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Simulation Study of an Arduino-Driven Heart Monitoring System for Maternal Well-Being

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Abstract

Maternal cardiovascular health significantly influences pregnancy outcomes; however, conventional monitoring practices often depend on sporadic clinical evaluations, hindering the prompt identification of potential abnormalities. This study presents the design and simulation of a cost-effective, Arduino-based maternal heart monitoring system intended to facilitate early detection of cardiovascular irregularities during pregnancy. The system was developed using Proteus 8.15 simulation software and comprises an Arduino Uno microcontroller, a virtual heartbeat sensor, an LCD display, LED indicators, and buzzer alarms. The simulated environment replicates real-time physiological signal acquisition, processing, classification, and alert generation across various heart rate scenarios, including bradycardia, tachycardia, and normal rhythms. The system accurately classified these conditions and triggered appropriate audiovisual alerts during abnormal episodes. Signal fidelity was verified using a virtual oscilloscope, and the system reliably identified critical thresholds such as severe bradycardia (≤25 BPM) and tachycardia (≥145 BPM). These results underscore the potential of the proposed solution as an offline, low-cost monitoring tool particularly suitable for deployment in resource-constrained settings. Future research should advance this work through physical prototyping, integration with fetal monitoring systems, and empirical validation in clinical and rural contexts to assess its practical efficacy and scalability.

Keywords: Maternal Health; Cardiovascular Monitoring; Arduino-Based System; Heart Rate Classification; Low-Resource Technologies

INTRODUCTION

Given its close relationship to fetal growth and the result of childbirth, maternal health throughout pregnancy continues to be a top priority in worldwide public health (Aliyu & Dantata, 2023). In particular, cardiovascular health is essential to a safe pregnancy and delivery. If not identified and treated very away, conditions including heart failure, arrhythmias, and hypertension can cause major problems for the mother and the fetus (Adeyemi & Salawu, 2022).

Significant physiological changes brought on by pregnancy, such as elevated blood volume, heart rate, and cardiac output, have an impact on the cardiovascular system. These alterations have the potential to exacerbate preexisting cardiovascular diseases or trigger the development of new ones (Al-Turjman & Zomaya, 2022). Continuous cardiac monitoring has therefore emerged as a crucial component of maternal care, particularly in high-risk pregnancies when early abnormality discovery can save lives (Bartholomew, 2020).

Traditional maternal monitoring programs sometimes depend on sporadic clinician visits, which might not be enough to identify abrupt or sporadic changes in cardiovascular function. Furthermore, in many disadvantaged and rural areas, access to specialist monitoring facilities is still restricted (Bhuyan & Hasan, 2020). These drawbacks highlight the necessity of accurate, accessible, and reasonably priced devices that can offer ongoing monitoring outside of hospital settings (Cain et al., 2024).

Portable heart monitoring devices that can record physiological data in real time have been developed as a result of recent developments in wearable technology and biomedical sensors (Eemayas, 2023). To track critical metrics like heart rate, blood pressure, and oxygen saturation, these systems frequently incorporate elements like photoplethysmogram (PPG) sensors, electrocardiogram (ECG) modules, and pulse oximeters (Ford, 2022; Ghamari, 2018). A wristwatch, for instance, was used in a case study to identify a pregnant woman's atrioventricular nodal re-entrant tachycardia (AVNRT), allowing for prompt medical intervention and avoiding needless exposure to antiarrhythmic drugs (Green et al., 2020).

Such devices are capable of monitoring heart rate variability (HRV) trends in addition to identifying irregular heart rhythms. HRV has lately gained attention as a potential digital biomarker for predicting problems, including preterm birth. According to studies, doctors can take action before problems worsen by identifying variations in HRV patterns between term and preterm pregnancies as early as the third trimester (Hawryszko et al., 2022; Islam & Hasan, 2021).

Moreover, contemporary cardiac monitoring devices are made to record and examine several physiological indicators at once. Clinical decision-making is improved by tools that measure temperature, blood pressure, and oxygen levels because they offer a more comprehensive picture of maternal health (Jasinski, 2024). In distant areas, where direct access to specialized treatment is frequently restricted, these technologies are especially helpful. Such solutions lessen the need for frequent hospital visits and help to improve the efficiency of healthcare delivery by facilitating data collecting outside of hospital settings (Kerrigan, 2023).

