

Research Article

Development of an Age-Calibrated Automatic Heart Rate Monitoring System with Real-Time Alerts Using Arduino Microcontroller & GSM Module

Adam Sunusi Haruna^{1*}, MutariHajara Ali², and Ibrahim Alkasim³

¹Zaihar Healthcare LTD, Kano, Nigeria, Department of Physics, Faculty of Physical Sciences Bayero University, Kano, Nigeria

²Department of Physics, Faculty of Physical Sciences Bayero University, Kano, Nigeria

³School of Cyber Security & Digital Forensics, National Forensic Science University, Gandhinagar, Gujarat, India

Corresponding Author: Adam Sunusi Haruna. Email: adamsunusiharuna@outlook.com

Received: 23/02/2026; Revised: 11/03/2026; Accepted: 25/03/2026; Published: 31/03/2026

DOI: <https://doi.org/10.69996/jsihs.2026002>

Abstract: Heart rate monitoring system is an essential tool to track patient vital signs for medical emergencies. Embedded (Arduino microcontroller, pulse sensor and GSM modules) and wireless heart rate monitoring systems were developed. However, employing universal thresholds without accounting for physiological variation across age groups is the main issue associated with the embedded monitoring system, while the wireless system works in a limited domain. This work presents the development of an age-calibrated automatic heart rate monitoring system with real-time alert. The system utilized the use of an Arduino Uno microcontroller, GSM module, and a photoplethysmography (PPG) heart rate sensor. The system was developed based on sensor mapping. An age-based evaluation algorithm was implemented to assess heart rate status (normal, high or low). Experimental results show that an abnormality alert is sent to the patient, next of kin, and medical personnel via the GSM module, if the measured heart rate exceeds or falls below the defined threshold for a given age group. The system demonstrated reliable detection of abnormal conditions, with calibration effectively reducing the error between raw sensor readings and reference values. The integration of age-dependent thresholds ensures personalized monitoring, while the GSM communication feature supports timely medical intervention. This approach provides a reliable solution suitable for continuous patient monitoring, especially in telemedicine and resource-limited healthcare environments.

Keywords: Arduino microcontroller, GSM module, Photoplethysmography, Remote patient monitoring, Serial communication.

1. Introduction

The human cardiovascular system plays a critical role in sustaining life by ensuring continuous circulation of oxygenated blood and nutrients to body tissues while facilitating the removal of metabolic waste products. Central to this system is the heart, whose rhythmic contraction generates the pressure required to maintain adequate blood flow across organs [1]. The rate at which the heart beats, commonly referred to as heart rate, is a fundamental physiological parameter and a key indicator of cardiovascular health. Variations outside normal limits may signal stress, illness, or the onset of life-threatening conditions, particularly when undetected for prolonged periods[2].

Heart rate regulation is closely linked to age, physical condition, and physiological state. Children typically exhibit higher resting heart rates compared to adults, while abnormal



deviations in either direction tachycardia or bradycardia may indicate underlying cardiovascular or systemic disorders. Continuous monitoring of heart rate is therefore essential, especially for vulnerable populations such as infants, elderly individuals, and patients with chronic medical conditions. Traditional clinical monitoring methods, however, often rely on intermittent measurements or manual intervention, which may delay timely detection of critical abnormalities [3-4].

Recent advances in embedded systems and communication technologies have significantly transformed healthcare delivery models. The emergence of telemedicine and the Internet of Health Things (IoHT) has enabled real-time acquisition and transmission of physiological data using low-cost sensors and microcontroller-based platforms[5-6]. Wearable and portable health monitoring devices now provide opportunities for remote diagnosis, early warning systems, and improved patient outcomes, particularly in regions with limited access to healthcare infrastructure [7-8].

Despite these advancements, many existing heart rate monitoring systems apply uniform threshold values across all users, neglecting age-dependent physiological differences. Such generalized approaches may reduce diagnostic accuracy and increase the likelihood of false alarms or missed abnormalities. Addressing this limitation requires the integration of personalized evaluation algorithms that adapt monitoring thresholds according to patient-specific parameters.

