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Innovative IoT-Based Wristlet for Early COVID-19 Detection and Monitoring Among Students

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ABSTRACT

The current global issue of the COVID-19 pandemic has prompted the push and utilization of all available means to halt its spread. COVID-19 is a highly infectious disease, and continuously monitoring early symptoms could help avert catastrophic devastation. This paper proposes an innovative use of the Internet of Things (IoT) enabled system to efficiently and effectively detect early COVID-19 signs at a relatively low cost. This study adopted an experimental approach in designing and constructing a low-cost hardware system using a Wi-Fi enabled microcontroller, a temperature sensor, and a heart rate sensor for students. The proposed system detected and distinguished normal and abnormal temperature, regular and irregular heartbeat and constantly displayed the student's status in a mobile application. Consistent tests proved that the developed IoT-enabled system was reliable, responsive, and cost-effective. The mass production of this device will aid in the early detection of the disease, thereby mitigating the spread among students, particularly in underdeveloped countries. The paper's merit stems from the microcontroller's intelligence programming and the sensor's operation via the mobile application, which enables low-cost early identification of abnormal temperature and heartbeat irregularities.

1. INTRODUCTION

Coronavirus 2019 (COVID-19) infection is a contagious disease that causes severe acute respiratory illness. The first recorded case was discovered in December 2019 in Wuhan, China [1, 2]. The epidemic then expanded worldwide, resulting in a pandemic that is still ongoing. Some symptoms include fever, cough, shortness of breath, headache, and loss of smell and taste [2]. The infection spreads when people come into contact with virus-containing respiratory droplets and airborne particles exhaled by an infected person. This particle may be inhaled or enter a person's mouth, nose, or eyes through touch or direct deposition (i.e., being coughed on) [1]. The risk of infection is most significant when people are in close contact for extended periods, particularly indoors in poorly ventilated and crowded areas [2].

There has been a surge in COVID-19 cases in Ghana after the government lifted the pandemic control measures [3]. The unavoidable reopening of schools with all of its activities has also increased the spread among students [4, 5]. New variants of the disease also threaten its control. During the pandemic, detecting cases early, tracing, and isolating affected people are still more critical and essential [6]. Right now, the best option to combat this coronavirus is to slow its spread, which can be accomplished by the use of measures such as universal vaccination, social distancing, hand washing, and face masks. Technology, on the other hand, may be able to slow the spread of the disease by detecting and monitoring new cases at its early stage [7, 8].

The increased use of mobile technologies and intelligent devices in the healthcare sector has a significance on the global impact of the disease [7, 9]. Healthcare has significantly improved as a result of medical professionals using new, cutting-edge, and sophisticated devices to track patients' health. Internet of Things (IoT) allows for the integration of physical devices that can connect to the internet and provide clinicians with real-time information about their patients' health status. IoT and related technologies have the potential to change how these diseases and other healthcare issues are treated [10]. IoT could also be used by public health agencies to collect data for monitoring the COVID-19 pandemic [10, 11].

Therefore, in this paper, a low-cost innovative device, more specifically a wristlet, is suggested to monitor changes in temperature and heartbeat rate of students in schools as a remedy to the critical current challenge that Ghana and other developing countries face. Patients with COVID-19 sometimes exhibit bradycardia (a condition indicating a slow heart rate) and tachypnea (a condition indicating an unusually fast breathing rate), both of which are considered to be quite rare [12, 13]. Also, Gul et al. [14] and Guan et al. [15] indicated, that high ambient body temperature was the most common symptom of COVID-19 patients.

This is achieved through a single mobile application that sends out an alert when a student's temperature or heartbeat rate exceeds a certain threshold (suspected of COVID-19 infections). The goal of this IoT system is to design and build a user-friendly wristlet that will monitor students' temperature and heart rate, as well as to implement a mobile application to display the data collected and aid in the detection of early potential COVID-19 carriers.

This paper proposes an innovative COVID-19 detection and monitoring system based on wearable sensor technology such a wristlet to capture real-time symptom data. The study adopted an experimental approach in designing and constructing the low-cost hardware system using a Wi-Fi enabled microcontroller (Node MCU8266), a DS18B20 temperature sensor, and an XD-58C heart rate sensor. The software phase entails creating a mobile application that analyses high temperature, and heartbeat anomaly on a mobile app display using the react native framework.