Continuous cardiac monitoring system adoption is not without its difficulties, despite its benefits. There are still several issues with patient compliance, data accuracy, and clinical procedure standardization. To guarantee user trust and compliance, concerns about data security and privacy must also be addressed (Kjabdpur, 2023; Kolb & Egger, 2022).

However, there are encouraging chances to enhance outcomes for moms and their infants by incorporating cardiac monitoring technologies into maternal healthcare. Reducing maternal morbidity and mortality, particularly in pregnancies complicated by cardiovascular problems, requires early detection and prompt intervention (Mandal & Choudhury, 2022; Melchiorre & Sania, 2024).

With the goal of providing continuous cardiac monitoring, this study explores an Arduino-based heart monitoring device for expectant mothers. It addresses usability and performance while modeling the system architecture, including sensor selection and data processing. The objective is to improve the early identification of cardiovascular issues during pregnancy, which conventional monitoring techniques frequently overlook. By providing real-time heart rate readings, this suggested system enhances maternal healthcare in environments with limited resources in an economical and expandable manner.

MATERIALS AND METHODS

System Structure

The system architecture for the suggested simulation-based maternal heart rate monitoring system is shown in Figure 1. From the simulated physiological signal source to data processing, categorization, presentation, alarm production, and virtual cloud transmission, the architecture replicates the entire signal flow (Nasir, 2017). Early system functionality validation that is adapted to the particular cardiovascular demands of pregnancy is made easier by this modular framework.

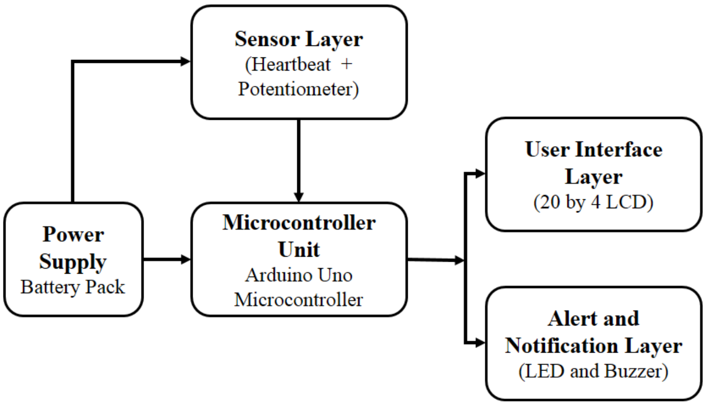

Figure 1: *Structure of the Heartbeat Monitoring System (Pentelopoulos & Bourbakis, 2010)*

Sensor Layer

This layer replicates real-world pulse oscillations frequently seen in pregnant women by using a potentiometer and a heartbeat sensor set up to mimic analog heartbeat signals (Rajkumar et al., 2025). Analog pin A0 is used to input the analog waveform into the microcontroller, enabling dynamic heart rate testing under a range of physiological circumstances.

Microcontroller Unit (Processing Layer)

In order to receive the incoming analog signals, compute the heart rate in beats per minute (BPM), and categorize the heart status according to maternal-specific thresholds, the processing layer makes use of a virtual Arduino Uno (VSM model). According to Rehan and Sultana (2021) and Schumacher (2023), this logic replicates on-board diagnostic capabilities that are crucial for obstetric surveillance.

Alert and Notification Layer:

The alert mechanism includes an LED connected to digital pin D4 and a buzzer on pin D2. These components provide immediate visual and audible feedback to indicate abnormal heart rate conditions. This mimics real-world clinical alarms and enhances system responsiveness for time-sensitive intervention (Sticker et. al., 2025; Tadesse, 2024).

User Interface Layer:

This layer includes a 24×4 character LCD module that presents system information in a clear and organized format. This setup allows users to easily monitor key health metrics directly on the device without requiring external screens or applications.