In this work, an age-calibrated automatic heart rate monitoring system with real-time alert capability is developed using an embedded microcontroller and a GSM communication module. The system incorporates an age-based evaluation algorithm to classify heart rate readings as normal, high, or low, and automatically transmits alert messages to caregivers and medical personnel when abnormal conditions are detected. By combining sensor calibration, real-time processing, and wireless communication, the proposed system offers a practical and reliable solution for continuous cardiovascular monitoring, particularly in telemedicine and resource-constrained healthcare environments.

2. Related Works

Several studies have explored heart rate and vital sign monitoring using embedded systems. Seth et al. [9] presented a pulse-based heart rate measurement system implemented with an Arduino platform. The system captures pulse signals through a fingertip sensor and processes the data to compute heart rate values, which are displayed in beats per minute (BPM) using the Arduino development environment. Austin et al. developed a GSM-enabled vital sign monitoring system emphasizing the importance of continuous physiological observation for early disease detection. Their study highlights how delayed access to medical care can lead to serious health complications. By employing photoplethysmography (PPG), the system detects variations in blood volume based on light absorption and reflection characteristics. The integration of Arduino, GSM technology, and biomedical sensors enables real-time monitoring and emergency alert transmission via SMS, without reliance on internet connectivity or smartphones.

Chavanet al. [10] proposed a health tracking framework incorporating GPS and GSM technologies to monitor heart rate and body temperature. The system automatically transmits alerts and location information when abnormal physiological conditions are detected. Heart rate values are presented on an LCD interface, while temperature and BPM readings are also logged through the serial monitor. The authors suggest that advancements in digital sensing can enhance accuracy and enable broader physiological measurements, including arterial pressure indicators and cardiac parameters. Sheta et al. [11] introduced an intelligent patient monitoring solution

aimed at managing cardiac emergencies. The system continuously evaluates patient vital parameters against predefined threshold values. When abnormal conditions are identified, an audible alarm is activated and patient data are transmitted through GSM communication to healthcare providers. The architecture supports real-time data access via both SMS and web-based platforms, improving responsiveness during critical situations.

Amirrudin et al. [12] developed an IoT-enabled heart rate monitoring system that integrates the **ESP32** microcontroller with the **MAX30102** and an OLED display. The system captures heart rate data and transmits it in real time to a web interface, enabling remote monitoring. Key challenges encountered included maintaining stable internet connectivity and minimizing power consumption. Despite these limitations, the system demonstrates practical applications in remote patient monitoring and fitness tracking, reflecting the growing convergence of IoT technologies and healthcare monitoring solutions. Hussain & Mohammed [13] introduces a real-time system for monitoring and predicting heart attacks by combining Internet of Things wearable sensors with deep learning models. It focuses on continuously tracking three key vital signs: systolic blood pressure, diastolic blood pressure, and heart rate. Data was transmitted to the ThingSpeak cloud platform for remote monitoring and storage. Local processing enables instant alerts for abnormalities. The system includes fall detection, activates a buzzer and sends notifications to family/caregivers.

Baban, Shehu, Abdussalam, et al. investigated the design and simulation of a heart rate monitoring device using Arduino technology. Their work demonstrates the integration of pulse sensors with wireless communication modules, including Bluetooth and GSM, to enable real-time physiological data transmission and system modeling. Shan et al. [14] conducted a comparative study of microcontroller-based systems for real-time health monitoring. The analysis examined PIC, ATMEGA32 with GSM, and NodeMCU ESP8266 platforms, focusing on differences in cost, signal processing methods, communication capabilities, and system performance. The study emphasizes the application of Fourier Transform techniques for improved signal accuracy and highlights the advantages of IoT-based systems in enabling efficient remote healthcare monitoring.

