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A viable prototype device for air quality and heart rate monitoring using the Internet of Things (IoTs)

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ABSTRACT

Air pollution poses a serious risk to every human's health and well-being, who have trouble breathing. Contaminants, such as gases, particulate matter, carbon monoxide, sulfur dioxide, and biologically generated particles found in the atmosphere are referred to as air pollutants. The traditional ways of monitoring pollution are quite laborious and inefficient. Mitigating the excessive air pollution that harms living things' health is pertinent. This brings motivation to carry out the objective of developing a device, an air pollution detector (APD) that monitors and measures both the quality of air and heart rate in a given environment. The IoT devices were used to collate data within a geographical area. The air data collected through the MQ-135 air quality sensor were calibrated and processed using Arduino programming language. The LCD module displays the air pollution data with the pulse of heartbeat in beats per minute (BPM) once the air gets denser. The system was tested in different five locations on the campus of Lead City University, Ibadan, Nigeria. Two sets of tests were carried out to measure the air quality index (AQI) and the pulse. The tests carried out were based on the effect of time of day on AQI, heart rate (HR) in action, and resting heart rate (RHR) taken hourly from 8:00 am to 8:00 pm. The obtained sensitivity results showed that a higher concentration of air pollution leads to an increase in heart rate and a lower concentration of pollution leads to a decrease in heart rate. Hence, the affordable and eco-friendly developed system has the potential to be used as a tool to explore for researchers, and students and bring awareness of the types of air pollutants for the general public.

INTRODUCTION

One of the biggest environmental issues affecting people worldwide is air pollution. In Nigeria, people living in urban areas are mostly affected by air pollution. The rise in air pollutants can be linked to industrialization, urbanization, and increased vehicular emissions which then pose a serious threat to public health (Tooki *et al.,* 2024). When compounds that are toxic to living organisms are discharged into the atmosphere, air pollution results (Manisalidis *et al.,* 2020). Its emission can cause a variety of health problems, such as respiratory diseases, cancer, dyspnea, and heart disease (Mani *et al.,* 2021). When chemicals that are bad for human health and the environment are present in the atmosphere, they can contaminate the air and damage materials or the climate. (Al-Ali *et al.,* 2010). Climate change is largely caused by air pollution and this has led to an increase in global warming across the globe. The contamination of indoor or outdoor surroundings by chemical activities, and physical or biological agents has altered the natural features of the atmosphere (WHO, 2022). However, the conventional methods of monitoring air pollution often involve manual data collection, which can be time-consuming and limited in accuracy. Also, traditional air pollution monitoring systems are typically based on fixed sensors in specific areas (Senthilkumar *et al.*, 2020). There are a multitude of distinct forms of air pollution, including gases such as Ammonia, Carbon monoxide, Sulfur dioxide, Nitrous oxides, Methane, and Chlorofluorocarbons, as well as particles, both organic and inorganic (Green, 2021). Air pollution can be caused by both human activities (Dimitriou *et al.*, 2011) and natural phenomena (Whitacre, 2021).

The World Health Organization (2022) estimated that air pollution kills approximately 7 million people every year worldwide. Chronic respiratory disorders, lung cancer, heart disease, and strokes are brought on by air pollution (Kortoçi *et al.*, 2022). Moreover, if more action is not taken, air pollution will continue to be a pivotal factor in global death (Henry *et al.*, 2019). Human exposure to air pollution can have several health effects depending on the types, quantity, length, degree of exposure, and nature of the pollutants exposed to as well as the related toxicity of the pollutants of concern at that moment (Dhankar *et al.*, 2018).

Black soot has resulted in poor air quality, especially in some regions in Nigeria (South-South) with high carbon emissions where their residents have to thoroughly clean their houses daily and households with infants at least twice daily. Black soot truly has a wide impact on a lot of things and not just on human health as shown in Figure 1 (Zanuto *et al.*, 2020). Human life, population health, and children's future prosperity are all at risk due to poor air quality. Since clean water and clean air are both necessary for life on Earth, air pollution likewise poses a threat to the sustainability of the planet's ecosystem (Africa *et al.*, 2022).

