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A Study On The Development Of A Heart Rate Monitoring System To Determine Its Accuracy And Effectiveness

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ABSTRACT

Heart rate monitoring systems are valuable tools in both medical and fitness settings since they provide crucial data for health assessment and activity optimization. The study's goal was to build and execute a heart rate monitoring system that used modern sensors and signal processing techniques, as well as to test the system's accuracy against a known heart rate measurement instrument. The development process involves System Design, which incorporates optical and electrical sensors to gather heart rate data, as well as a microprocessor for signal processing and transmission. The next step is prototype development, which focuses on portability and user comfort. Testing and validation entail using human participants to compare system results to those from clinically approved heart rate monitors. Various activities, such as relaxing, walking, and severe activity, are used to evaluate performance in various settings. The designed heart rate monitoring system has good accuracy, with an average deviation of less than 5% compared to reference devices. Accuracy was constant throughout activities, with little differences noted during high-intensity exercise. The device tracked heart rate variations in real-time, providing accurate data for both short- and long-term monitoring. The study emphasizes the relevance of sensor quality and signal processing in creating accurate heart rate monitoring devices. While the system performed admirably in most situations, further refinements could increase accuracy during high physical activity. The use of machine learning techniques for adaptive filtering and noise reduction holds promise for future iterations.

1.0 Introduction

Recently, there have been several incidents of sudden mortality caused by sudden heart failure (HF), particularly among young people in Malaysia. About 64 million people worldwide have HF, with 50% having severe HF. Malaysia had one of the highest HF prevalence rates in Southeast Asia, with 721 cases per 100,000 persons in 2017 (Siew, 2023).

As stated by the World Health Organization (WHO), cardiac diseases are the foremost cause of death globally with 17.9 million deaths annually [6]. According to the World Health Report 2023, there are several risk factors for cardiovascular diseases, including behavioral factors, such as insufficient physical activity, high sodium intake, high alcohol consumption, and tobacco smoking. Furthermore, metabolic factors, such as high blood pressure, high fasting plasma glucose, high body-mass index, high levels of low-density lipoprotein (LDL) cholesterol, and diabetes. Besides that, environmental factors, such as ambient air pollution are also a risk factor for the disease (Mariachiara, 2023).

Malaysia's life expectancy is around the age of 75. Premature death is defined as lives that are lost between 30 and 69. Heart disease is the main culprit of premature deaths in Malaysia, where a total of 95,266 deaths making 18.4% medically certified as premature deaths were recorded in 2022, according to the Department of Statistics Malaysia (The Star, 2023).

An important development that has altered our understanding of and approach to managing heart health and fitness, in general, is heart rate monitoring. An apparatus or gadget that measures and tracks a person's heart rate constantly or at predetermined intervals is called a heart rate monitoring system. Heart rate is an important metric in the operation of the heart (Sahana & Mohammed Rafi, 2020). Thus, heart rate is one of the key vital signs that should be considered when evaluating an individual's health because it tells you about the overall health and function of the cardiovascular system as well as the heart.

Everyone acknowledges the sophistication of the modern world, which is highly beneficial in many ways, particularly for health. As technology advances, this system becomes more accessible and used by all levels of society, offering major benefits to individual and community health. Monitoring health metrics using the Internet of Things (IoT) is a trend for future well-being (Abdul Hannan, Sehrish & Ivan, 2024, Md Hussin et al.,2023). The availability and advancement of wearable IoT devices help people monitor and control their health parameters (Jahangir, et al., 2019). To stop the disease from getting worse and reduce the chance that a person would die from cardiovascular problems, it is crucial to evaluate the severity of cardiovascular disease in individuals (Icmi, Ardian, et al., 2024).

Nowadays, the Internet of Things (IoT) has changed the way communication occurs alongside data collection sources aided by smart sensors. Incorporating IoT and artificial intelligence-based solutions has emerged as potential solutions in medical care. The utilization of IoT technology has enabled medical professionals to access patients' records without requiring them to physically visit medical clinics (Muhammad Umer, 2023).