Simulation Monitoring Layer:

Within Proteus, a Virtual Terminal is employed to observe internal serial communication between the Arduino and connected peripherals (e.g., LCD, buzzer). This supports real-time debugging, signal tracing, and monitoring of system outputs without physical hardware deployment.

Materials

The simulation uses virtual hardware and software from the Proteus library, integrated with the Arduino IDE, to model and visualize real-time heart rate data.

Software components

Proteus is an advanced electronics simulation environment that supports Virtual System Modeling (VSM), enabling the real-time analysis of embedded system behavior. In this project, the Proteus software is used to design, simulate, and validate the circuit architecture of the maternal heart monitoring system. It facilitates interactive testing of virtual components such as the Arduino Uno, pulse sensor, 20×4 LCD, and LED indicators.

Methods

System design

The design of the maternal heart rate monitoring system was developed entirely within a virtual simulation environment, leveraging Proteus for circuit modeling and Arduino IDE for embedded firmware development. The simulation integrates virtual hardware components, including a pulse generator, Arduino Uno, LCD, LEDs, and buzzer, along with embedded logic to replicate real-time physiological monitoring and classification of maternal heart rate conditions.

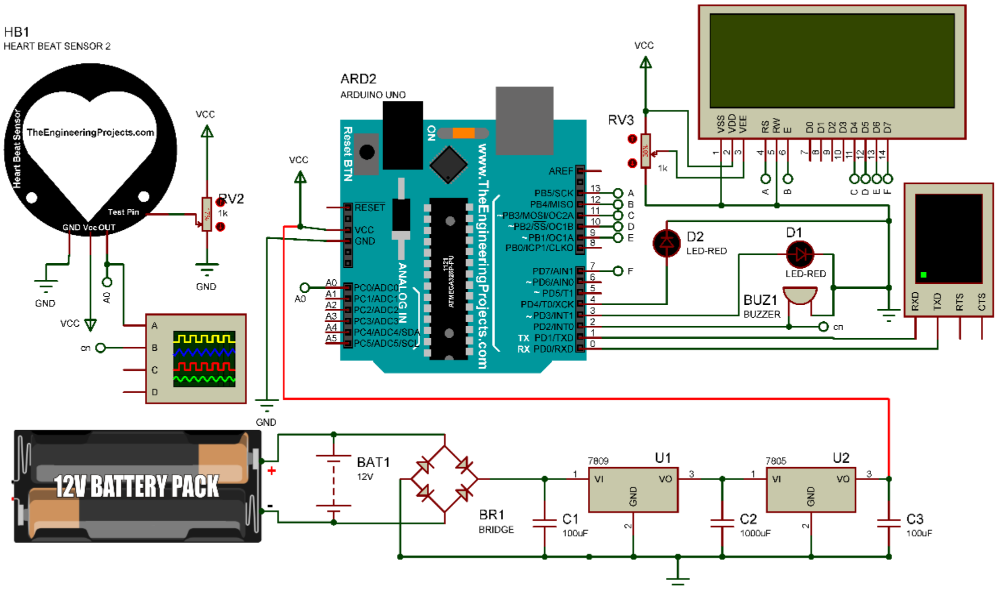

Figure 5: *Simulated Circuit Diagram of the Heartbeat Monitoring System in Proteus*

This section presents an overview of the system design, including the block diagram and flowchart that illustrate signal flow and component interactions. It also highlights how the system's virtual components interact within the simulation environment.

Block Diagram

The block diagram shown in Figure 6 represents the flow of data within the system, from data collection to processing, storage, and real-time visualization.

