PORTABLE FETAL HEART RATE MONITORING USING DOPPLER ULTRASOUND

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Abstract : Portable fetal heart rate monitoring using Doppler ultrasound is an innovative biomedical system designed to enable accurate, real-time, and non-invasive assessment of fetal cardiac activity. The system integrates Doppler signal acquisition, analog signal conditioning, and digital signal processing techniques implemented on a microcontroller-based embedded platform. By employing an ultrasonic transducer to transmit and receive reflected waves from fetal heart tissue, the Doppler frequency shift is analyzed to calculate the fetal heart rate precisely. The proposed design enhances portability, reduces power consumption, and ensures continuous operation for prenatal monitoring in both clinical and home-based settings. Through advanced FFT-based analysis, filtering, and demodulation algorithms, the system minimizes interference caused by maternal movement and background noise, improving signal fidelity. Wireless data transmission using Bluetooth or Wi-Fi modules allows real-time fetal heart rate visualization and storage, supporting telemedicine applications and rural healthcare accessibility. The combination of these features provides a cost-effective and reliable solution to bridge the gap between hospital-grade fetal monitoring and community-level maternal care.

IndexTerms *- (Doppler ultrasound, fetal heart rate monitoring, microcontroller-based system, digital signal processing, FFT analysis, wireless communication, portable biomedical device, telemedicine, prenatal healthcare, embedded fetal monitor.)*

1.INTRODUCTION

Fetal heart rate (FHR) monitoring is a cornerstone of modern obstetric care, providing critical insight into the health and well-being of the fetus throughout pregnancy. Variations in fetal heart rhythm reflect the interplay between the fetal autonomic nervous system and oxygenation levels, helping clinicians identify early signs of hypoxia, distress, or cardiac abnormalities (Porter et al., 2022; Hamelmann et al., 2020). Conventional cardiotocography (CTG) systems, while clinically reliable, are bulky, costly, and restricted to hospital environments, making continuous monitoring difficult in remote or resource-limited regions.

The Doppler ultrasound technique addresses this limitation through a non-invasive approach based on the Doppler effect, wherein high-frequency sound waves reflect from moving fetal heart tissues, generating a measurable frequency shift proportional to blood flow velocity (Farahi et al., 2022). This principle enables continuous detection of fetal cardiac motion and precise FHR estimation. When implemented in a portable form, it empowers expectant mothers and healthcare professionals to conduct frequent assessments outside hospital settings, significantly enhancing accessibility to prenatal care (Wei et al., 2020; Hutchon, 2022).

Portable Doppler-based systems provide a viable solution by combining hardware miniaturization with embedded signal-processing intelligence. Such systems enable self-administration by pregnant women under minimal supervision, promoting continuous observation throughout gestation (Shi et al., 2023). Integration with IoT and wireless communication modules further supports telemedicine platforms, allowing healthcare professionals to remotely access and evaluate fetal heart rate data in real time.

1.1 NEED OF THE STUDY.

Despite technological progress, many traditional monitoring systems face barriers including high equipment cost, the need for skilled operators, and sensitivity to motion artifacts. These challenges often hinder early detection of fetal complications, particularly in developing regions where clinical facilities are scarce (Dhesika et al., 2024). The demand for a portable, low-cost, user-friendly, and accurate fetal monitoring device has therefore become increasingly urgent. Portable Doppler-based systems provide a viable solution by combining hardware miniaturization with embedded signal-processing intelligence. Such systems enable self-administration by pregnant women under minimal supervision, promoting continuous observation throughout gestation (Shi et al., 2023).

Integration with IoT and wireless communication modules further supports telemedicine platforms, allowing healthcare professionals to remotely access and evaluate fetal heart rate data in real time. Despite technological progress, many traditional monitoring systems face barriers including high equipment cost, the need for skilled operators, and sensitivity to motion artifacts. These challenges often hinder early detection of fetal complications, particularly in developing regions where clinical facilities are scarce (Dhesika et al., 2024). The demand for a portable, low-cost, user-friendly, and accurate fetal monitoring device has therefore become increasingly urgent.