In this study, an intelligent IoT-based framework is used to monitor heart rate and blood oxygen saturation based on real-time data. Thus, the goal of this project's development was to create a low-cost IoT heart rate and blood oxygen monitoring device, while also figuring out the ideal location for obtaining a precise and accurate output rate.

2.0 Literature review

There has been a lot of study on IoT heart rate and blood oxygen monitoring devices recently. This is due to the understanding of health monitoring wherever the person goes. This proactive approach allows for timely interventions and promotes overall better health outcomes. One of the systems is where two smartphone sensors were used for data recording which is at the rear camera and the microphone to create a photoplethysmogram(PPG) from the camera data. The main advantage lies in their portability and the ability to use them anywhere, making them handy for quick assessments or regular monitoring in non-medical settings. However, for precise medical diagnoses or treatments, certified medical devices should still be relied upon (A. Nemcovaa, 2020).

Next, the fiber-optic catheter oximeters use hard glass fiber waveguides to deliver light from an external source to the blood at the catheter's tip. These devices also transmit some of the backscattered light back to an external unit for detection. The system typically includes a catheter probe connected to a light source and sensing module, which interfaces with processing and driving circuits, a display monitor, and controlling software. The system effectively monitors venous oxygenation by inserting the catheter probe through a vein to the desired location. It provides real-time data on oxygen levels in the blood, which is crucial for medical monitoring and treatment (Lu et.al, 2021).

Another research on IoT systems integrates hardware using Raspberry Pi 4B, python software, cloud storage, and mobile application components (compatible with Android and iOS) to create a comprehensive solution for remote health monitoring. It aims to improve patient care by providing continuous monitoring, timely alerts, and accessible health data to medical professionals, thereby enhancing patient outcomes and healthcare delivery efficiency (Mohammed, 2022).

There is one more IoT-based system for remote monitoring and early detection of health issues in home clinical settings where the system utilizes three types of sensors, including the MAX30100, AD8232 ECG sensor module, and MLX90614 Non-contact Infrared Body Temperature Sensor, to collect physiological data from the human body. The collected data is then transmitted to a server using the MQTT protocol for analysis (Suprayitno et al., 2019).

Some other devices are novel wearable and contactless devices that measure heart rate, respiratory rate, and oxygen saturation in the clinical setting. The wearable devices demonstrated less measurement bias and more precision at extreme vital signs (Chan et al, 2022). Clinical diagnoses, exercise applications, and health tracking all depend on heart rate monitoring. The technology employed, the location of the sensors, and the surrounding conditions all affect how precise and accurate these data are. There are a few technologies Used in Heart Rate Monitoring which are Electrocardiography (ECG) and Photoplethysmography (FPG). Because of its great accuracy, ECG is regarded as the gold standard for heart rate monitoring. ECG provides extremely accurate heart rate readings by measuring the electrical activity of the heart. It is frequently used to diagnose and track heart problems in medical settings (He et al. 2019).

However, they have limitations in that continuous monitoring in non-clinical settings may become challenging due to the requirement for electrodes to be placed on the chest (Bashar et al., 2019). PPG sensors, which measure blood volume changes in the microvascular bed of tissue, are extensively employed in wearable devices. PPG is widely used in consumer products such as smartwatches and fitness trackers because of its ease of integration and non-intrusive nature (Tamura et al., 2014). However, accuracy can be influenced by motion artifacts and changing ambient conditions, which are especially problematic during physical exercise (Zhang et al., 2019).

Another paper introduces a smart healthcare system within an IoT framework designed to monitor both a patient's vital signs and the real-time conditions of their environment. The system employs five sensors: a heartbeat sensor based on plethysmography theory to detect changes in blood volume, an LM35 series temperature sensor providing linear centigrade temperature outputs, a DHT11 sensor for measuring temperature and humidity using an embedded 8-bit microcontroller, an MQ-9 sensor for detecting LPG, CO, and CH4 gasses with high sensitivity, rapid response and MQ-135 gas sensors used for detecting NH3, Nicotine, Benzene, Smoke and CO2, featuring a digital pin for autonomous operation without a microcontroller, beneficial for targeted gas detection in air quality control systems (Islam et al.,2020).