The remainder of this paper is organized as follows. Section 2 consists of a review of the pertinent literature. Section 3 describes the proposed IoT system in detail, including the hardware and software. Section 4 focuses on identifying new cases with the designed system. Finally, Section 5 concludes the paper.

2. RELATED WORK

There is a plethora of information available in literature regarding the Internet of Things (IoT) to deliver healthcare. Yousif et al. [16] conducted a comprehensive analysis of literatures on IoT Technologies during and after the COVID-19 pandemic. The paper also presented a thorough evaluation of major Internet of Things (IoT) solutions that had impact on healthcare during COVID-19, contact tracing, and transportation throughout the pandemic. Wu et al. [17] proposed a hybrid IoT safety and health monitoring system to improve outdoor workers safety. Multiple wearable sensors were integrated into the proposed network system to monitor environmental and physiological parameters. Their design was divided into two layers: one for data collection from users and another for data aggregation throughout the internet. The authors concluded the successful integration and working of their systems. Their system was limited to a specific geographical location and the authors recommended using a smartphone-based IoT gateway.

Dong and Yao [18] proposed an integrated fog-cloud combined IoT platform for structured and smart COVID-19 prevention and control, which includes five interventions: COVID-19 symptom diagnosis, quarantine monitoring, contact tracing and social distancing, COVID-19 outbreak forecasting, and SARS-CoV-2 mutation tracking. The authors claimed that their approach yielded more promising results than other approaches. Using the concept and framework of the "Internet of Things" (IoT) and machine learning model prediction, Choyon et al. [19] proposed an IoT-based system that monitors the health status of people's biological data such as body temperature, heart pulse. Their developed method provided valuable healthcare information of patients over a wide range of distances to the emergency medical support team. However, the researcher recommended using a wearable device that could constantly and continually monitor patients' health statistics.

For COVID-19 public safety, Yadessa and Salau [20] developed an IoT and hand washing system for monitoring and recording real-time occupancy. The approach is built on a decentralized traceability subsystem used to secure personal information and ensure user privacy by ensuring the availability, security, and immutability of the real-time data acquired.

Bashir et al. [21] developed a low-cost IoT-enabled COVID-19 standard operating procedure (SOP) compliance system that counts the number of persons entering and departing a specific area while maintaining physical distance and monitoring body temperature. Their method comprises multiple sensor nodes communicating with a centralized server. A wide-angle camera module for the Raspberry Pi (RPi) was utilized to identify violations in the minimum distance between queuing individuals. The data stored on the server can be used for compliance auditing, real-time monitoring, and planning purposes.

3. METHODOLOGY

3.1 System design and description

The proposed system consists of a low-cost hardware system using a Wi-Fi enabled microcontroller. The software phase of the system entailed the development of a mobile application which uses the react native framework, as shown in the block diagram in Figure 1.

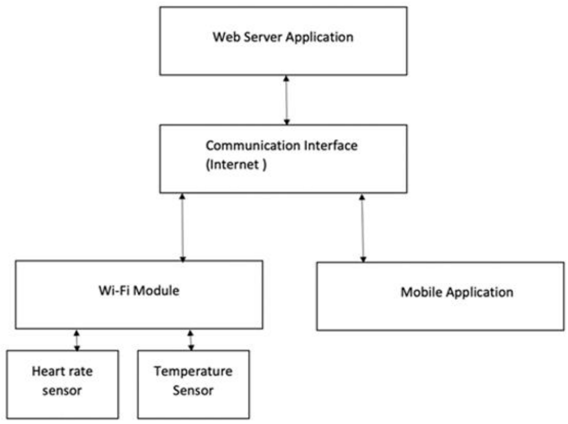

Figure 1. Block diagram of the proposed system

A temperature sensor and pulse sensor were used to monitor and measure the heart rate and temperature. When a reading is acquired, it is stored on the webserver and communicated to the mobile application, allowing the temperature and heart rate sensors to monitor tasks over time. An alert is triggered when an abnormal health scenario arises, and a notification is sent to the mobile application. Communication between the system and the mobile application is initiated via an ESP8266 Wi-Fi module.