While many of these studies demonstrate low-cost heart rate monitoring using Arduino platforms combined with pulse sensors and GSM or IoT communication, most employ fixed threshold values that do not account for age-related physiological variations. Systems based on PPG sensors with GSM or cloud connectivity typically apply uniform alarm limits across all users, which may lead to inaccurate assessments in pediatric or elderly populations. Furthermore, internet-dependent systems are less suitable for resource-constrained environments with limited connectivity. The proposed age-calibrated heart rate monitoring system addresses these limitations by integrating a user-defined age calibration mechanism directly into the microcontroller firmware, thereby improving accuracy and reliability across diverse population groups.

3. Design Procedure

The work presents an automatic heart rate monitoring system. The purpose of developing the system is to send Heart rate readings quickly over a GSM network. The work will eliminate the need of any manual assistance by making heart rate reading and sensing automatic. The materials used are: Arduino uno microcontroller and Integrated Development Environment (IDE), GSM module (SIM 800L), pulse/heart rate sensor (Sen-11574), connecting wires, and circuit board (bread board), external power supply. The development followed a structured approach, combining both hardware and software components to read the pulse using analog input to bpm

evaluation, with age calibration factor, and reliable data communication.

3.1 Circuit Design

The hardware design involved assembling the devices/modules acquired, process, and transmit heart rate data to GSM module for communication purpose. The microcontroller power supply is connected from the Personal Computer Universal Serial Bus (USB) terminal to power the Arduino board. The Heart rate sensor signal line is connected to the Analog input pin (A0) of the microcontroller that reads the pulse signal from the wrist, and powered by 5V (VCC,) and 0V (GND). GSM module for wireless communication and alert delivery is powered by an external power supply with a regulated voltage to meet the required input voltage (3.4V to 4.4V), the RX and TX terminals were connected to 0 and 1 digital input pins of the board respectively. Wires are used as connectors between modules and the bread board. Figure 1 shows the experimental setup (circuit design) and the data extraction method was organized using flowchart in Figure 2. The software aspect focused on programming the microcontroller to read and process heart rate data, compare it with normal thresholds, and trigger alerts if needed.

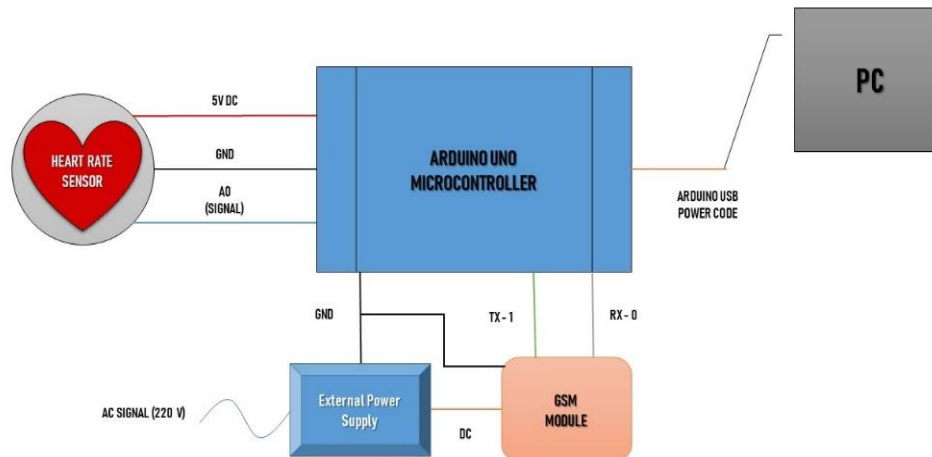


Figure 1: Circuit Design

3.2 Design Equations and Parameters

The heart blood output in a single minute is the cardiac output (CO), it is the product of heart rate (HR), and stroke volume (SV) [15-16]:

$$CO = HR \times SV \quad (1)$$

Heart rate monitors/sensors uses an optical measurement technique to detect blood volume changes in the skin known as Photoplethysmography (PPG)[14-15]. The sensor is composed of a light-emitting diode (LED) to emit light of a certain wavelength and a photo detector to detect the light reflected by the skin. PPG work on Beer–Lambert's law, which relates the absorption of light to the properties of the material (blood) [17]:

$$I = I_0 e^{-\epsilon c l} \quad (2)$$

where:

I = transmitted light intensity.