Finally, this paper is purposely to develop and deploy a smart system for tracking patient health. Sensors are integrated into the patient's body to monitor temperature and heartbeat. Additionally, two sensors are positioned within the patient's home to monitor room humidity and temperature. These sensors are linked to a control unit, which computes the data from all four sensors. The calculated data is then transmitted via an IoT cloud to a base station. From there, doctors can access the data from any location. By analyzing the temperature, heartbeat, and room sensor data, doctors can assess the patient's condition and initiate appropriate actions. (Valsalan et al 2020).

Recent advancements in IoT technology have spurred significant innovation in healthcare monitoring, particularly in the areas of heart rate and oxygen monitoring. These developments aim to provide continuous, remote monitoring capabilities that enhance early detection of health issues and improve patient outcomes. These technologies offer promising benefits, **but** challenges such as accuracy under varying conditions and integration complexities remain pertinent. Nonetheless, the evolution of IoT in healthcare holds great potential to transform traditional healthcare delivery into more efficient, accessible, and proactive models through continuous monitoring and timely interventions.

3.0 Methodology

The project was separated into three (3) phases: Phase 1 is the circuit production phase, Phase 2 involves locating the best spot to get the reading's accuracy and precision and Phase 3 involves gathering data. This project began with the creation of a flow chart for item construction to facilitate programming. At the same time, the hunt for affordable but highly effective modules was highlighted.

3.1 Production Phase

The production phase encompasses various stages such as design, components sourcing, circuit assembly, and testing. The weight of the product is also stressed to guarantee that this project creates a product that utilizes the least amount of money. The hardware, which consists of a 1000mAh battery, an ESP8266 WiFi Controller, and an MAX30100 pulse oximeter sensor, is shown in the accompanying diagram.

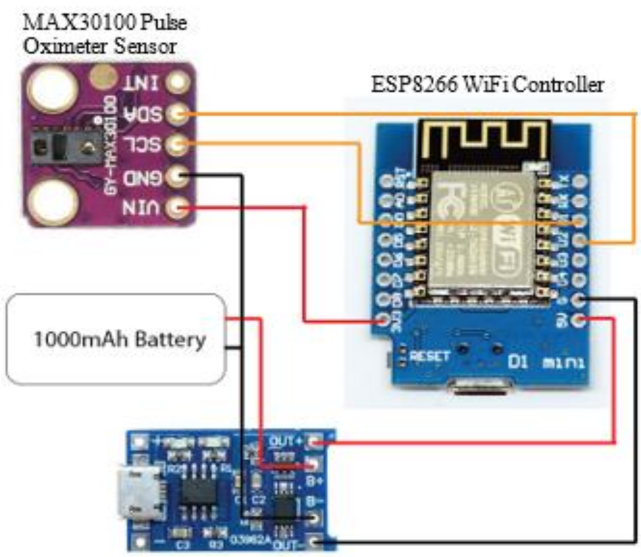

Figure 1: Product circuit assembly

The Max30100 heart rate and oxygen sensor measures heart rate (bpm) and blood oxygen level (% O_2) using only the tip of a finger. An oximeter is a device that monitors the level of oxygen in the blood without the need for a blood test. This gadget employs infrared light waves that are transmitted through tissue and reflected from bones and other biological tissues, red LED characteristics, and a light sensor as a light wave receiver.

When the pulse oximeter sensor picks up a pulse or heartbeat, the circuit begins to function. The microcontroller is turned on by this pulse. Because the ESP8266 has an embedded WiFi module, it can transmit signals to the data storage when it receives input signals. This is the advantage of using ESP8266 over other modules. The microcontroller will process this signal before forwarding it to the data collection facility. The controller does have an incorporated WiFi module that aids in the reliable transmission of signals.