3.1.1 Hardware

The hardware system consists of the following components that work together to achieve the system's goal: NODE MCU8266, DS18B20 temperature sensor, XD-58C heart rate sensor and ESP8266 Wi-Fi module. The NodeMCU8266 is the device's main component, and it is critical to the system's operation. This device is in charge of connecting temperature and heart rate sensors and gaining access to the temperature and heart rate data collected by the various sensors. A microprocessor and a Wi-Fi module are at the heart of it. Thanks to this one-of-a-kind design, the complete system is smaller and more compact. When the gadget is turned on, it instantly begins reading and sending data through Wi-Fi to a server where it is stored. V_{dd}, data, and ground are the three pins that make up the temperature sensor. The data pin is connected to the microcontroller's D1, and the positive pin, V_{dd}, is connected to the microcontroller's 3v. The negative pin, ground, is connected to the microcontroller's ground. The heart sensor is made up of three pins: ground, data, and V_{dd}. The tap power pins are connected to the first two power pins, and the analogue component of the microcontroller is attached to the last pin. The microcontroller is attached to one end of a USB cable connected to a laptop, and the laptop serves as the microcontroller's power supply. Figure 2 shows the schematic of the hardware circuit.

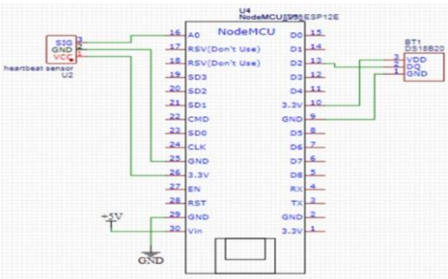

Figure 2. Schematic diagram of the hardware circuit

a. Description of key hardware components

i. NODE MCU8266

NodeMCU is a free firmware that comes with free prototype boards. Figure 3 shows the NodeMCU8266 microcontroller. The firmware is written in the Lua scripting language. The firmware is built on the Espressif Non-OS platform SDK for ESP8266 and is based on the eLua project. It heavily relies on open-source applications like lua-cjson and SPIFFS. The firmware can be customized to meet specific requirements. Support for the 32-bit ESP32 is also included. A dual in-line package (DIP) circuit board that combines a USB controller with a smaller surface-mounted board holding the MCU and antenna is widely utilized for prototyping. On breadboards, the DIP format allows for quick prototyping. The initial design was based on the ESP8266's ESP-12 module, which combines a Wi-Fi SoC with a Tensilica Xtensa LX106 core, which is commonly used in IoT applications [18]. The pin layout of the NodeMCU8266 is shown in Figure 4.

Figure 3. NodeMCU8266 microcontroller

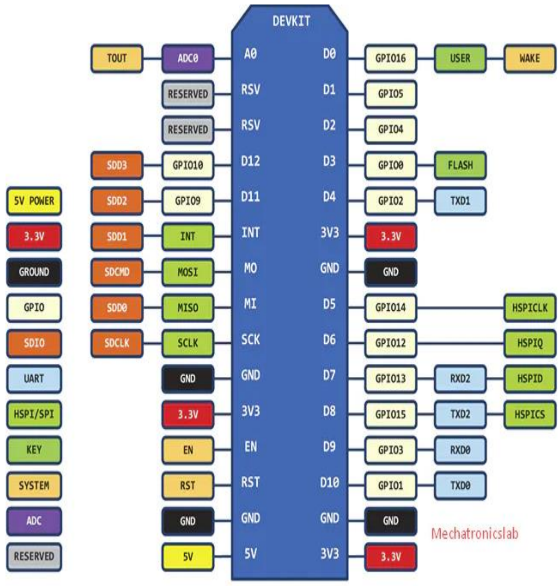

Figure 4. Pin-out configuration of a NodeMCU8266

The ESP8266 is an inexpensive Wi-Fi SOC (system-on-a-chip) that has TCP/IP networking software and microcontroller functionality. All microcontrollers have access to any Wi-Fi network because of the integrated TCP/IP protocol stack. The 4MB of flash memory and 80MHz clock speed of the NodeMCu makes it the perfect device for IoT applications. It uses 15 A less current than the Arduino Uno, which uses 35 mA. Additionally, it doesn't need a shield or peripheral unlike Arduinos and is less expensive than similar microcontrollers. The digital temperature sensor used is the DS18B20 which is depicted in Figure 5.

