Real-time monitoring tool for heart rate and oxygen saturation in young adults

Siti Fatimah Abdul Razak, Yap Jia Wee, Sumendra Yogarayan, Sharifah Noor Masidayu Sayed Ismail, Mohd Fikri Azli Abdullah
Faculty of Information Science and Technology, Multimedia University, Melaka, Malaysia

Article Info

ABSTRACT

Health monitoring is crucial to maintain optimal well-being, especially for young adults. Wearable sensors have become popular for collecting healthcare data, but there are concerns regarding their reliability and safety, particularly with wireless sensors that use radio-frequency (RF) based devices. Researchers have proposed real-time monitoring systems for measuring heart rate beats per minute (BPM) and blood oxygen saturation (SpO2) saturation levels, but more studies are needed to determine the accuracy and user acceptance of these tools among young adults. To address these concerns, this study proposes a real-time monitoring tool that incorporates MAX 30100 sensors to collect heart rate BPM and SpO2 data. The collected data is then connected to a visualization platform, i.e., InfluxDB and Grafana, to provide valuable insights of the body's physiological state. By testing the feasibility and usability of the tool, we found motivating differences in resting heart rates and changes in heart rate after activity between male and female participants. By developing this real-time monitoring tool and investigating gender-specific differences in heart rate and activity-induced changes, our study contributes to the advancement of health monitoring technologies for young adults, ultimately promoting personalized healthcare and well-being.

Corresponding Author:

Sumendra Yogarayan
Faculty of Information Science and Technology, Multimedia University
Jalan Ayer Keroh Lama, 75450 Melaka, Malaysia
Email: sumendra@mmu.edu.my

1.   INTRODUCTION

Monitoring heart rate in beats per minute (BPM) and blood oxygen saturation (SpO2) is important for young adults to maintain optimal health and prevent serious health issues [1]-[3]. Regular monitoring of BPM and SpO2 levels can provide valuable insights into the body's physiological state, and may help identify potential health problems before they become more serious. This is especially important in today's world, where young adults may be at increased risk of developing respiratory illnesses, including COVID-19 [4]-[6]. In addition to respiratory illnesses, young adults who engage in certain activities such as endurance sports or weightlifting may also benefit from monitoring their BPM and SpO2 levels during exercise to ensure they are performing at a safe level [7], [8]. By utilizing reliable real-time monitoring systems, young adults can stay informed about their BPM and SpO2 levels and take necessary steps to maintain optimal health and well-being.

Wearable sensors are commonly used to collect healthcare data, which can be transmitted using wired or wireless technology [9]. While wired sensors can be reliable, they can also be cumbersome, expensive, and power-intensive. Wireless sensors that use radio-frequency (RF) based devices, such as Bluetooth, ZigBee, and 6LowPAN, are often preferred due to their convenience and ease of use [10]-[12]. However, long-term exposure to electromagnetic radiation (EMR) from RF devices can potentially have negative effects on human

health and may also impact the performance of medical instruments. Additionally, RF devices are not always secure and can be affected by inter-channel interferences, which can compromise their reliability [13], [14]. As a result, there is a growing need for alternative technologies that can complement or replace RF-based devices, while ensuring the safety and reliability of healthcare data collection.