I_0 = incident light intensity (LED output).

ϵ = absorption coefficient of blood at LED wavelength.

c = concentration of absorbing material

l = optical path through tissue/vessel

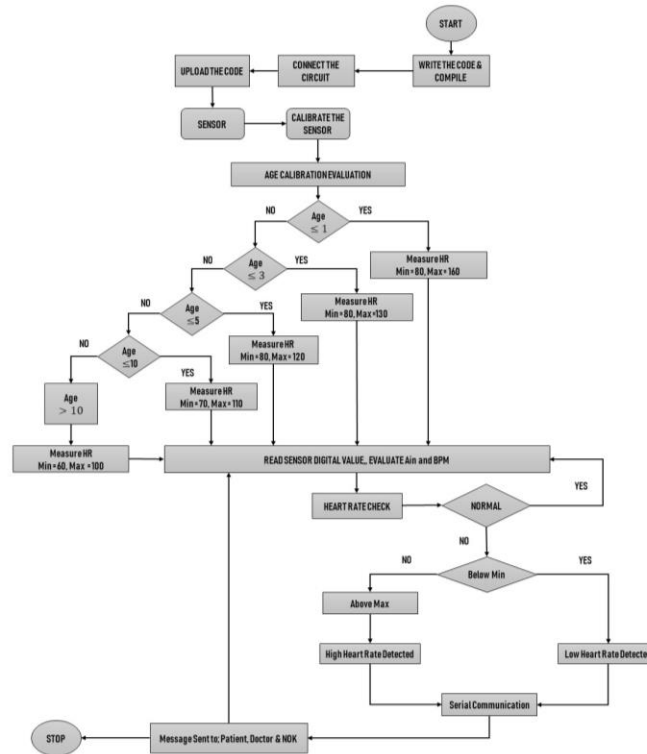


Figure 2:Design Procedure (Flowchart)

The hardware also consists of a few components: a signal amplifier and some basic signal filters. To amplify the intensity of the light received by the detector [18]. The photodiode converts light intensity into a current, which passes through a resistor or amplifier to become voltage:

$$V(t) = G \cdot R_{load} \cdot S \cdot I(t) \quad (3)$$

where:

G = gain of the amplifier.

R_{load} = resistor value.

S = photodiode sensitivity (A/W).

$I(t)$ = total light intensity reaching the photodiode.

When we interface sensors to the microcontroller, the output of the sensor mostly is analog in nature. But the microcontroller processes digital signals. Arduino Uno has on-board ADC channels which can be used to read analog signal in the range 0 to 5V, with 10-bit ADC (2^{10}) 0 to 1024[19]. Arduino process analog signal with its built-in analog-to-digital converter (ADC). To know what input analog value fed, the digital value is converted back to analog[20].

$$Ain(V) = Digital\ Output \times \frac{V_{ref}}{2^n - 1} \quad (4)$$

where:

V_{ref} = reference voltage (the maximum value the ADC can convert).

For 0 Vin, Digital output value = 0, For 5 Vin, Digital output value = 1023 (10-bit)

The analog input Ain and the bpm are related by the equation [21]:

$$bpm = \frac{Ain + 0.1746}{0.0283} \quad (5)$$

Maintaining a healthy heart rate is important for all body functions. An adequate heart

rate ensures oxygen and nutrient-rich blood is delivered throughout the body while waste products are removed. Edward Charbek in his article (updated: Feb 16, 2024) from Medscape (emecine) the normal heart rate range by age reference is given in Table 1.