Figure 5. DS18B20 digital temperature sensor

ii. XD-58C HEART RATE SENSOR

Principle and working of the heartbeat sensor: The heartbeat sensor is powered by photoplethysmography. It detects any change in blood volume that results in a change in the intensity of light in any organ of the body (avascular region). When monitoring the heart rate, the timing of the pulses is critical. The volume of blood flowing through the body is determined by the rate of heartbeats, and because blood absorbs light, signal pulses are equal to heartbeat pulses [22-24].

The most basic heartbeat sensor is made up of a light-emitting diode and a detector, such as a light-detecting resistor or a photodiode. The heart's pulses influence the flow of blood to various body parts. When a light source such as an LED, shines on the human tissue, it either reflects or transmits the light (as in finger tissue). The amount of light absorbed in the tissue is proportional to the volume of blood in that tissue. The detector generates an electrical signal proportional to the heart rate. This signal is a direct current signal related to tissues and blood volume, with an alternating current component placed on top of it that is synchronized with the pulse and formed by pulsatile oscillations in arterial blood volume. The detector output is first filtered with a two-stage HP-LP circuit before being converted to digital pulses with a comparator circuit or a simple ADC to obtain the AC signal. The digital pulses are sent to a microcontroller, which uses the formula [14] BPM (Beats per minute) = 60*f, where f is the pulse frequency, to calculate the heartbeat rate. Figure 6 depicts a XD-58C heart rate sensor.

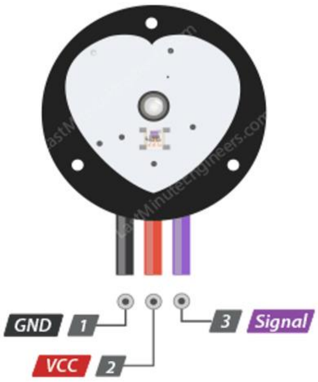

Figure 6. A XD-58C heart rate sensor

- Pin configuration:

1-Ground: Connect to the ground of the circuit.

2-VCC: Pin supplies power for the sensor, which can be between 3.3V to 5V.

3-Signal: This is the signal output that connects to the analogue input.

3.1.2 Software

The software development process is described in this section. The software phase entails creating a mobile application using the react native framework. The device was programmed in Lua scripting language using the ESP8266 Software Development Kit (SDK). Additional simulations were carried out with the help of the EasyEDA simulation software.

The procedures of the primary program and subsequent programs for disease symptoms detection and alert are depicted in flowcharts.

b. Main software program design

The flowchart in Figure 7 shows the logic and sequential flow of the software program that runs in the microcontroller utilized for the processing and control unit. When the system is first turned on, the temperate and heartbeat sensors are initialized by blinking on the LED light on the MCU8266 board, indicating a successful booting of the software and hardware. When the system is first turned, the output and input pins are initialized and the network access point. Each sensor node analyses and process values captured. The values are then sent to the server API over the HTTP protocol. The received data from the microcontroller is then read and displayed to the user from the server. MySQL is used as the database management system in software design. Figure 8 shows the database architecture of the system.