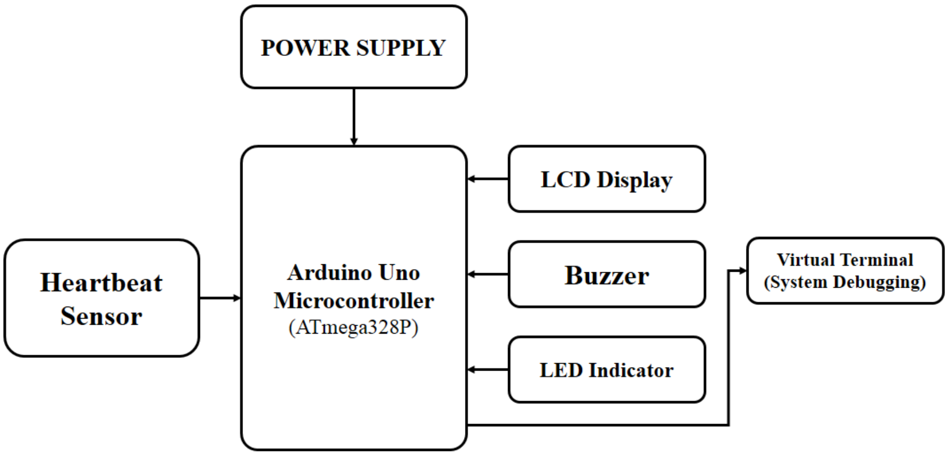

Figure 6: *Block Diagram of Heartbeat Monitoring System*

The system block diagram outlines a simulation environment comprising a potentiometer simulating heartbeat sources with analog voltage variations that represent maternal pulse signals. These signals are processed by an Arduino Uno microcontroller, which reads analog input to detect pulse peaks, calculate beats per minute (BPM), and classify heart rates based on set thresholds. The results are shown on a 20×4 LCD for real-time monitoring, while an alert system (LED and buzzer) warns when BPM deviates from normal limits. A virtual terminal displays serial outputs, aiding in debugging and verifying firmware accuracy.

System Flowchart

The system flowchart shown in Figure 7 illustrates the step-by-step execution logic of the heart monitoring simulation. It highlights how the system senses, processes, and responds to heart rate data in real time.

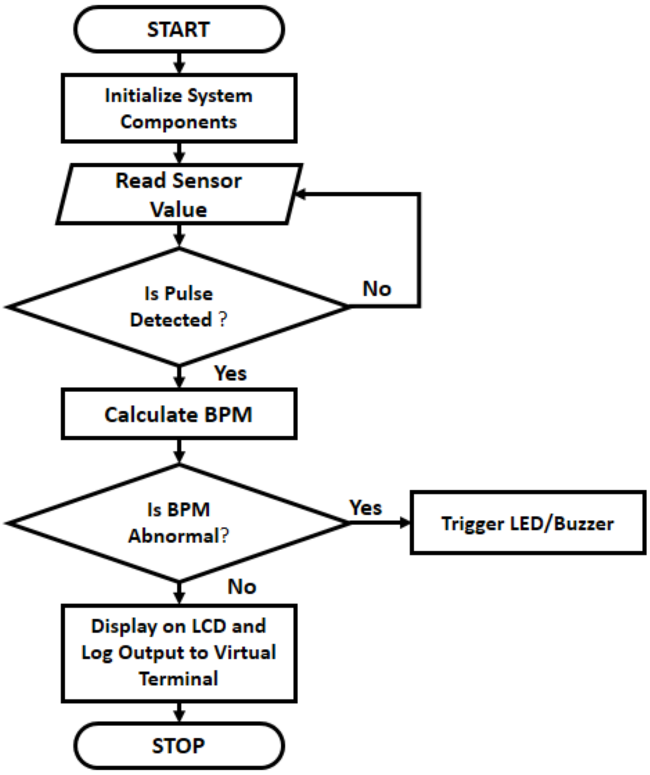

Figure 7: *Flowchart of the Heartbeat Monitoring System*

The flowchart illustrates the operational sequence of a simulated maternal heart rate monitoring system. It begins with the initialization of components such as the LCD and pulse input. The system continuously reads analog input values to detect a pulse. If no pulse is detected, it remains in standby mode. Once a pulse is identified, the microcontroller calculates the Beats Per Minute (BPM) based on heartbeat intervals and evaluates it against thresholds to classify the heart rate as normal, bradycardic, or tachycardic. If abnormal, alert mechanisms are activated through an LED and buzzer. The BPM and classification are displayed on the LCD while diagnostic data is logged, allowing for real-time monitoring and feedback.