Several researchers have proposed and implemented real-time monitoring systems to measure BPM and SpO2 levels in various settings. For instance, Ahmed *et al.* [15] utilized an Atmel Atmega 328P microcontroller unit (MCU) and a MAX30100 sensor to detect COVID-19, while Wan *et al.* [16] designed a SpO2 monitoring system with a smartphone app using a MAX30100 sensor and Contex-M3 MCU. Similarly, Abbasi *et al.* [17] implemented a real-time monitoring system for critical individuals using red and infrared light-emitting diode (LEDs) and Arduino IDE. Tamam *et al.* [18] proposed a system capable of measuring BPM, SpO2, and body temperature, utilizing sensors with the Arduino Due, MULTISIM® software, and BASCOM® SIMULATOR program. Soni [19] used Arduino Uno microcontroller, infrared (IR) transmitter, infrared detector, and MCP602 Opamp to enable continuous heart rate monitoring. Das *et al.* [20] proposed an internet of things (IoT) enabled health monitoring system based on a Raspberry Pi and a cloud-based platform, while Bakhri *et al.* [21] designed a low-cost oximetry system using the MAX30100 sensor with Arduino Uno and Raspberry Pi. Susana and Tjahjadi [22] created a portable oxygen saturation monitor based on the Raspberry Pi for use in home care, and Tham *et al.* [23] developed an elderly real-time monitoring system that measures BPM and SpO2 levels using a Node MCU (ESP8266) microcontroller and MAX30100 sensor. These studies have proposed and implemented real-time monitoring systems for measuring BPM and SpO2 levels, but the accuracy and reliability of these systems can vary depending on the technology usage. While real-time monitoring systems can be beneficial for young adults, but they also require individuals to wear sensors or carry devices with them at all times. Thus, in this work, a real-time monitoring tool is designed to investigate the user experience and acceptability of the tool among young adults to identify any barriers or challenges that may prevent widespread adoption. The rest of the paper is organized as follows. Section 2 presents the proposed system design. Section 3 includes the experimental testing and results of the study. Finally, the paper is concluded in section 4.

2. SYSTEM DESIGN

In this work, an indoor scenario is considered, wherein an individual health is continuously monitored. We used the MAX30100 sensor to collect and monitor the individual BPM and SpO2 in real-time. The sensor is connected with a Raspberry Pi, and is composed of an LED light, modulated using the sensing data. Simultaneously, the data is transmitted to InfluxDB platform and Grafana was used to visualize the data. Figure 1 shows the block diagram of the proposed system.
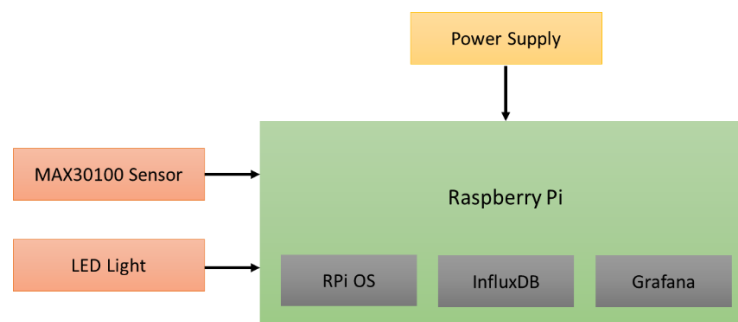

Figure 1. Block diagram

2.1. Breadboard diagram and prototype

The breadboard diagram of the prototype is shown in Figure 2(a). The system uses Raspberry Pi 4 as a small single board computer, MAX30100 as a blood oxygen and heart rate sensor, and LED to alert when the result is abnormal. Besides, the prototype design is shown in Figure 2(b).

2.2. InfluxDB configuration

InfluxDB is a distributed time series database designed for high write and query loads, commonly used for storing and processing performance metrics, sensor data, and events. It is horizontally scalable, has a structured query language (SQL) query language, and can be integrated with various tools and platforms.

InfluxDB is popular in IoT, DevOps, and real-time analytics applications [24]. The installation and setup were made using a MAC OS through secure shell (SSH) to Raspberry Pi. Figure 3 shows the service that has been launched successfully.
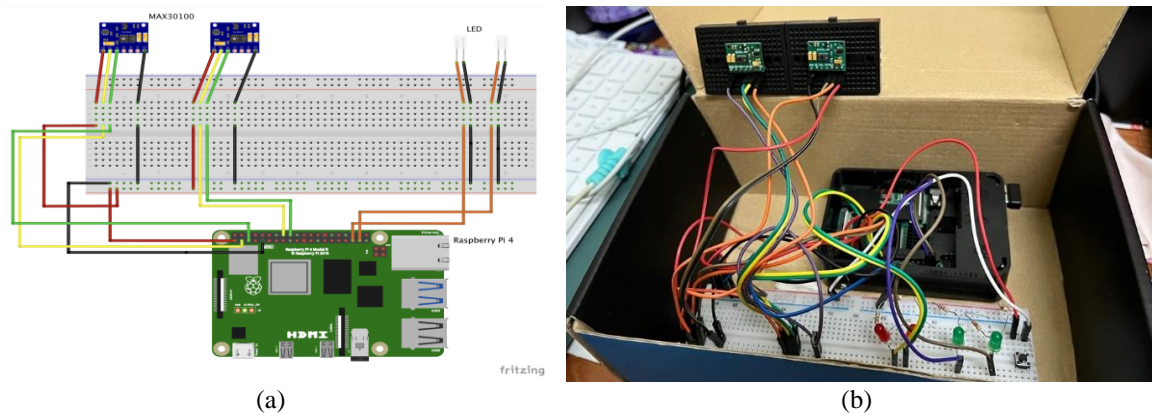