Figure 7. Flowchart of developed software program

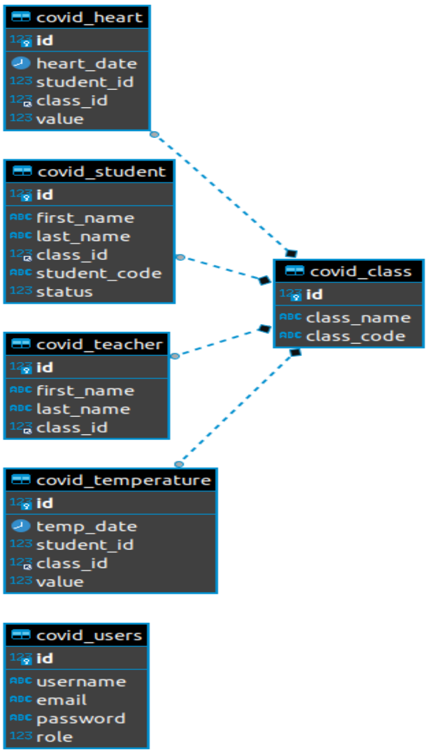

Figure 8. Systems database architecture

c. Detection algorithm of the system

The suggested approach requires the instantaneous and average signal value data from the temperature and heart rate sensors and uses a straightforward digital signal processing strategy. The suggested scheme determines the regular and irregular pulse rates from the heart rate sensor, as well as the normal and abnormal output from the temperature sensor. The likelihood of a potential COVID-19 case is estimated using a threshold, input data from the sensors, and an average value. The proposed disease detection technique is shown in flow chart form in Figure 7 and is based on conditionality parameters predicted for the probable COVID-19 patient. The following steps are taken in order to process the proposed scheme:

1. For each student wearing the device, student (stu (i)).
2. Label (stu (i)) final temperature average value, ΔXstu (i).
3. Label (stu (i)) final heart rate average value, ΔYstu (i).
4. Begin: Read the data from both sensors for temperature ($t_{stu(i)}$) and the heart rate ($hr_{stu(i)}$) for each established connection with the microcontroller (m).
5. Compare the ($t_{stu(i)}$) and ($hr_{stu(i)}$) values with the threshold values (TH_{vt}) for temperature and (TH_{vhr}) heart rate for each (stu (i)) respectively.
6. Identify the detection condition, possibility of COVID-19 if the signal value exceeds the threshold values ((TH_{vt}) and/or (TH_{vhr})) for each sensor.
7. If any of the threashold value is exceeded, repeat the step 2 for the (stu (i)) 3 times and COMPUTE an average value, ΔXstu (i) and ΔYstu (i).
8. Compare the average values, ΔXstu (i) and ΔYstu (i) with ((TH_{vt}) and/or (TH_{vhr})).
9. If ((TH_{vt}) and/or (TH_{vhr})) > ΔXstu (i) and ΔYstu (i); Output: Potential COVID-19 case.
10. End: Send student to the server API over the HTTP protocol.

4. RESULTS AND DISCUSSION

4.1 Results

This section aims to explain the project's outcome and its results based on a critical examination of the outcomes generated during and after the device's construction and testing. This section also describes the results achieved throughout and after the device's development and testing phases. The device was designed to aid in the early detection of COVID-19 cases and prevent the disease's transmission during school hours. This was performed by monitoring students' temperature and heart rate changes and relaying all acquired data to a teacher-interactive mobile app-based dashboard. Additionally, an alarm will be sounded if a student produces data that surpasses a threshold set in the system for identifying COVID-19 suspected persons.

After a prototype of the device was designed using the EasyEDA to produce the accurate schematic sketch, it served as a guideline for the actual connections on the matrix board on which the device sits. As illustrated in Figure 9, the entire system was assembled by soldering individual components to the matrix board.

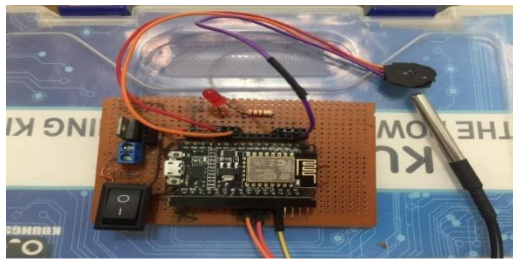

Figure 9. Connection mode of developed system with heart rate and temperature sensors

Individual sensors were isolated and examined to evaluate the overall system's capacity. This was done to determine the level of interference caused by any component and eradicate it. Ten individuals were tested in a class with the wristlet, and the results are summarized in the Table 1.