Figure 1. Diagram of feet and hand covered with black soot

With the advancement in Internet of Things (IoT) technology, one can develop a real-time IoT-based Air Quality and Heart-Beat Monitoring System (AQH-BMS). In light of the United Nations (UN) Sustainable Development Goal-3 (SDG-3), which is designed to guarantee healthy lifestyles and promote well-being for all people, of all ages, this will aid in tackling the issues related to air pollution.

Challenges and Prospects of Air Pollutant

This section briefly discussed the concept of air quality index, black soot, particulate matter, heart rate, and implementation of IoTs. The AQI is a daily metric used to report on air quality. The AQI is concerned about the potential short- and long-term health effects of breathing in dirty air (Abulude *et al.*, 2022).

Black soot is a form of air contaminant. It has a 2.5mm diameter. It also contains a variety of other contaminants, such as metals, chemical acids, and dust particles. Based on its nature, it can exist in a solid, liquid, or gaseous state. Soot is typically a by-product of fossil fuel combustion, such as oil refining and car emissions. Soot particles are discharged into the air due to their small size, while others create gas particles that can travel thousands of kilometres from their source (Owhor *et al.*, 2023).

Particulate matter (PM) is the most frequent type of air pollution linked to negative health impacts on an individual. Sulfate, Nitrates, Ammonia, Sodium chloride, black carbon, mineral particles, and water are the main constituents of PM. It is composed of a complex mixture of liquid and solid particles of organic and inorganic materials that are suspended in the air (Olukanni *et al.,* 2021). PM varies in size, chemical content, surface area, concentration, and source of origin. PM is mostly categorized as coarse (PM10), fine (PM2.5), or ultrafine (PM0.1) particles (Warburton *et al.,* 2019: Dong *et al.,* 2020). The most dangerous type of particulate matter is PM2.5. This may absorb a wide range of poisonous and hazardous compounds due to its huge surface area (Yang *et al.,* 2020). PM2.5 with a diameter of 2.5 micrometres increases the risk of respiratory and cardiovascular infections, chronic illnesses, and birth defects than PM10 (Olukanni *et al.,* 2021). PM10 hurts the cardiovascular and respiratory systems while ultra-fine and coarse particles do not inflame the brain, but they do contribute to diseases such as asthma, allergies, and cardiovascular disease (Smith, 2020).

Heart rates showcase the number of times a person's heart contracts and relaxes at a particular time (usually per minute). Heart rates differ based on age group. The normal RHR for an adult at least 18 years is 72 beats per minute (bpm) while older children's heart rates fall around 90 bpm. Babies' heart rates are substantially higher than adults at around 120 bpm (Parihar *et al.,* 2017). The heart must pump blood both inward and outward at a specific rate, to supply blood to the entire body and sustain life (Quer *et al.,* 2020: Bartels *et al.,* 2021). A person's heartbeat is said to be normal when it falls between 60 and 100 bpm. Table 2 shows the normal resting heart rates at different ages (Yilmaz *et al.,* 2017).

The third wave of technological advancements is IoTs. IoTs is a global network that enables global communication between numerous objects and people (Yacob *et al.,* 2020). IoT stands out as a core part of commercial and industrial performance, but more importantly for raising the quality of living. Commercialization of IoT projects is possible in the field of electrical control such as lights, fans, and other electrical equipment (Villamil *et al.,* 2020).

Table 2: Normal Heart Rates at Different Ages

Age	Normal Heart Rate (bpm)
Up to 1 month	70 to 190
1 to 11 months	80 to 160
1 to 2 years	80 to 130
3 to 4 years	80 to 120
5 to 6 years	75 to 115
7 to 9 years	70 to 110
Over 10 years	60 to 100

Synergy of Air Quality and Heart Rate

A multitude of health issues, such as the progression of heart and lung illnesses, elevated risk of asthma, heart attacks, strokes, and early mortality have connections with air pollution (Warburton *et al.,* 2019). It is a recognized risk factor for cardiovascular disease and related mortality that contributes to 27% of deaths from heart disease and 34% of deaths from stroke. People who are overweight and exposed to air pollution are more likely to acquire cardiovascular problems (Biel *et al.,* 2022).