Design of the Heart Rate Scenario

The following calculations were applied to enhance the functional accuracy of the simulation model and to guide future hardware deployment scenarios:

Although the simulation does not physically consume power, it is important to model typical power requirements based on the specifications of real-world components. The estimated power consumption is determined using:

$$P = V \times I \qquad - \quad - \quad - \quad - \quad - \quad (1)$$

Where:

P = Power in watts (W); V = Supply voltage, typically 5 V for Arduino Uno and peripheral devices; I = Total current drawn by the components (Amperes)

This estimation supports planning for power supply design in actual implementation, such as selecting an appropriate battery and voltage regulator configuration.

Heart rate is calculated from the time interval between two consecutive pulse peaks—also known as the Inter-Beat Interval (IBI). The system uses this formula:

$$HR = \frac{60}{T_b} \qquad - \quad - \quad - \quad - \quad - \quad (2)$$

Where:

HR = Heart Rate in beats per minute (BPM); T_b = Time between two pulse peaks (in seconds), calculated using millis() in Arduino.

This formula is implemented in the Arduino code to convert real-time analog pulse readings into BPM values. The system also uses this BPM to trigger alerts based on predefined thresholds.

RESULTS AND DISCUSSION

Table 1 presents simulated test cases to evaluate how the system responds to varying heart rate levels. It shows the corresponding heart condition classification and the system's alert behavior via LED and buzzer indicators.

Table 1: System Response Based on Input Heart Rate Signals

BPM	Range	Heart Condition	LED Status	Buzzer Response	Action Taken
0	No Signal	No Beat Detected	Off	Off	Monitoring, Waiting for BPM
25	Critical Low	Critical Bradycardia	Solid RED	Continuous	Call Emergency
45	Low	Bradycardia	Blinking RED	Intermittent	Seek Medical Help
75	Normal	Normal	Off	Off	Healthy Range – No Action
130	High	Tachycardia	Blinking RED	Intermittent	Rest & Monitor
145	Critical High	Severe Tachycardia	Solid RED	Continuous	Call Emergency

Table 1 presents the system's diagnostic responses to various simulated heartbeat signals. At critically low BPM (25 BPM), the system identified Critical Bradycardia, activating a solid red LED and a continuous buzzer while displaying an emergency message for medical attention. At a normal heart rate (≈75 BPM), the system correctly indicated Normal status with no indicators activated. At a higher BPM (130 BPM), classified as Tachycardia, it showed a blinking red LED and intermittent buzzer alerts. In the absence of a detected signal, all indicators were off, and a message indicated no pulse detected.

Signal Validation Using Oscilloscope

During the simulation, a virtual oscilloscope module was used to observe and validate the analog pulse signals from the heartbeat sensor module, ensuring that the simulated heartbeat waveform matched expected physiological patterns. Signals were captured from the heartbeat sensor's output pin to the Arduino Uno's analog input (A0), representing electrical pulse patterns. Each waveform corresponds to a different heart condition, allowing for accurate validation of signal responsiveness in various physiological states.

Response at 0 BPM

At 0 BPM, the waveform appears as a straight horizontal line with no visible oscillation. This reflects an absence of heartbeat activity, simulating either a disconnected sensor, system inactivity, or a clinical flat-line scenario. In the system's logic, this state is interpreted as "No Pulse Detected," and no alerts are triggered. The LCD instead displays a "Waiting for BPM" message, indicating standby mode.

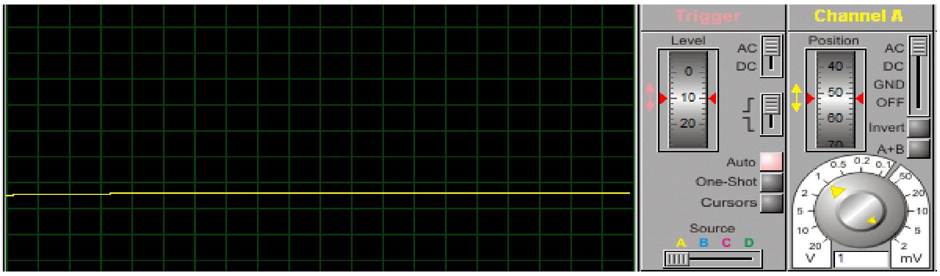

Figure 8: *Oscilloscope Output at 0 BPM Showing No Pulse Activity (Flatline Condition)*