Table 1. Results of the test conducted on the students

Persons	Temperature readings (°C)	Heartbeat rate readings (BPM)
1	35.7	67
2	36.5	89
3	36.6	71
4	36.2	61
5	37.0	70
6	36.3	66
7	37.4	69
8	35.4	70
9	36.8	67
10	36.6	72

The device was tested at the tertiary level. The results from construction and testing of the mobile app are shown in the Figures 10-14.

Figure 10 shows the login user interface of the mobile application used by the teacher in class, and Figure 11 shows the side menu where the teacher can assess all data. Figure 12 shows the list of students in a particular class, their names, and the status of their conditions, represented by the colours red and green. Red represents suspected COVID-19 cases, and green represents healthy.

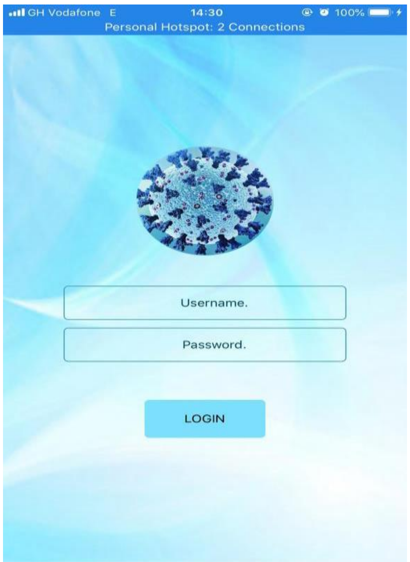

Figure 10. Login user interface

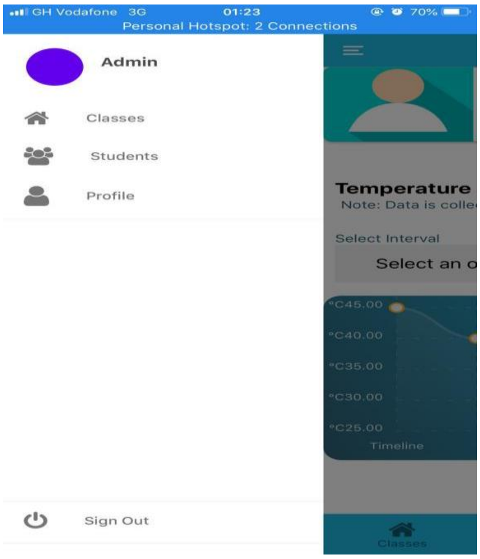

Figure 11. Side menu

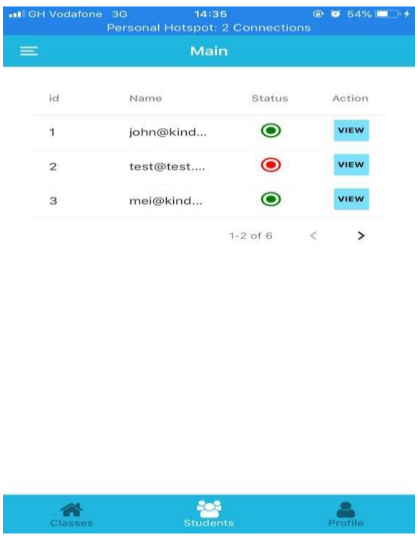

Figure 12. Students' page

Figures 13 and 14 show the students' profile page, which includes charts of their temperature and heart rate progression, respectively.

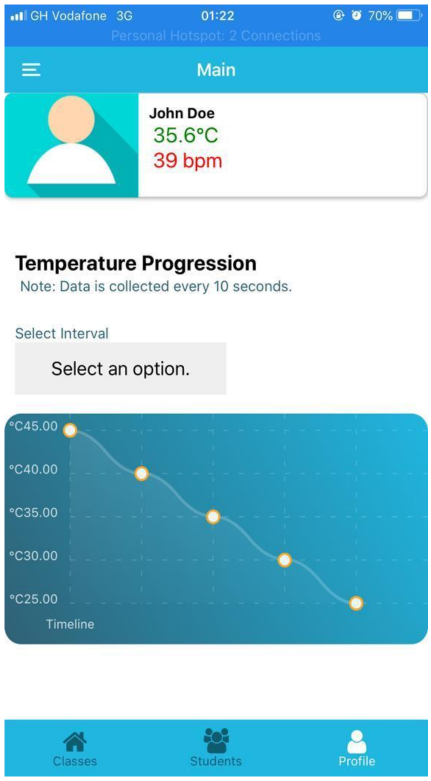

Figure 13. Student profile page (Temperature progression)