(a)   (b)
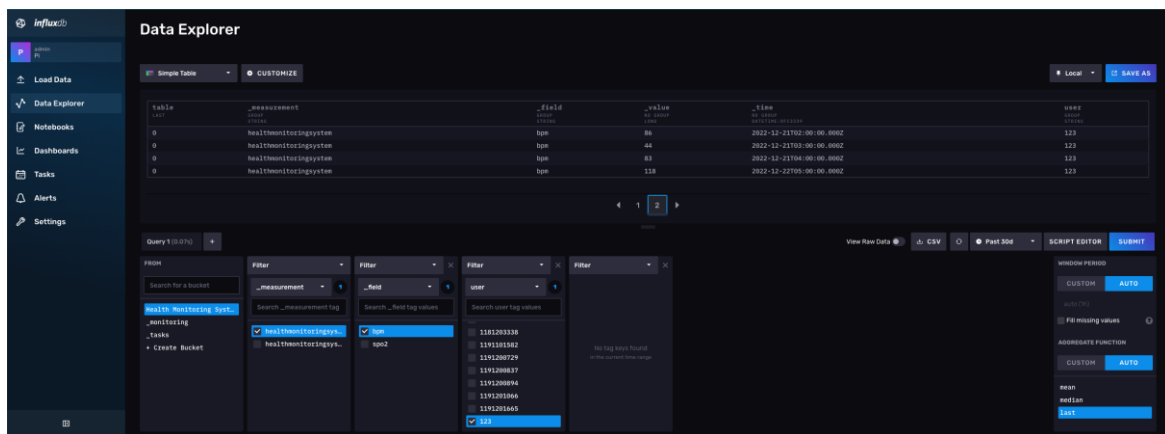
Figure 2. Development of; (a) breadboard diagram and (b) prototype

Figure 3. InfluxDB service

2.3. Grafana configuration

Grafana is an open-source data visualization and monitoring platform that allows users to create and display data dashboards from various sources, such as InfluxDB, Prometheus, and Elasticsearch. It has a flexible web interface and a large plugin ecosystem for data visualization options. Grafana is widely used for visualizing time series data for internet infrastructure and application analytics, and in other domains such as industrial sensors, home automation, weather, and process control [25]. Like InfluxDB, Grafana was accessed on a Mac OS using SSH for this study. Figure 4 shows the service that has been launched successfully.
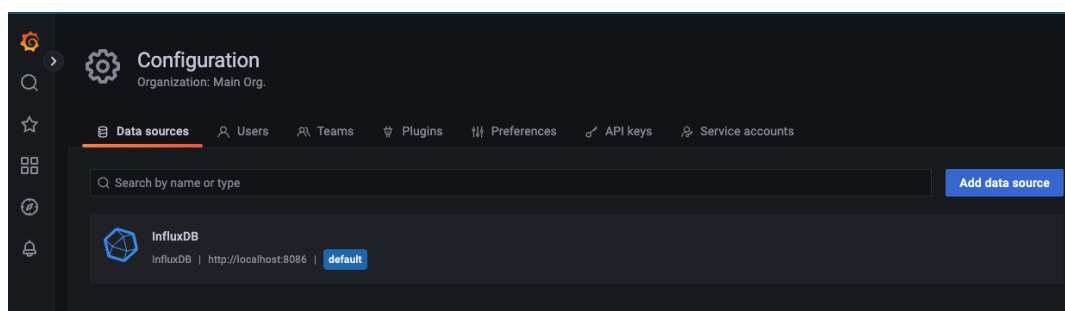