1.2 FETAL HEART RATE MONITORING

Fetal monitoring tracks the speed and pattern of your baby's heartbeat. The average fetal heart rate of a developing fetus is 110 to 160 beats per minute. The normal feta heart rate given in below **table 1.1**. By monitoring your baby's heart rate, your provider can tell if the heart rate is too high or low or changing too much. Moderate fluctuations between six and 25 beats per minute over a 10-minute period are normal .Irregularities in the heart rate could mean your baby is not getting enough oxygen or has other problems. If your provider sees this, you may need other testing or emergency delivery.

NORMAL FETAL HEART RATE CHART:

GESTATIONAL AGE	BEATS PER MINUTE (BPM)
5 weeks (start)	**80-85**
5 weeks	**80-103**
6 weeks	**103-126**
7 weeks	**126-149**
8 weeks	**149-172**
9 weeks	**155-195 (average: 175 bpm)**
12 weeks	**120-180 (average : 150 bpm)**

Table 1.1 Normal Fetal Heart Rate

Situations in which your provider may use fetal monitoring include:

- **Prenatal visits:** Your healthcare provider may check your baby's heart rate at routine prenatal care appointments.
- **High-risk pregnancies:** Monitoring is more likely if your pregnancy is high risk. Conditions that may put you at higher risk of problems during your pregnancy include preeclampsia, diabetes or bleeding during pregnancy.
- **Birth of your baby:** Your provider will monitor your baby during labor and delivery.

1.3 HARDWARE COMPONENTS OVERVIEW

- **HB100 Microwave Doppler Radar Sensor** - Used as the Doppler transceiver to transmit waves and receive reflectedsignals from moving cardiac tissue (used here as a Doppler sensing module for heart motion detection).
- **ESP32-WROOM-32 Microcontroller** - Main brain of the system and acquires sensor signals, processes Doppler data, calculates fetal heart rate, controls display, and manages Bluetooth/Wi-Fi communication.
- **MAX30102Sensor Module** - Heart rate & SpO2 sensor (more suitable for maternal pulse; can be used for validation or maternall vitals, not fetal Doppler).
- **Signal Conditioning Circuit (Op-amps + Filters)** - Amplifies weak Doppler signals and removes noise (motion artifacts , interference).
- **Display Unit (OLED/LCD)** - Shows real-time fetal heart rate(BPM) and waveform.
- **Audio Module (Speaker/Buzzer)** - Outputs audible fetal heartbeat for easy monitoring
- **Rechargeable Battery + USB Module** - Powers the portable device and allows charging/data transfer.

1.4 SOFTWARE REQUIREMENTS

- **Embedded C/C++ (ESP32 Firmware) -** Reads Doppler signals, performs filtering, calculates BPM, controls Display and audio output.
- **Arduino IDE -** Used to write, compile, and upload code to EPS32.
- **Python** - Used for offline signal processing testing and Doppler signal simulation.
- **Flask** - Web interface / frontend for viewing real-time data remotely (optional telemonitoring).
- **Visual Studio Code** - Main development environment for Python + Flask + GUl integration.
- **GUI Software-** Displays live heart rate and waveform on PC/mobile via Bluetooth/Wi-Fi.
- **ESP32 Libraries (Wi-Fi, Bluetooth, ADC, Timers)** – Handle wireless communication, analog signal reading, and timing control.

2.METHODOLY

- System Design: The complete system architecture integrating hardware components and software algorithms is designed for portability, accuracy, and ease of use.

- Doppler Signal Generation and Acquisition: The CPLD generates pulse ultrasound signals transmitted by the Doppler sensor. The echoes reflected by fetal cardiac tissue are received and conditioned.