(Source: <https://emecine.medscape.com/article/2172054-overview#a2>)

Table 1: Normal Heart Rate Range by Age Reference

S/N	Age Span (Years)	Normal Heart Rate Range (bpm)
1	≤ 1	80 – 160
2	≤ 3	80 – 130
3	≤ 5	80 – 120
4	≤ 10	70 – 110
5	> 10	60 – 100

4. Results

The heart rate sensor is connected to the analog input pin of the microcontroller. Signal lines are filtered and stabilized using capacitors or software smoothing algorithms. Arduino IDE was used to write and compile the code. The code perform analog-to-digital conversion, evaluate the voltage signal, and evaluates the sensor bpm. The program was developed and tested using equation 4 and 5 to evaluate Ain and bpm respectively. Figure 3 and 4 shows the set of data compiled by the sensor, the serial monitor displays the calibration factor of the age input as 21 and 15 respectively, initializing the expected heart rate range 60 to 100 bpm. Normal heart rate was recorded and no indication of abnormal reading, the system keeps track of the beats recorded until an abnormality is observed. Abnormal heart rate was seen with a message “*abnormal heart rate detected*”, and a serial communication was established by the GSM module to deliver a message to the registered personnel.

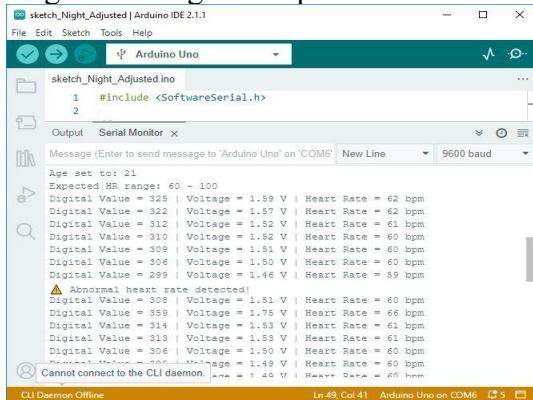


Figure 3:Serial Monitor Output (with age calibration factor of 21)

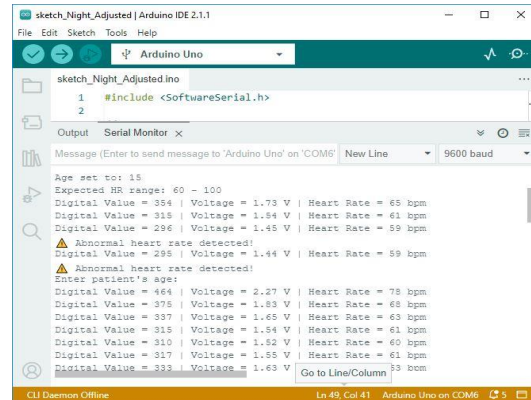


Figure 4:Serial Monitor Output (with age calibration factor of 15)

Table 2 shows the summary of some data set as recorded by the sensor with the corresponding parameters; Digital value, Ain, bpm, Heart rate status and serial communication status.

Table 2: Measured HR Sensor Reading

S/N	Digital Value (bit)	Ain (V)	bpm	Heart Rate Status	Message
1	351	1.72	65	Normal	Not sent
2	327	1.60	62	Normal	Not sent
3	429	2.10	74	Normal	Not sent

4	375	1.83	68	Normal	Not sent
5	464	2.27	78	Normal	Not sent
6	295	1.46	59	Low HR	Sent
7	589	2.88	108	High HR	Sent
8	716	3.50	130	High HR	Sent
9	775	3.79	141	High HR	Sent
10	820	4.01	148	High HR	Sent

As seen in Figures 3 and 4 abnormalities were detected with low bpm. Figure 5 and 6 shows the experimental set up and a serial communication message sent from the GSM module to one of the registered numbers respectively for early and emergency response.

