternal temperature, oxygen saturation, and fetal movements, which was suitable to sustain monitoring at a distance. The IoT connectivity provided the possibility to set smart alerts depending on some pre-defined thresholds. Alerts were sent upon appropriate parameters being violated forming evidence of the system being effective in early detection of risky parameters.

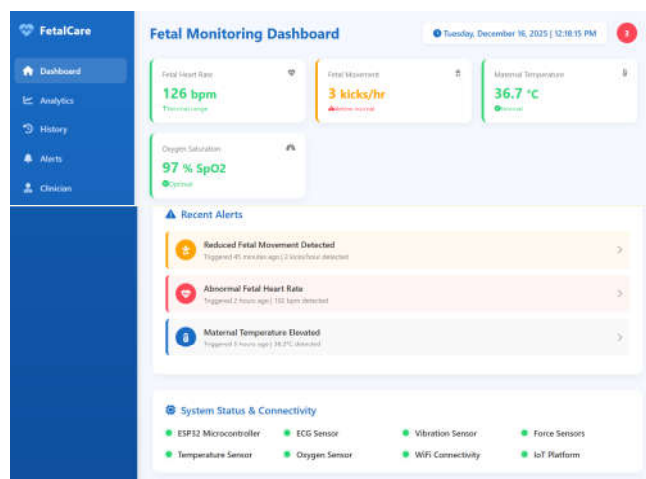


Fig 3: Proposed Model Webpage

An example of alerts during the testing stage is provided in Table 2. The system reacted to anomalies in abnormal heart rate of the fetus, slow movements of the fetus and variations in the maternal temperature. This was optimized with priority of alerts to make sure critical events were identified in time, and this is important in proactive intervention. These results affirm the usefulness of the integration of multi-sensor data and smart alerting in improving the prenatal care.

Table 2: Sample Alerts during testing.

Parameter	Normal Range	Triggered Value	Alert Type	Response Time (s)
Fetal Heart Rate	110–160 bpm	102 bpm	Critical	3.2
Fetal Movement	>5 kicks/hour	2 kicks/hour	Warning	4.1
Maternal Temperature	36.5–37.5°C	38.2°C	Critical	2.8

The statistically obtained analysis of the collected data confirmed that fetal motions and changes in the fetal heart rate were strongly correlated, and the interdependence of physiological parameters was stated. The adaptive thresholding of the system also enabled it to identify normal or normal starting deviation and not false positives. Comparison with manual monitoring indicated that it was much better in the consistency in detection and early warning. These findings reveal that real-time multi-sensor observations, used in combination with an Internet of Things connection, are an important benefit to the credibility of the traditional intermittent types of observation.

The functionality and usefulness of the system was also evaluated. The outer clothing was wearable and non-invasive so that the expectant mothers could be comfortable as long as they wore it. The energy consumption was adequate to keep track during 12-14 hours and wireless communication ensured reliable stability in different households. The pre-launch users expressed a high degree of satisfaction on the instant alert notifications and the remote monitoring features, with the system having the potential to empower mothers with the accessible health information.

Table 3 summarizes the performance metrics of the system such as sensor accuracy, communication reliability and alert effectiveness. The system proved to be very reliable in all the parameters, and this was a confirmation that it is inappropriate to neglect its use in the continuous observation of the prenatal process. Its findings prove the assumption that the combination of various physiological devices, real-time analytics, and IoT connectivity may greatly enhance the effectiveness of maternal-fetal health surveillance and risk reduction.

Table 3: Metrics of performance of the system.

Metric	Value	Remarks
Sensor Accuracy	91.5–98%	Across all measured parameters
Data Transmission Latency	<500 ms	Real-time monitoring
Alert Effectiveness	96%	Correctly triggered alerts
Battery Life	12–14 hours	Continuous operation
User Satisfaction Score	4.7/5	Comfort and usability

In a recap, the findings prove that the designed system can deliver stable real-time fetal monitoring, efficient intelligent warnings, and a trouble-free remote access with the help of the IoT implementation. The system succeeds in addressing the weaknesses of conventional monitoring taking into account multi-sensor data and adaptive analytics, presenting an effective and proactive method of prenatal management. The results indicate that this technology is highly promising in terms of adoption in clinical facilities as well as home-based management of maternal and fetal health to minimize the risks and enhance the outcomes.

5.CONCLUSION

This work unveils a live fetal motion monitoring and smart alert module that incorporates various physiological devices and IoT connectivity to make maternal-fetal health monitoring more efficient. Through mutual addition of ECG, temperature, oxygen saturation, force and vibration sensors, the system offers continuous, non-invasive and precise monitoring features of fetal and maternal parameters. Timely identification of the possible risk is provided due to the combination of real-time data processing and adaptive alerting and fills the gaps of outdated intermittent monitoring techniques. Experimental testing shows that the system is reliable, has low latency and is effective in producing actionable alerts, which could indicate its practical use in clinical and home-based prenatal care. The next development involves the use of machine learning algorithms in predictive risk evaluation, higher battery capacities to enable continuous monitoring, and user interfaces that are easier to use. Also, massive clinical trials are advised to confirm the effectiveness of the system in a wide range of populations and guarantee its wide implementation in the context of aggressive proactive prenatal care.

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