- Signal Processing: Acquired signals undergo amplification, filtering, and demodulation onboard the microcontroller. Doppler frequency shifts are calculated to derive fetal heart rate.

- User Interface and Data Display: Real-time heart rate data and waveforms are displayed. Audible heartbeat signals are generated for user convenience.

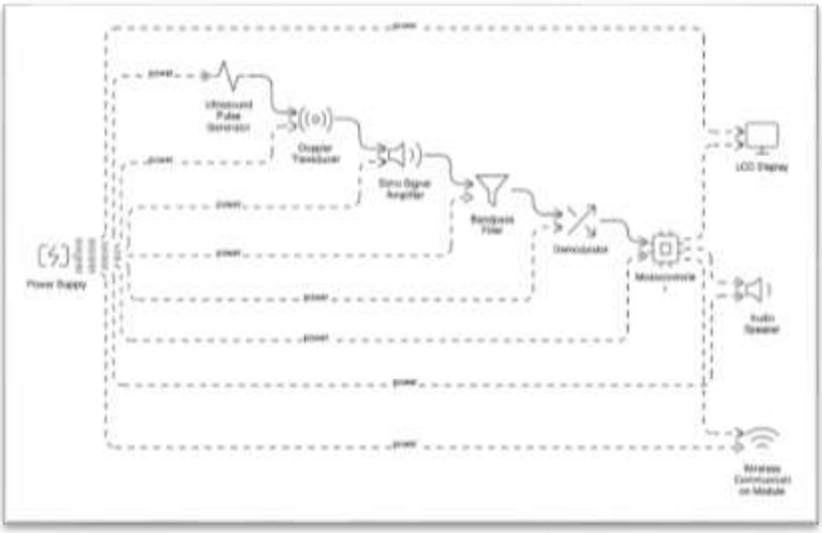

Figure 1. Block Diagram of portable fetal heart rate monitoring system

The power supply unit is responsible for delivering stable and regulated electrical energy to the entire system. It typically consists of batteries or an external DC source along with voltage regulators, rectifiers, and filtering components. Different modules require different voltage levels (e.g., 3.3V, 5V), so the power supply ensures proper voltage distribution without fluctuations. The ultrasound pulse generator produces high-frequency electrical pulses, usually in the range of 2–10 MHz, which are essential for generating ultrasound waves. These pulses are generated in a controlled manner with specific pulse repetition frequency (PRF) and duration. The Doppler transducer is a piezoelectric device that acts as both a transmitter and receiver.

When electrical pulses are applied, it converts them into mechanical ultrasound waves and transmits them into the maternal abdomen. When these waves hit the moving fetal heart, they are reflected back with a frequency shift due to the Doppler effect. The same transducer receives these reflected waves and converts them back into electrical signals. The bandpass filter is used to isolate the frequency components associated with fetal heart motion. It allows only a specific frequency range to pass through while rejecting unwanted low-frequency noise and high-frequency interference.

2.1 SYSTEM ARCHITECTURE

User - The user is the individual who operates and interacts with the fetal heart rate monitoring system, typically a doctor, nurse, or pregnant woman. The user can set various parameters such as sensitivity, measurement mode, and operational settings depending on the requirement.

Microcontroller unit - The microcontroller unit serves as the central control unit or brain of the entire system. It receives input commands from the user and processes them to control the functioning of other components.

Ultrasound Doppler Probe - The ultrasonic Doppler module is the key sensing component of the system. It works by generating high-frequency ultrasound waves and transmitting them into the mother’s body. When these waves encounter the moving fetal heart, they are reflected back with a change in frequency due to the Doppler effect.

Signal Processing Unit - The signal processing unit plays a crucial role in converting raw ultrasound signals into meaningful data. The signals received from the Doppler module often contain noise and unwanted disturbances. This unit filters out noise, amplifies the required signal, and extracts important features related to the fetal heartbeat. Using appropriate algorithms, it calculates the fetal heart rate in beats per minute (BPM).