Figure 4. Grafana service

3.   EXPERIMENTAL TESTING AND RESULTS

During the testing phase, a total of 18 participants were engaged to evaluate the performance of the system. The testing was carried out on 21st December 2022 at the Multipurpose Lab, Faculty of Information Science and Technology, Multimedia University. The participants were selected from diverse backgrounds, including individuals of different genders, to ensure a representative sample. The aim of the testing was to determine how well the system performs under practical conditions and to identify any issues or areas for improvement. The participants were instructed to carry out a series of tasks using the system, while their interactions with the system were monitored and recorded. The tasks were designed to assess the system's functionality, and overall performance. The results of the testing are presented in this section, including a detailed analysis of the performance of the system. To begin the study, a survey was administered to the participants to gather initial data. The survey included participants of both genders, with representation of male and female respondents as shown in Figure 5.

According to the results obtained from the survey administered to the participants, it was found that most of them (55.6%) reported engaging in regular physical activity, either by playing badminton or basketball. On the other hand, the remaining 44.4% of the participants reported not engaging in any regular physical activity, as illustrated in Figure 6. These findings suggest that a significant proportion of the participants lead an active lifestyle, while a sizeable minority do not prioritize physical activity in their daily routines.
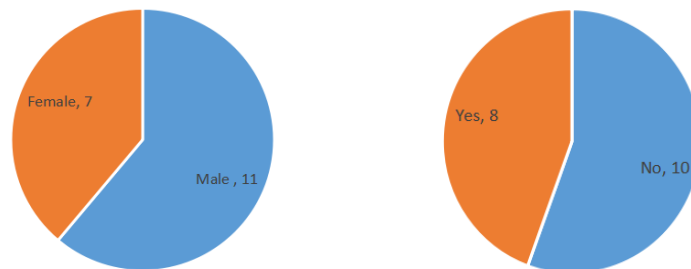

Figure 5. Participants gender data   Figure 6. Participants exercise/sports data

Besides, the survey responses obtained from the participants revealed that most of them (66.7%) engage in physical activity once a week, while a smaller percentage (11.1%) reported exercising or playing sports twice a week. Only a few participants (5.6%) claimed to engage in physical activity three times a week but not on consecutive days. Additionally, a significant number of participants (16.7%) reported not engaging in any form of physical activity at all, as depicted in Figure 7. These findings suggest that while many of the participants do engage in some form of physical activity, they may not be meeting the recommended course of action for regular exercise, which is at least 150 minutes of moderate-intensity aerobic activity or 75 minutes of vigorous-intensity aerobic activity per week, spread out over at least three days per week.
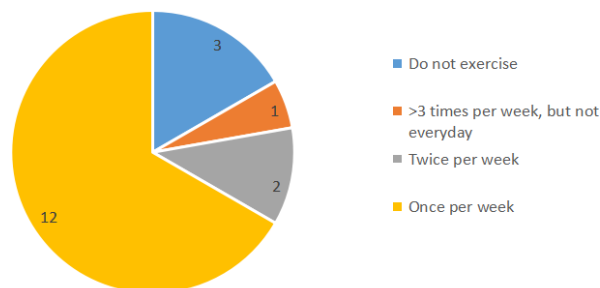

Figure 7. Participants frequency of exercise/sports data

The experiment was conducted using a setup comprising of two monitors and a laptop. The Raspberry Pi 4 was connected to one monitor, while the Nintendo Switch was connected to the other monitor, as depicted in Figure 8. The Nintendo Switch is a hybrid video game console which was utilized in the experiment to provide a range of activities for the participants. The use of multiple monitors also facilitated a more immersive and engaging experience for the participants, contributing to the overall effectiveness of the experiment.
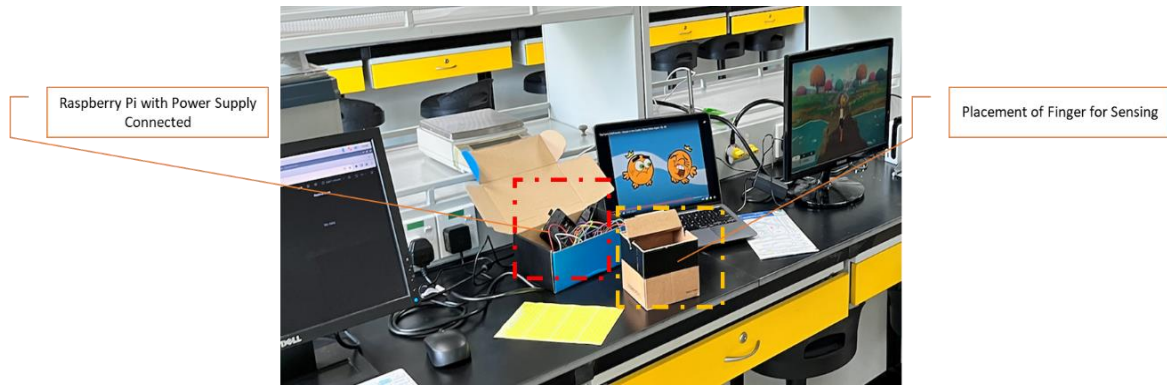
Figure 8. System testing setup