REVIEW OF RELATED WORKS

The summary of related works and the gaps identified were reviewed in this section. Chattopadhyay *et al* (2019) developed a system that uses low-cost air quality monitoring nodes, which are made up of Wi-Fi modules and low-cost semiconductor gas sensors. This system measures the concentrations of gases such as Carbon monoxide (CO), Carbon dioxide (CO2), Sulphur dioxide (SO2), and Nitrous oxides (NO2) using semiconductor sensors. The sensors gather information about various environmental aspects and transmit it to the Raspberry Pi, which acts as a base station, for analysis. Thus, this system is strictly for industrial use only. Tekale *et al* (2020) proposed a device using Arduino Uno-based air quality monitoring and filtering. Different sensors were used in the system to measure the quality of the air such as the analog MQ-135 gas sensor for air quality, the digital MQ-6 gas sensor to detect the presence of additional gases in the air, and the analog MQ-5 and MQ-9 sensors to detect contamination. The sensitivity result justified that people who breathe in airborne particles have a higher risk of developing lung cancer. However, there is no storage means and data cannot be uploaded and retrieved in real-time. Pavithra *et al* (2021) developed an IoT-based smart mask with air purification and body vitals monitoring system. The IoT-based portable unit was designed for inhaling pure air, sunstroke alleviation, and remote monitoring. Initially, the machine detects the temperature of the surroundings, and the degree of air pollution and supplies pollution-free air to breathe in a heavily polluted environment. Information was transferred to a useful destination through a Wi-Fi module, where automatic monitoring and necessary actions were launched. Thus, it is expensive when considering the family. Tooki *et al* (2024) worked on a sustainable real-time air quality monitoring system (AQMS) using the IoT, In Kaduna metropolis as a case study. The IoT-based AQMS was used to measure the concentration of Carbon monoxide (CO), The IoT devices were used to collate data within a specific area. The data collected, by the sensor, were processed using an application written in C/C++. The system also includes a user interface that allows users to view real-time air pollution data and receive alerts when pollution levels exceed the safe threshold. The system was tested in different environments in densely populated areas of Kaduna State, Nigeria. The result obtained within the selected location in parts per million (PPM) of CO ranges from 0.4 ppm to 0.7 ppm with Boy’s Hostel being the worst area to stay. However, the traditional ways of monitoring pollution are laborious and involve inefficient processes. Therefore, this was done to demonstrate the high level of accuracy and reliability of the system.

Most of the recent work in the literature only emphasizes the air quality monitoring system using Arduino and IoT at an unaffordable rate for personal use. However, no account was reported on a device that monitors and measures both the quality of air and heart rate in a given environment Therefore, the shortcoming motivates the interest of this paper to deploy a device - an air pollution detector (APD) that will monitor and measure both the quality of air and heart rate in a given environment with the purpose to identify various types of air pollutant prevalent in a given location, measure and display the humidity and temperature levels of the environment and understand how the quality of air in a given environment affects the heart rate. Also, this device is constructed to ultimately be affordable, eco-friendly, and more effective for air quality monitoring by providing early detection and alarm systems in real time.

METHODOLOGY

This section detailed the basic theory, components, working principles, and the design procedure. The hardware components comprise of Arduino UNO microcontroller, ESP8266 module, air quality sensor, heartbeat sensor, DHT11, and 20x4 LCD module.

Arduino UNO Microcontroller: The microcontroller used for this work is Arduino Uno due to its ease of programming. The board was programmed using the Arduino IDE (Integrated Development Environment) and a type B USB cable. It contains six analog I/0 pins and fourteen digital I/0 pins, six of which can be used for PWM output. Its normal operating current is 5V DC while the pins can take a current of up to 20mA. It has 32kb flash memory of which 0.5kb is used for the bootloader. It has a clock speed of 16MHz (Ojo *et al.*, 2023).

ESP8266 Module: The ESP8266 Wi-Fi module has a built-in Transmission Control Protocol/Internet Protocol (TCP/IP) stack that allows any microcontroller to connect to the Wi-Fi network. The ESP8266 has two options: it can either host an application or assign all Wi-Fi networking duties to a different application processor.

Air quality sensor: The air quality (AQ) sensor detects impurities that are present in the air such as particulates and contaminants that are potentially hazardous to human health. The air quality sensor used for the system design is MQ-135. The AQ sensor is used to detect contaminants like black soot in the air and gas detection in the workplace.

Heartbeat sensor: This electrical gadget is used to gauge an individual's heart rate. It is measured in beats per minute (bpm).