Response at 25 BPM

At 25 BPM, the waveform reveals slow, infrequent rising-edge peaks with wide intervals between each beat. This represents a condition of critical bradycardia, where the heart rate is dangerously low. Such a state, particularly in a pregnant patient, could signify compromised cardiac output and warrants immediate clinical intervention. The system responds by activating continuous LED and buzzer alerts, highlighting the severity of the condition.

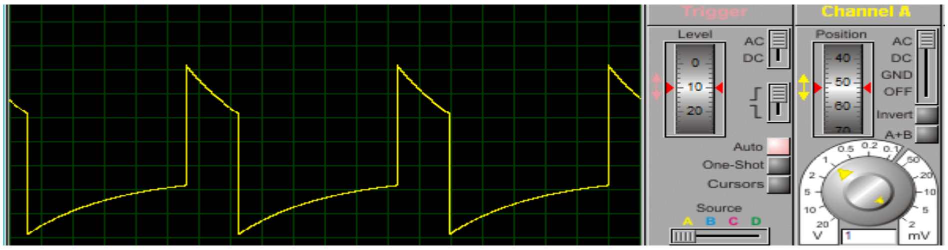

Figure 9: *Oscilloscope Output at 25 BPM Representing Critical Bradycardia*

Response at 45 BPM

The waveform at 45 BPM demonstrates a low-frequency but more regular pattern compared to the 25 BPM signal. The peaks remain moderately spaced, indicating a mild bradycardia scenario. Although not critical, this heart rate falls below the typical resting range and may require medical attention depending on the patient's overall health status. The system classifies this condition and triggers intermittent alert signals, prompting the user to seek evaluation.

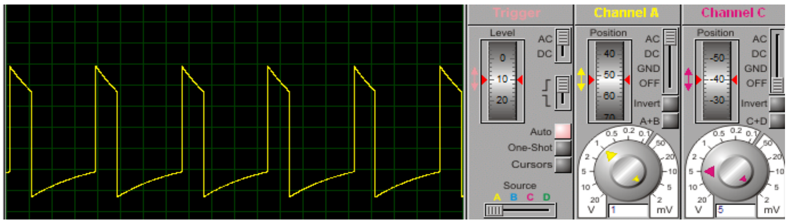

Figure 10: *Oscilloscope Output at 45 BPM Indicating Mild Bradycardia*

Response at 75 BPM

At 75 BPM, the signal is characterized by uniformly spaced and stable peaks. This waveform reflects a normal resting heart rate, typically expected in healthy individuals, including pregnant women under non-stressed conditions. No alerts are triggered in this state. The system displays the BPM and "Status: OK" on the LCD, affirming a healthy range and confirming stable sensor and logic behavior.

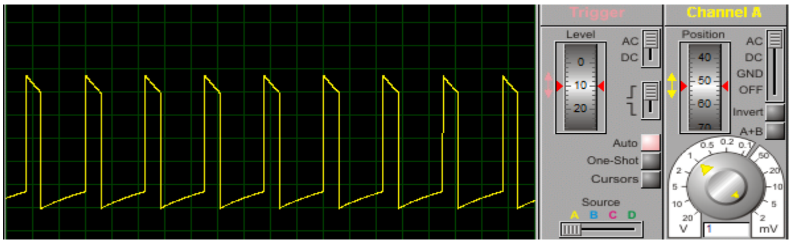

Figure 11: *Oscilloscope Output at 75 BPM Representing Normal Heart Rate*

Response at 130 BPM

The waveform at 130 BPM displays rapidly occurring pulse peaks with significantly reduced intervals between them. This condition represents mild tachycardia, which could be attributed to exertion, anxiety, or early-stage cardiovascular irregularities. Although not classified as critical, the system initiates blinking LED and intermittent buzzer alerts to prompt user awareness and suggest rest or observation.