The initial step in the testing procedure involves measuring the participant's resting blood oxygen level and heart rate. This can be achieved by asking the participant to hold the designed prototype in a particular manner for three minutes as shown in Figure 9.

Figure 9. Testing process (part 1)

Following the initial measurements, participants will be required to engage in activities involving using Nintendo Switch, with a duration of approximately three minutes. To perform these activities, participants will play a game called "Ringfit Adventure" that involves jogging based on the game map. These activities are intended to simulate exercise for the participants as shown in Figure 10.

Figure 10. Testing process (part 2)

After completing the activities, participants will be instructed to sit in a straight and relaxed position for three minutes while their blood oxygen level and heart rate are measured once again as shown in Figure 11. It is essential that individuals maintain an upright and motionless posture while measuring their pulse or oxygen blood level. Participants are advised to refrain from any physical movements or talking during this period to ensure precise and reliable readings.

The data from sensors were analyzed based on the participant's gender and lifestyle. These data were retrieved from the InfluxDB and shown in BPM for heart rate and SpO2 for blood oxygen level. The blue line in the graphs represents BPM, while the purple line represents SpO2. The data are represented for heart rate monitoring as x-axis labeled with time scale (seconds) and the y-axis labeled with the heart rate values BPM as shown in Figure 12. Additionally, the Grafana refresh time for our data updates occurred every 3 minutes. The results of the analysis showed that some male participants had a higher resting heart rate, with their heart rate before activity ranging between 100 to 120 bpm, as seen in Figure 12(a). However, their heart rate increased after doing some activities, as shown in Figure 12(b). After resting for three minutes, the participant's heart rate started to drop, indicating that the participant had rest from the previous activity. On the other hand, a few female participants had a lower resting heart rate compared to male participants, with their average resting heart rate ranging between 65 to 90 bpm. An example of a female participant's heart rate before activity is shown in Figure 12(c), while their heart rate after activity is shown in Figure 12(d). Table 1 compares the results from male and female participants. The average heart rate before and after the activities did not differ much among male participants, with an average heart rate of 110 bpm. The average blood oxygen level remained constant among male and female participants, as there were no uncertainties observed. However, the average heart rate slightly increased for female participants after the activities, with an average resting heart rate of 77.5 BPM before activities and 82.5 BPM after activities.
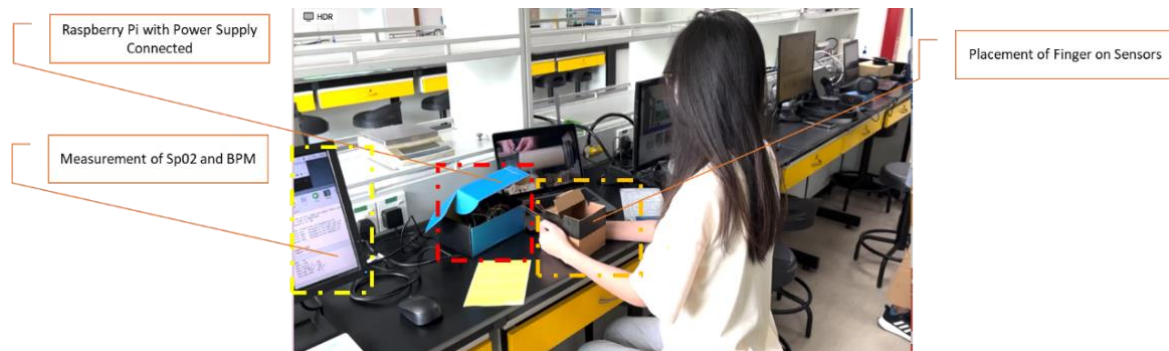