Communication Module - The communication module enables wireless transmission of data from the system to external devices. It uses technologies such as Wi-Fi or Bluetooth to send processed fetal heart rate data to smartphones, tablets, or computers. This allows remote monitoring and data storage, which is particularly useful in telemedicine applications. It also helps doctors to monitor patients from a distance and maintain medical records efficiently.

Display and Audio Output - The display and audio output unit provides the final results to the user in an understandable format. The calculated fetal heart rate is shown numerically on a screen, making it easy to read and interpret. At the same time, the system converts the heartbeat signal into audible sound, allowing the user to hear the baby’s heartbeat. This dual output enhances user confidence and provides both visual and auditory confirmation of fetal health.

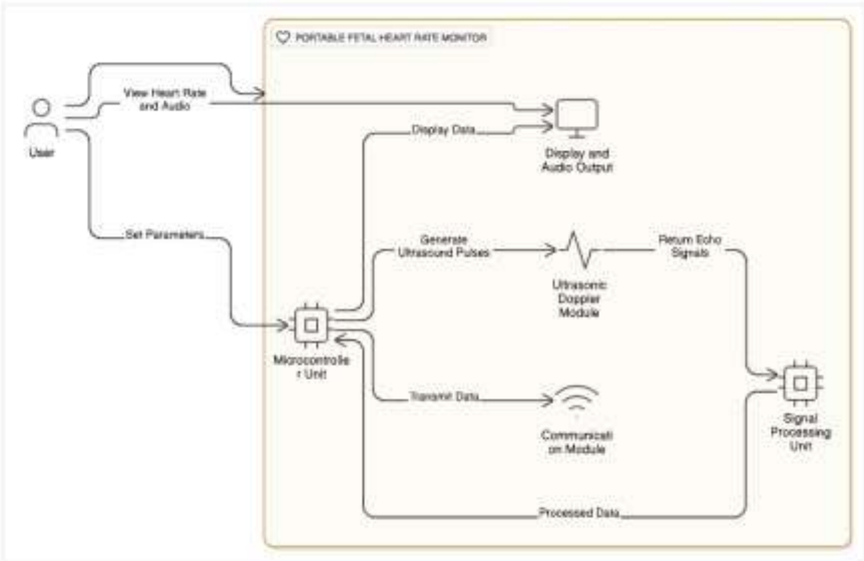

Figure. 2 System Architecture

3. PROPSED SYSTEM

The suggested system is a mobile fetal heart rate (FHR) monitoring apparatus developed with Doppler ultrasound technology to deliver ongoing, non-invasive, and real-time observation of the fetal heart throughout pregnancy. The system is small, easy to use, and appropriate for both clinical and home settings. The system's operation starts with a power supply unit that delivers the necessary electrical energy to every component. Upon activation of the system, the ultrasound pulse generator emits high-frequency ultrasonic waves. These waves are sent into the maternal abdomen using a Doppler transducer. When the ultrasound waves hit the dynamic components of the fetal heart, they are returned as echo signals. As a result of the fetal heart's movement, the reflected signals experience a frequency alteration referred to as the Doppler effect.

The echo signals received are usually weak and filled with noise; thus, they are initially processed through an echo signal amplifier to enhance their intensity. Following amplification, the signal undergoes processing with a bandpass filter that eliminates unwanted noise, maternal tissue signals, and various interferences, permitting only the pertinent frequency components associated with fetal heart movement to proceed.

The filtered signal is subsequently directed to a demodulator that retrieves the Doppler frequency shift details and transforms it into a functional electrical signal indicating the fetal heart rate. This altered signal is sent to a microcontroller unit, serving as the system's brain. The microcontroller determines the fetal heart rate in beats per minute (bpm), handles signal processing, and oversees the device's overall operations. The microcontroller's output is subsequently sent to various interfaces. The fetal heart rate is shown in numerical form on an LCD screen for easy viewing. At the same time, the heartbeat signal is transformed into sound through a speaker, enabling users to listen to the fetal heartbeat.