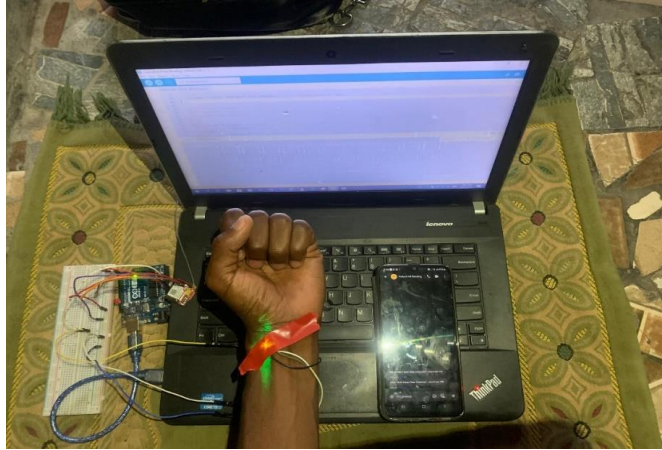


Figure 5: Experimental Set up

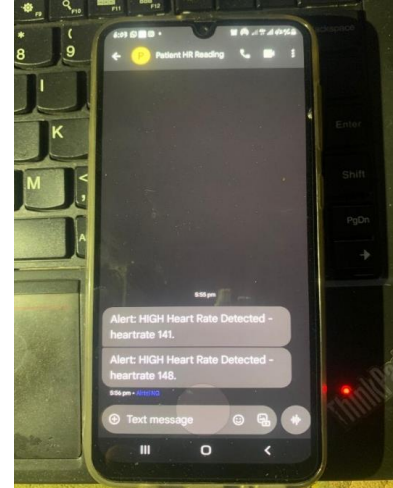


Figure 6: Serial Communication (Message Sent)

5. Conclusion

The age-calibrated automatic heart rate monitoring system with real-time alerts using arduino and GSM module was successfully developed. With this system a lot of life will be saved due to prevention of heart of attack. The serial communication exists to overcome distance barrier, and can communicate with both smart and future phones that operate on a 2G network. It also overcomes delay as it is time saving for assistance. The implementation of this system demonstrates integration of age-calibrated thresholds with regression based approach that combines real-time pulse detection, and sensor calibration has proven to be both effective and practical. The use of embedded coding, analog evaluation, and mobile app comparison ensures that sensor readings are accurate and actionable. Arduino microcontroller provides real-time computation, while the GSM module ensures immediate communication with caregivers and medical personnel. Results confirmed that the system can accurately monitor and detect abnormal heart rates across different age categories, offering a reliable and dependable monitoring solution. In other to achieve a high performance of the system, there is a need to introduce a noise reduction factor during the design of the sensors. Data recording factor can be introduced to keep the date safe in an excel sheet for tracking and follow up over a period of time. The same technique can be used to add up cloud server-based monitoring system.

Acknowledgment: Not Applicable.

Funding Statement: The author(s) received no specific funding for this study.

Conflicts of Interest: The authors declare no conflicts of interest to report regarding the present study