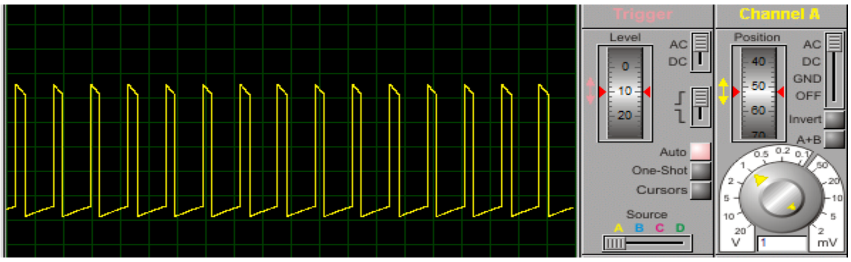

Figure 12: *Oscilloscope Output at 130 BPM Illustrating Mild Tachycardia*

Response at 145 BPM

At 145 BPM, the waveform becomes highly compressed with tightly packed peaks, indicating a state of severe tachycardia. This condition is potentially life-threatening, especially during pregnancy, as it may compromise both maternal and fetal oxygenation. The system identifies this state and triggers continuous audio-visual alerts to simulate an emergency notification.

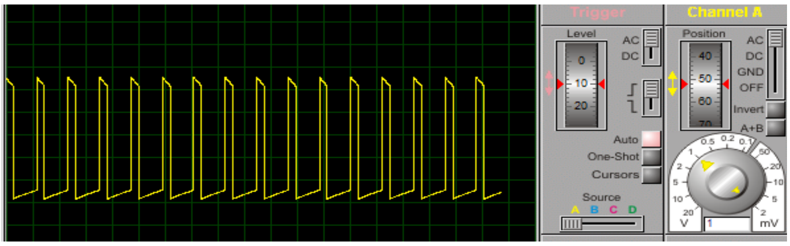

Figure 13: *Oscilloscope Output at 145 BPM Depicting Severe Tachycardia*

The simulation developed an Arduino-based maternal heart rate monitor featuring a tiered alert system aligned with obstetric thresholds. Key classifications include critical bradycardia (≤25 BPM) and mild bradycardia (45 BPM), both triggering alerts for potential hypoxia or toxicity. Conversely, a normal heart rate of 75 BPM suppresses alerts, denoting system stability. For tachycardia, mild (130 BPM) and severe (≥145 BPM) rates prompt intermittent and continuous alerts, respectively, addressing risks such as hypotension and fetal hypoxia. Although validated under controlled conditions, significant gaps in testing for motion artifacts and fetal heart rate integration remain. The system's real-time capabilities enhance maternal healthcare in underserved regions, with a non-internet-dependent design suited for rural applications and potential for future expansion.

CONCLUSION

This study presents the design and simulation of a low-cost maternal heart monitoring system developed using Proteus 8.15 and Arduino IDE, aimed at facilitating early detection of cardiovascular abnormalities during pregnancy. The system successfully simulated real-time acquisition and classification of heart rate signals—bradycardia, tachycardia, and normal rhythms—using an Arduino Uno, virtual heartbeat sensor, and audiovisual alert components. Signal integrity was validated via a virtual oscilloscope, and the system reliably detected critical thresholds such as severe bradycardia (≤25 BPM) and tachycardia (≥145 BPM), demonstrating its functional viability within simulated environments.

The primary contribution of this research lies in its integration of accessible hardware and simulation tools to develop a scalable, offline maternal monitoring prototype, addressing the technological and infrastructural constraints prevalent in low-resource settings. Theoretically, it underscores the applicability of embedded systems in maternal health surveillance, while practically offering a cost-effective framework for early cardiovascular risk identification outside clinical settings.

Future research should progress toward physical prototyping and hardware validation under real-world physiological conditions. Additionally, integrating the system with fetal monitoring technologies and conducting empirical assessments in both clinical and rural environments would be essential to evaluate its diagnostic accuracy, user acceptability, and operational scalability in diverse maternal care scenarios.

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