DHT11 sensor: DHT11 sensor stands for digital humidity and temperature sensor. It measures the air quality in the space or surroundings using a thermistor and a capacitive humidity sensor before sending back a digital signal.

Liquid Crystal Display (LCD): LCD is used to display AQI level, heart rate level, temperature, and humidity level once the push button has been clicked. The diameter of the LCD Module used for the system design is 20x4cm.

MODEL AND ITS WORKING PRINCIPLE

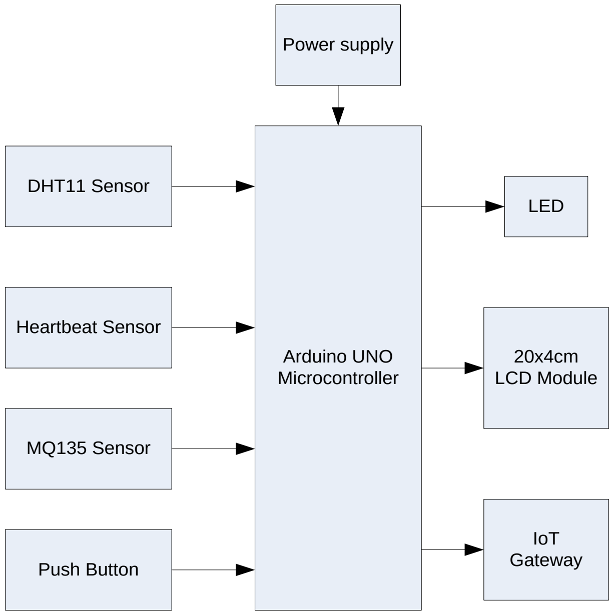

Figure 2. Design model of AQH-BMS

Figure 2, shows the model of air quality and heart rate monitoring system (AQH-BMS) using IoTs. In the air monitoring phase, the MQ-135 sensor collects air data, the concentration of dust, and black soot in the air. The sensors were calibrated and processed to ensure that the analogue outputs were obtained. Once the air gets denser, this indicates that there are pollutants in the air through the help of the MQ-135 sensor detector. Therefore, the LCD module displays the obtained air data concerning the heart pulse in beats per minute (bpm), the temperature and humidity of the environment. The circuit design of the AQH-BMS using IoT is shown in Figure 3. The heart rate monitoring phase involves individuals placing their finger on the heartbeat sensor, and a digital output of the heartbeat is produced. The digital output is connected directly to the microcontroller. Each heartbeat causes the beat LED to flash in unison.

The pulse or heartbeat sensor operates on the fact that each pulse causes a change in the amount of light that is modulated. The sensor is made up of a light detector with a very bright red LED.

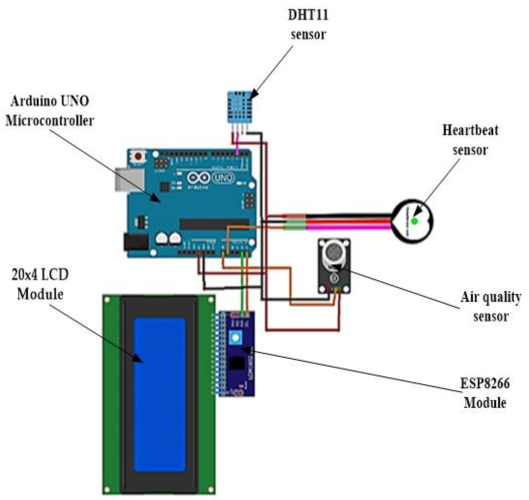

Figure 3. Circuit diagram of the AQH-BMS using IoTs

A large amount of light has to go through the finger and be recognized by the detector. As the finger indicator is opaque, a lesser light reaches the sensors. The heart pumps blood through the blood arteries and the detector signal changes in response to each heartbeat. An electrical pulse is created from this variance. The software tools used for the design and programming are Proteus and Arduino. The flowchart of AQH-BMS using IoT is shown in Figure 4.