References

- [1] R. Chaudhry, J. H. Miao, and A. Rehman, "Physiology, Cardiovascular," *StatPearls Publishing LLC*, pp. 1–8, 2022.
- [2] O. A.-L. Mohammed, "Physics of the Cardiovascular System," in *Medical Physics*, no. 1, pp. 66–162, 2018.
- [3] M. Saudi, "Heart Disease," *Ministry of Health*, Saudi Arabia, 2024.
- [4] H. Series H3, UNDERSTANDING HEART DISEASE. Scotland: Chest Heart & Stroke Scotland, 2014.
- [5] S. Hindinamani and A. B. Bodas, "Implementation of Zigbee Technology for Patient HealthCare Monitoring System," *Int. J. Adv. Res. Comput. Commun. Eng.*, vol. 6, no. 3, pp. 400–402, 2017.
- [6] U. T. Baban, A. B. Shehu, and M. B. Ahmad, "Using an Arduino and GSM Module to Simulate Heart Rate Monitoring Devices with Pulse Sensors," *Glob. J. Res. Eng. Comput. Sci.*, vol. 5, no. 1, pp. 6–15, 2025.
- [7] P. Yadav, R. Agrawal and K. Kashish, "Performance Evaluation of ad hoc Wireless Local Area Network in Telemedicine Applications," *Procedia Comput. Sci.*, vol. 125, pp. 267–274, 2018.
- [8] M. Dachyar, T. Y. M. Zagloel and L. R. Saragih, "Knowledge growth and development : internet of things (IoT) research, 2006 – 2018," *Heliyon*, vol. 5, no. April, 2019.
- [9] M. Seth, V. Patel, A. Mishra, S. Gupta and K. Sheikh, "Measuring Heart Rate Using the Pulse Sensor," *Int. J. Adv. Res. Ideas Innov. Technol.*, vol. 7, no. 3, pp. 2183–2185, 2021.
- [10] S. Chavan, S. Shukla, P. Vethekar and S. Singh, "Health Monitoring Tracking System Using GPS and GSM Module," *Int. J. Trend Sci. Res. Dev.*, vol. 6, no. 3, pp. 2137–2138, 2022.
- [11] M. A. E. Sheta, R. A. E. El-Adly and A. E. E. ElAlfi, "Developing Smart System for Managing Heart Patients' Crises," *Res. J. Specif. Educ. Fac. Specif. Educ. Mansoura Univ. MBSE Journals*, no. 67, pp. 315–346, 2022.
- [12] N. A. Amirrudin, M. Nazreen, M. A. Syafiq, M. H. Irwan and F. A. Bolang, "Heart rate sensor with IoT features," *Res. J. Specif. Educ. Fac. Specif. Educ. Mansoura Univ. MBSE Journals*, vol. 05002, pp. 4–8, 2024.
- [13] N. Hussain and A. A. Mohammed, "An IoT-Based Vital Signs System for Early Heart Attack Detection," *J. Sensors, IoT Heal. Sci.*, vol. 03, no. 04, pp. 17–30, 2025.
- [14] L. E. Shan, M. Zeedhan, M. H. Baswaid and A. Noor Ul, "IoT-Based Heart Rate Monitoring: A Comparative Analysis of Microcontroller Systems for Real-Time Health Monitoring," *Prepr. MDPI*, no. March, 2025.
- [15] B. Maheswaran, O. Ciaravino, and S. Antonio, "Heart Rate Monitor," *Ohio*, 2022.
- [16] M. A. G. Santos, "Online heart monitoring systems on the internet of health things environments : A survey , a reference model and an outlook," *Inf. Fusion*, vol. 53, no. May 2019, pp. 222–239, 2020.
- [17] A. Galli, R. J. H. Montree, S. Que, E. Peri and R. Vullings, "An Overview of the Sensors for Heart Rate Monitoring Used in Extramural Applications," *MDPI Sens.*, vol. 22, pp. 1–29, 2022.

-
- [18] M. M. A. Hashem, R. Shams, M. A. Kader, and M. A. Sayed, "Design and Development of a Heart Rate Measuring Device using Fingertip," in IEEE International Conference on Computer and Communication Engineering (ICCCE'10), Kuala Lumpur, Malaysia, 2010, pp. 197–201.
 - [19] J. Blum, "Exploring Arduino: Tools and Techniques for Engineering Wizardry," *Second Edi. John Wiley & Sons, Inc.*, 2013.
 - [20] M. Mcroberts, Beginning Arduino, First Edit. United States of America: Apress, 2010.
 - [21] A. S. Haruna and M. H. Ali, "Analog Voltage to Bit Per Minute (bpm) Conversion in Heart Rate Sensor : A Least Square Regression-Based Approach Using Arduino Microcontroller," *Dutse J. Pure Appl. Sci.*, vol. 12, no. 1b, pp. 360–369, 2026.