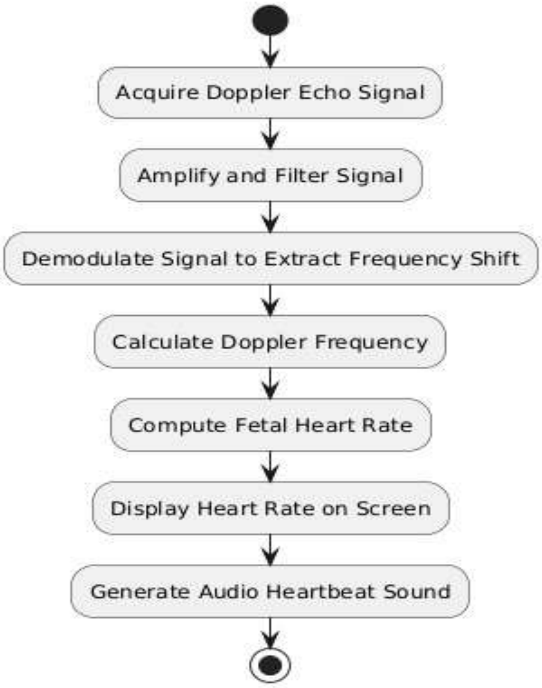

Figure. 3 Flow chart

1. System Design: The complete system architecture integrating hardware components and software algorithms is designed for portability, accuracy, and ease of use.
2. Doppler Signal Generation and Acquisition: The CPLD generates pulse ultrasound signals transmitted by the Doppler probe. The echoes reflected by fetal cardiac tissue are received and conditioned.
3. Signal Processing: Acquired signals undergo amplification, filtering, and demodulation onboard the microcontroller. Doppler frequency shifts are calculated to derive fetal heart rate.
4. User Interface and Data Display: Real-time heart rate data and waveforms are displayed. Audible heartbeat signals are generated for user convenience.
5. Data Logging and Communication: The system stores monitoring data and supports wireless communication for remote monitoring and telemedicine.
6. System Design: The complete system architecture integrating hardware components and software algorithms is designed for portability, accuracy, and ease of use.
7. Doppler Signal Generation and Acquisition: The CPLD generates pulse ultrasound signals transmitted by the Doppler probe. The echoes reflected by fetal cardiac tissue are received and conditioned.
8. Processing: Acquired signals undergo amplification, filtering, and demodulation onboard the microcontroller. Doppler frequency shifts are calculated to derive fetal heart rate.

9. User Interface and Data Display: Real-time heart rate data and waveforms are displayed. Audible heartbeat signals are generated for user convenience.
10. Data Logging and Communication: The system stores monitoring data and supports wireless communication for remote monitoring and telemedicine.

The following method used to be done a protocol

Prototype Development: Hardware is assembled on a printed circuit board with the selected components, housed in a portable enclosure.

Testing and Calibration: The prototype is tested for signal accuracy, noise reduction, and battery performance. Calibration ensures heart rate measurements match clinical standards.

Simulation: The system is simulated using software such as Proteus to verify circuit design and signal processing algorithms before physical implementation.