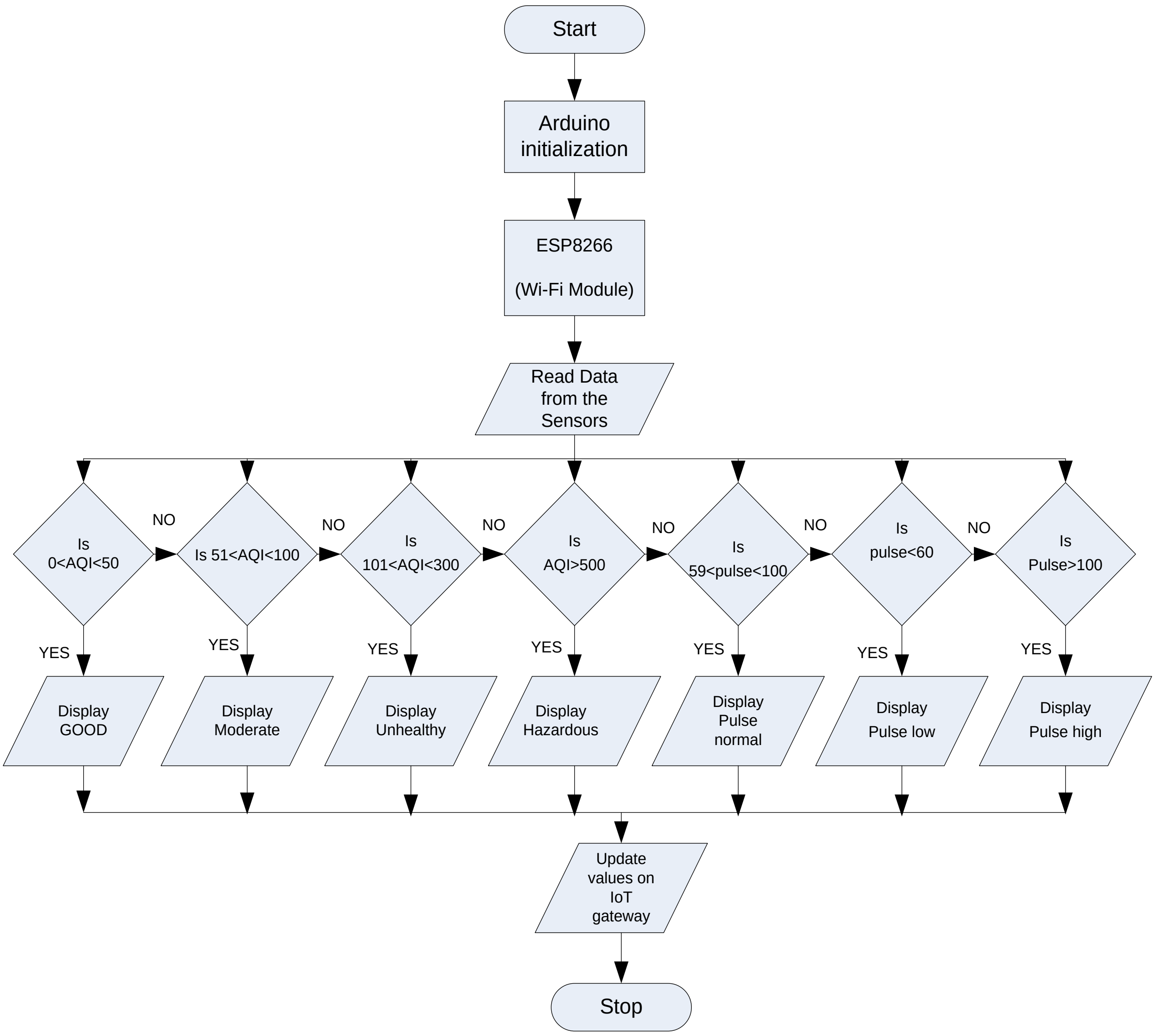

Figure 4. Flowchart of the AQH-BMS using IoTs

RESULTS AND DISCUSSIONS

This section evaluates the performance analysis of the AQH-BMS using IoT. The analysis involves the effect of time of day on air quality index (AQI), heart rate (HR) in action, and resting heart rate (RHR). The system design and tests were carried out at Lead City University, Ibadan, Oyo State, Nigeria. Different five locations on the school's campus environments such as Male Silver 2 Hostel, Male Silver 3 Hostel, Glasshouse, Food Court, and Sports Complex were used for the test execution. Two healthy young male students were sensitized. The participants were healthy with no respiratory or cardiovascular conditions to consider. Two sets of tests were carried out to measure AQI and pulse. Table 3 shows the tests that were carried out based on the effect of the time of day taken hourly from 8:00 am to 8:00 pm. A set of tests were performed to investigate the effect of temperature on AQI.