3.2 Position Determination Phase

A pulse is the heart rate. It is the number of times the heart beats in one minute. A healthy pulse is between 60 and 100 beats per minute (bpm). An extremely slow pulse combined with dizziness can indicate shock and identify internal bleeding. On the other hand, if the pulse is too quick, it points to high blood pressure and cardiovascular problems (Medical News Today, 2024).

The heart rate can be measured via an apical pulse, which points at the bottom tip (apex) of our heart, located at the ventricle, which points downward on the left side of our chest. It pushes blood out of our heart through the aorta to the rest of each time it contracts. It is also called the point of maximal impulse (PMI). Apical pulse gives the most accurate reading of heart rates (Cleveland Clinic, 2024).

Besides that, the pulse can be measured using the radial artery in the wrist or the carotid artery in the neck (Sandhya Pruthi, 2024). The arteries run close to the skin in this area. The oximeters in this study were placed in 2 positions, which are the left chest and wrist to determine the most accurate heartbeat and blood oxygen saturation reading.

3.3 Gathering Data Phase

Data on heart rates and blood oxygen saturation was collected from 16 various age samples. The data was recorded and analyzed to determine the body position which gives the most accurate readings. Furthermore, the data of MAX30100 Pulse Oximeter Sensor and another 3 similar products from different brands were calculated and compared to determine the percentage difference between the proposed product and the average of another 3 similar stated products.

4.0 Discussion of analysis and findings

4.1 Position Determination

Heart rate monitoring is essential for medical diagnosis, fitness tracking, and other health applications. The precision and accuracy of heart rate measurements are considerably affected by the sensor's positioning. As illustrated in the diagram below, two body positions have been identified for the placement of this heart rate monitor. Position 1 is on the left chest, monitoring the Apical pulse. The chest is usually recognized as the gold standard for heart rate monitoring due to its proximity to the heart and direct recording of electrical activity. Electrocardiogram (ECG) sensors on the chest offer extremely accurate heart rate data. Studies have shown that chest-mounted sensors are less prone to motion artifacts than peripheral sites (Allen, 2007). Chest Electrocardiograms (ECGs) are routinely used in clinical settings to diagnose cardiac problems and track heart rate continuously (Bashar et al., 2019).

Position 2 is at the wrist, where the radial artery pulse is found. Tamura et al., 2014 mentioned that wrist-based Photoplethysmography (PPG) sensors are extremely useful, their accuracy can be impaired by variables such as movement and unpleasant fit. Zhang et al. (2019) found that wrist-based monitors, while typically trustworthy, can reveal considerable variations in readings during high-intensity exercises compared to chest ECG monitors.