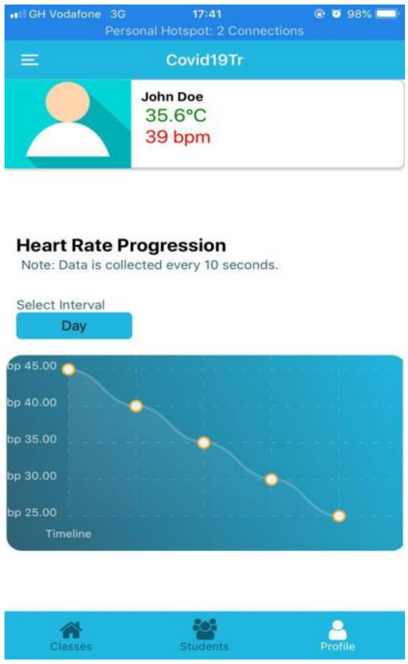

Figure 14. Student profile page (Heart rate progression)

4.2 Discussion

This paper presents the design of a COVID-19 monitoring system using temperature, heartbeat sensors, and a microcontroller to effectively and efficiently manage the COVID-19 pandemic. The easy to use COVID-19 classroom monitoring system designed in this study comes with improved functionalities than other Internet of Things (IoT)

COVID-19 detection systems [19, 20, 23-26], even though it has rigorous control and monitoring functionalities. The undertaken measurements and testing have revealed that our proposed system functions admirably under all conditions.

This implementation of our system is both cost-effective and reliable. This system can be deployed in schools and any enclosed building with people occupying for an extended period. Additionally, the system can be expanded to undertake additional measures by sending messages to the COVID-19 task force set up by the school, city and government for contact tracing. The system's primary advantages include early detection, which helps reduce the incidence of COVID-19 infection and ultimately saves lives and cost-effectiveness.

To show how cost effective the proposed system is, we present the designs cost implication in Table 2.

Table 2. Budget of the designed system excluding software cost

No.	Items	Quantity	Unit	Cost (GHC)
1	Microcontroller	1	12.00	12.00
2	Temperature sensor	1	10.00	10.00
3	Heartbeat rate sensor	1	10.00	10.00
4	Voltage regulator	1	7.00	7.00
5	Electric switch	1	5.00	5.00
6	LED	1	1.00	1.00
7	Jumper wire	1 set	10.00	10.00
	Total			**55.00**

The cost analysis presented in Table 2 indicates that the proposed system is cost effective (low cost).

5. CONCLUSION

The COVID-19 virus has caused adverse health implications and deaths to many people all over the world. Despite the development and the mass vaccination worldwide and large adherence to safety protocols, the virus has continued existence. In addition, a large number of people have not received the vaccination, and some have also ignored the safety precautions. Governments from all over the world have pushed for the lifting of the earlier restrictions put in place during the height of the virus spread, including allowing students to return to class in order to prevent economic hardship for the populace of the highly underdeveloped countries. Such actions have once more ignited the virus's spread. Returning students to schools have accelerated the virus's spread, especially among young people. The situation has necessitated the use of technology to help stop the virus's spread. This paper suggests an innovative implementation of an IoT-enabled system to quickly and efficiently identify early COVID-19 symptoms at a reasonable cost. One of the functions that allowed system administrators to confirm the early detection of suspected individuals was one of the features of the prototype designed and built in the system. Despite numerous challenges, we succeeded in achieving our objective of developing a simple circuit device and a functional, user-friendly smartphone application for the early detection of COVID-19. Numerous tests' outcomes showed that the system was capable of flagging anyone whose temperature or heartbeat rate was abnormal or irregular and sending an alarm via the developed mobile app. The system can be improved to allow messages to be sent to any task forces in charge of managing the COVID-19 pandemic, including contact tracing.

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