Table 3: Effect of Time of Day on AQI, HR, and RHR

Location	Average AQI levels	AQI Level of Concern	RHR (bpm)	HR in action (bpm)	Temperature (^{0}C)
Male Silver 2 Hostel	83	Moderate	73	123	35
Male Silver 3 Hostel	89	Moderate	73	125	35
Glasshouse	95	Moderate	62	120	35
Food Court	140	Unhealthy for Sensitive Groups	87	172	35
Sports Complex	133	Unhealthy for Sensitive Groups	89	183	35

Figure 5 illustrates the effect of temperature on AQI. The result deduced that during the early hours of the day and late hours of the day, the AQI levels increase, during the midday between 12:00 pm and 4:00 pm when the workload is much the AQI levels are balanced because by then the individual is already settled in for the day. Figure 6 illustrates the effect of temperature on HR and RHR. When the student is resting (RHR), the heart rate levels decrease provided that the environment is free from pollution from 8:00 am to 8:00 pm. When the students perform an activity, their heart rate levels increase provided that the environment is engaged with pollution at a particular time. The sensitivity results indicate that a higher concentration of pollution leads to an increase in heart rate and a lower concentration of pollution leads to a decrease in heart rate. The final viable prototype device of air quality and heart rate monitoring system (AQH-BMS) using the Internet of Things (IoTs) is shown in Figures 7 and 8, respectively.

CONCLUSIONS

An air quality and heart rate monitoring system has been designed and developed for the measurement, monitoring, and predictive analysis of air pollution in different areas such as industrial areas, urban areas, and densely populated areas.

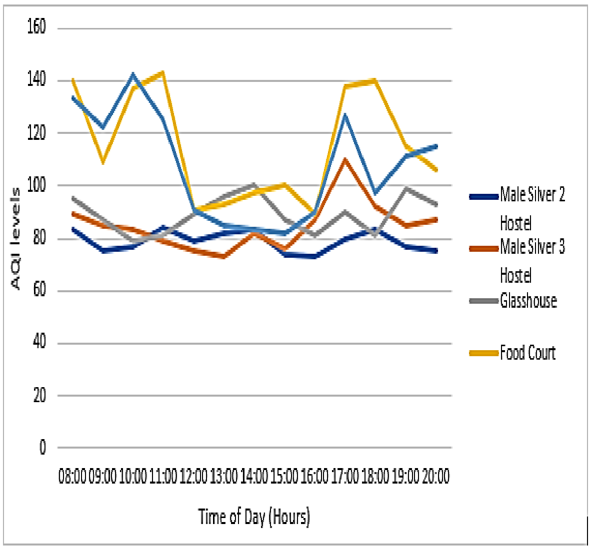

Figure 5. Effect of temperature on AQI

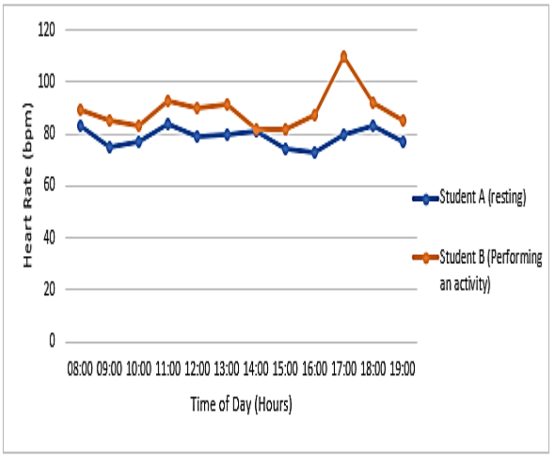

Figure 6. Effect of temperature on HR and RHR

Figure 7. Prototype device of AQH-BM before the finger is placed

Figure 8. Prototype device of AQH-BM after the finger is placed

The data obtained serves as a yardstick to measure and validate the environmental conditions and the impact it has on human health, specifically the heart rate. The device is made portable for ease of usage in checking pollution levels and heart rate levels in real-time. Consequentially, the developed system would be a useful tool for academics, policymakers, and environmentalists to make homes healthier and cleaner and to make informed decisions about the health risks associated with air pollution. In the future, researchers can improve more on the size reduction and increase the component's functionality.

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