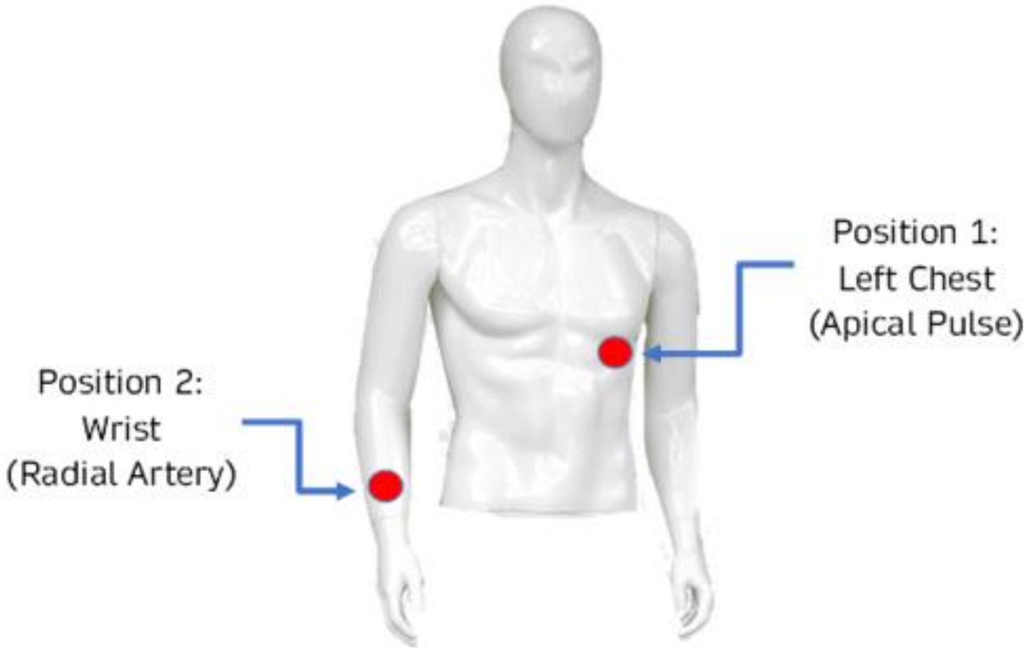

Figure 2: MAX30100 pulse oximeter sensor positions

Figure 3: Oxytech pulse oximeter

In terms of determining the accuracy of the proposed body position, the Oxytech pulse oximeter (OPO) was chosen as the reference oximeter due to its high accuracy measurement compared to the previous system that used the same MAX30100 pulse oximeter. Referring to Table 1, the heart rate (bpm) and blood Oxygen Saturation (Sp02) differ by +-0.84% and +-0.91% respectively. The accuracy percentages are highly encouraging to prove that the heart rate and blood oxygen saturation monitoring for the proposed system is acceptable (Nurul Izzati et al, 2023).

Table 1: Average accuracy of heart rate and blood oxygen saturation (Nurul Izzati et.al, 2023)

Measured Parameters	Average Accuracy (%)
Heart Rate (HR)	99.16
Blood Oxygen saturation (SpO_2)	99.06

Table 2 shows the results of the difference in measurement accuracy between these two variables compared to Oxytech pulse oximeter (OPO).

Table 2: Product evaluation over two positions by using MAX30100 Pulse Oximeter Sensor

Sample (Age)	**Oxytech Pulse Oximeter (Reference)**		**1**		**2**	
	Heart rate (bpm)	**Blood Oxygen Saturation (SpO_2) %**	**Heart rate (bpm)**	**Blood Oxygen Saturation (SpO_2) %**	**Heart rate (bpm)**	**Blood Oxygen Saturation (SpO_2) %**
19	86	95	86	95	85	96
20	90	98	90	98	89	98
21	87	99	87	99	85	99
22	88	98	88	98	87	98
30	93	98	92	97	90	96
31	90	96	89	95	89	95
32	96	99	96	98	95	97
33	81	98	80	98	78	97
40	90	96	90	96	88	96
41	95	96	95	96	94	97
42	90	89	90	89	89	89
43	110	92	110	92	109	90
50	102	88	102	88	100	88
51	97	89	97	89	97	87
52	111	91	111	91	110	91
53	115	86	115	86	115	86

4.2 Comparison Between Proposed And Three (3) Similar Products From Different Brands For Monitoring Heart Rate (bpm)

Table 3: Comparison Between Proposed and Three (3) Similar Products From Different Brands For Monitoring Heart Rate (bpm)

Sample (Age)	Heart Rate Monitor (Proposed)	Heart Rate Monitor (Brand A)	Heart Rate Monitor (Brand B)	Heart Rate Monitor (Brand C)
19	86	85	86	86
20	90	89	90	90
21	87	86	87	88
22	88	87	88	88
30	92	91	93	92
31	89	88	90	89
32	96	96	96	97
33	80	80	81	79
40	90	91	90	89
41	95	96	95	95
42	90	91	90	90
43	110	111	110	110
50	102	103	102	102
51	97	98	97	96
52	111	112	111	110
53	115	116	115	114

Table 3 compares heart rate readings between the proposed items with three (3) similar products from different brands that have been on the market. This comparison is meant to assess the accuracy of items that are equivalent to market products. The same specimens were utilized to determine the precision of product positioning.

Figure 4 depicts the degree of variance between market items and those in development. The difference rate is found to be between 0 to 0.187%, which is equivalent to 99.83% accuracy. This demonstrates that the rate of difference is very small and that the product's capability is equivalent to the present product.