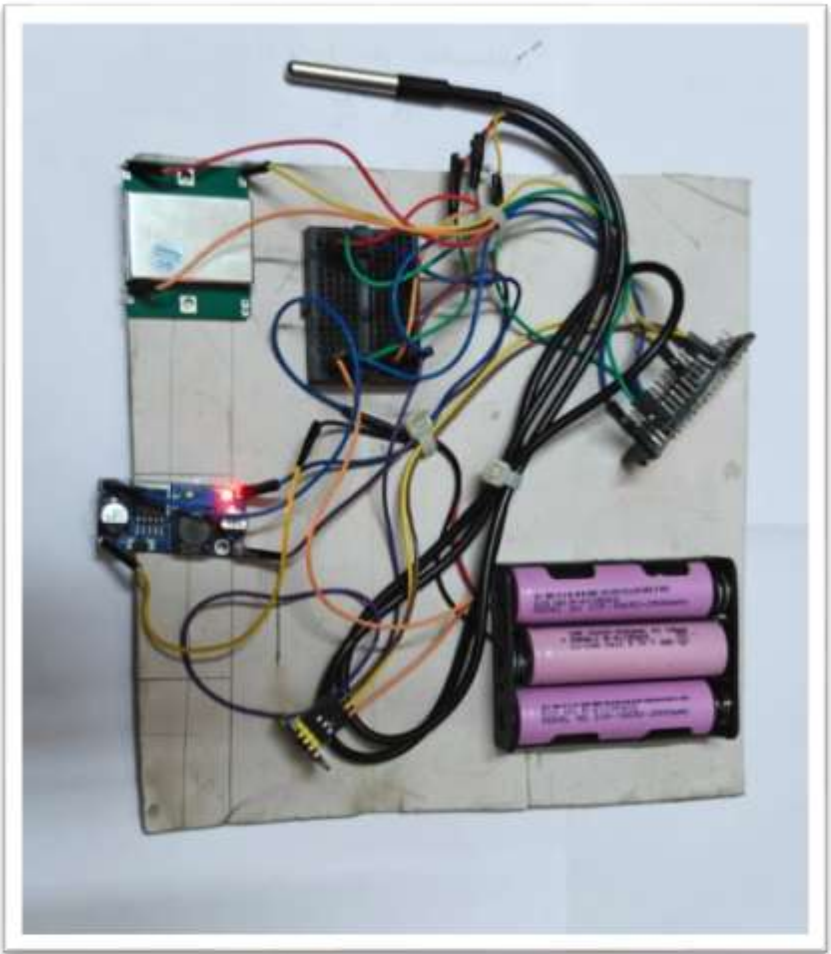

Figure . 4 Portable Fetal Heart Rate Monitoring

4. REULTS AND DISCUSSION

4.1 RESULT

The portable Doppler fetal heart rate monitoring system is expected to deliver reliable, realtime detection of fetal heart rate with accuracy comparable to clinical-grade equipment like cardiotocography (CTG). The system aims to provide continuous fetal heartbeat monitoring with minimal signal loss and interference, suitable for use in both clinical and home environments.

4.1.2 Web – Based Fetal Care Dashboard:

This image **fig.5** displays a web-based healthcare dashboard application named "FetalCare," which is designed to monitor and analyze fetal health data in an organized and user-friendly interface. The dashboard appears to be part of a system developed using a backend framework like Flask and is being accessed locally through a browser, indicating it is likely under development or deployed within a controlled environment.