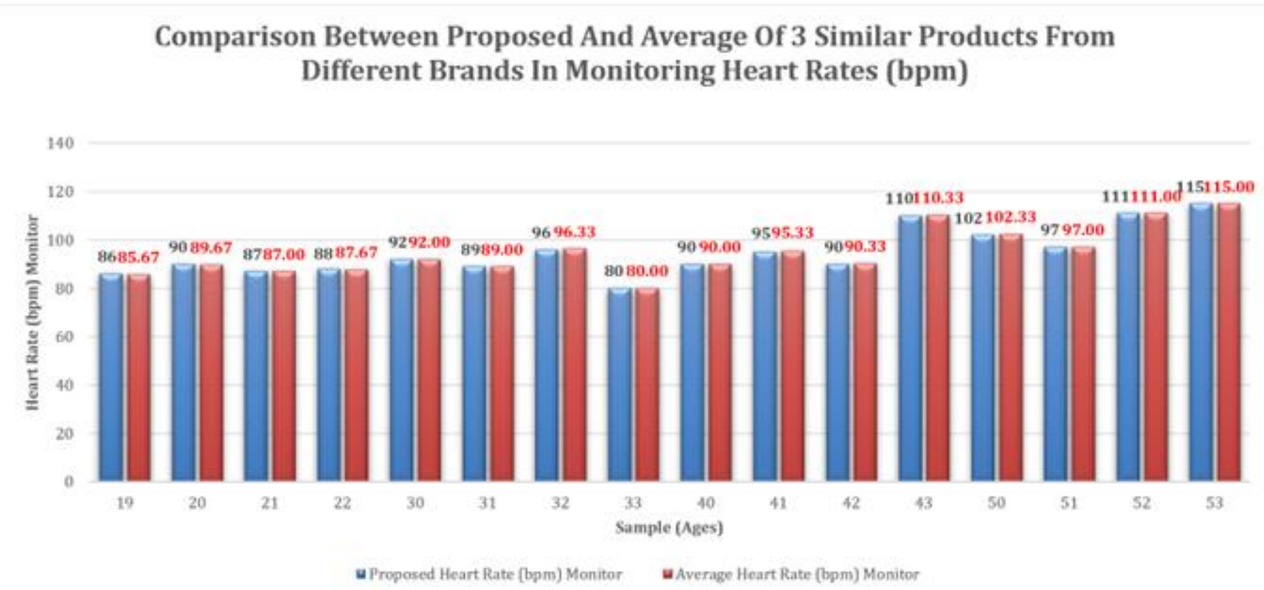

Figure 4: Comparison Between Proposed And Average Of 3 Similar Products From Different Brands In Monitoring Heart Rates (bpm).

To enhance the product's accuracy, the blood oxygen saturation level tests were performed on the same product and utilizing the same sample, as shown in Table 4.

Table 4: Comparison Between Proposed And Average Of 3 Similar Products From Different Brands In Monitoring Blood Oxygen Saturation (SpO2)%

Sample (Age)	Blood Oxygen Saturation (SpO_2)%			
	Proposed	Brand A	Brand B	Brand C
19	95	94	95	95
20	98	97	98	98
21	99	98	99	100
22	98	97	98	98
30	97	96	98	96
31	95	94	96	94
32	98	97	99	99
33	98	98	98	97
40	96	97	96	95
41	96	97	96	95
42	89	90	89	89
43	92	93	92	92
50	88	89	88	88
51	89	90	89	89
52	91	91	91	90
53	86	86	86	85

The same sample is used to determine blood oxygen saturation levels. In general, there is minimal difference between all of the items. To bolster the findings, the difference between the average number of items that have been on the market and products that have been developed. As illustrated in Figure 5, this investigation discovered that the proposed approach has an average accuracy of 99.81%.