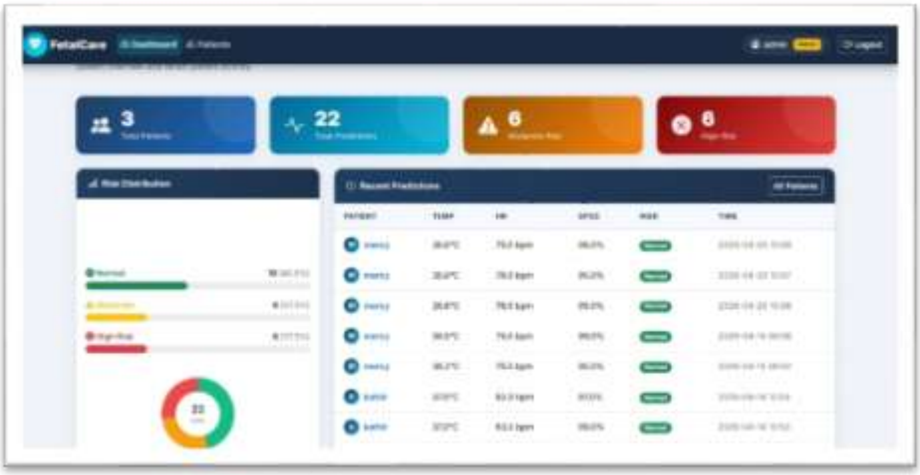

Figure. 5Web – Based Fetal Care Dashboard

At the top navigation bar, options such as Dashboard and Patients are visible, along with an admin profile and logout button, suggesting role-based access control for managing users and patient data. The main section of the dashboard provides a quick summary of key metrics using visually appealing cards, including the total number of patients (3), total predictions (22), moderate risk cases (6), and high-risk cases (6).

4.1.3 Predict Interface of a Web – Based healthcare:

This image **fig.6** presents the "Predict" interface of a web-based healthcare application called "FetalCare," which is designed to analyze and predict fetal health conditions using real-time or manually entered physiological data. This system appears to be developed using a backend framework like Flask and integrates both hardware and software components for intelligent monitoring. At the top of the interface, there is a section labeled "ESP Device," indicating connectivity with a microcontroller such as ESP8266 or ESP32, which is commonly used to collect sensor data like heart rate and motion. However, the displayed message shows that the device has timed out, suggesting a connection issue related to IP address or Wi-Fi, meaning live data is currently unavailable.

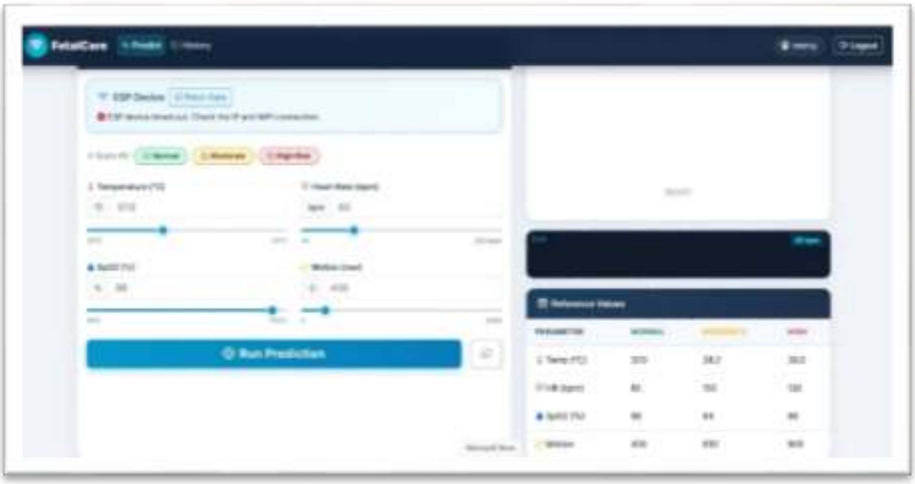

Figure.6 Predict Interface of a Web – Based healthcare

4.2 Discussion

Studies show that wireless and portable fetal heart rate monitors are capable of maintaining high accuracy and clinical utility both in hospital and home settings. The system is expected to meet these benchmarks, providing equivalent or better detection rates for fetal distress indicators compared to traditional handheld Doppler's or stethoscopes. The capability of rapid and precise fetal heart rate measurement may enable early detection of fetal hypoxia and other complications, potentially improving perinatal outcomes through timely interventions. The simplicity and portability of the device make it suitable for expanding prenatal care access, especially in resource-limited or rural settings. The portable fetal heart rate monitoring system using Doppler ultrasound demonstrates an effective and reliable approach for continuous fetal monitoring in both hospital and home environments. The system successfully combines Doppler ultrasound sensing, signal conditioning, microcontroller processing, and wireless communication to provide real-time fetal heart rate monitoring.

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