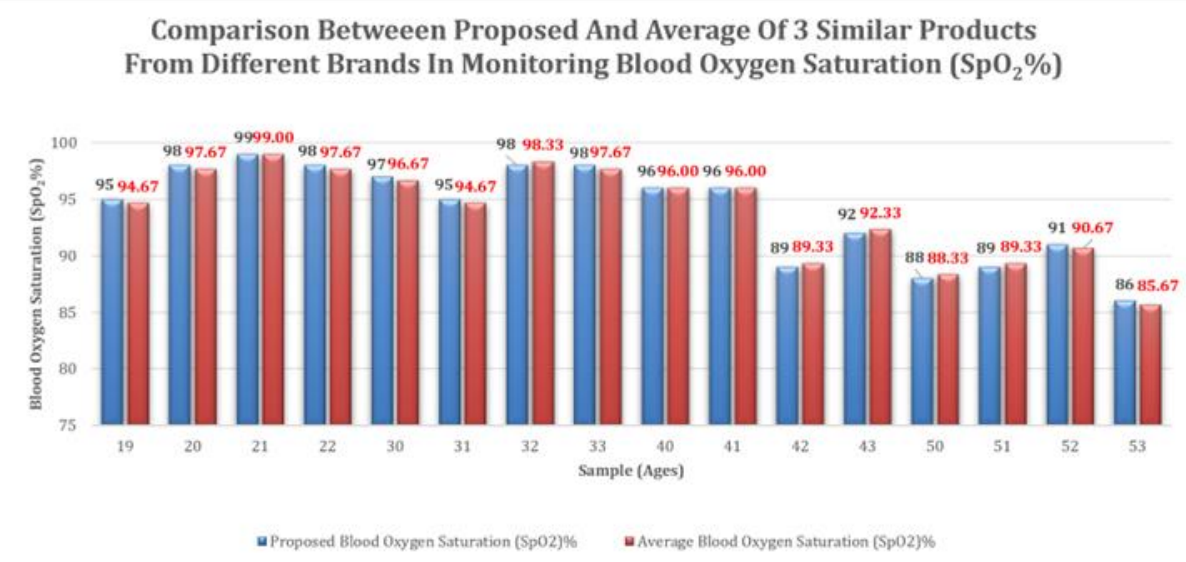

Figure 5: Comparison Between Proposed And Average Of 3 Similar Products From Different Brands In Monitoring Blood Oxygen Saturation (SpO2%)

5.0 Conclusion and Future Research

This study was focused on 3 main points. Firstly, a comparison of the body position which gives the most accurate oximeter reading. Secondly, a comparison between the proposed and average of 3 similar products from different brands in monitoring heart rates (bpm), and lastly, a comparison between the proposed and average of 3 similar products from different brands in monitoring blood oxygen saturation (SpO_2%).

Referring to the first point's result, both positions have a high ability to measure heart rate and blood oxygen saturation accurately. But, Position 1 which is on the left chest produced the most accurate oximeter reading due to position 1 being closer to the heart than position 2 on the wrist. The result satisfied the statement that the Apical pulse on the left chest gives the most accurate reading of heart rates (Cleveland Clinic, 2024).

For the second point, the result shows that the proposed product, the MAX30100 Pulse Oximeter Sensor's ability to monitor the heart beats is trusted since the average reading difference with another three similar products from different brands was just 0 to 0.39%, which is very small. Furthermore, for the third point, the result shows that the proposed also has a very high ability to monitor blood oxygen saturation since the proposed and the similar product's average reading was only up to 0.39%. Lastly, this study proved that the MAX30100 Pulse Oximeter Sensor works successfully with the ESP8266 WiFi Controller in transmitting and storing data.

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Author Contributions

Yusmahaida Y.: Conceptualization, Methodology, Software, Writing- Original Draft Preparation; **Mardiah M.**: Data Curation, Validation, Supervision; **Yuzi S.**: Software, Validation, Writing-Reviewing and Editing; **Muhammad Hashim D.:** Funding Acquisition, Writing-Reviewing and Editing.

Conflicts of Interest

The manuscript has not been published elsewhere and is not being considered by other journals. All authors have approved the review, agree with its Submission, and declare no conflict of interest in the manuscript.

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