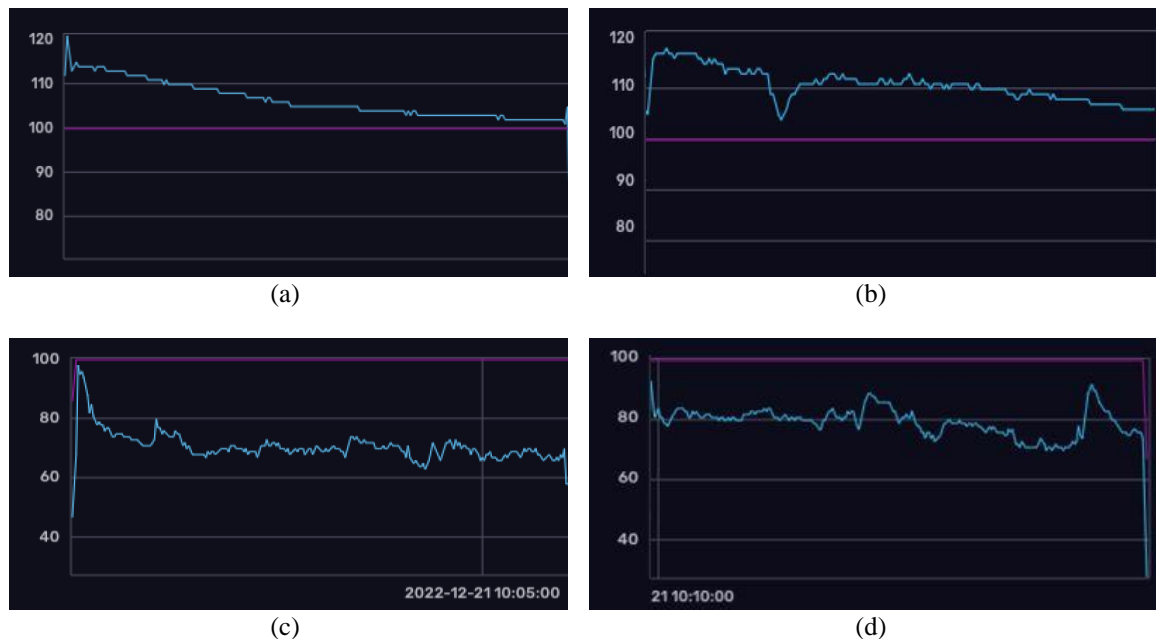Figure 11. Testing process (part 3)

(a)

(b)

(c)

(d)

Figure 12. Male and female heart rate of before and after activities: (a) male resting heart rate BPM before activities, (b) male heart rate BPM after activities, (c) female resting heart rate BPM before activities, and (d) female heart rate BPM after activities

Subsequently, participants were categorized as either sporty or non-sporty based on their regular exercise or sports activity habits. The results of the study indicated that some sporty participants displayed a more stable heart rate BPM during physical activity as shown in Figure 13. Specifically, Figure 13(a) shows that sporty individuals exhibited a heart rate between 90 and 93 BPM before engaging in physical activity, and Figure 13(b) illustrates that their heart rate did not significantly increase after activity. In contrast, non-sporty participants displayed lower baseline heart rates (between 80 and 100 BPM) compared to sporty participants before physical activity as shown in Figure 13(c). After engaging in activity, non-sporty participants demonstrated a significantly higher heart rate, as depicted in Figure 13(d). On average, sporty individuals had a heart rate of 91.5 BPM, while non-sporty individuals had an average heart rate of 110 BPM, as reported in Table 2. Notably, the average heart rate of sporty participants before and after activity was nearly identical, whereas non-sporty participants exhibited a substantial increase in heart rate following an activity. Both sporty and non-sporty participants had an average blood oxygen level of 100%, as they did not have any known health conditions.

Table 1. Male and female heart rate of before and after activities

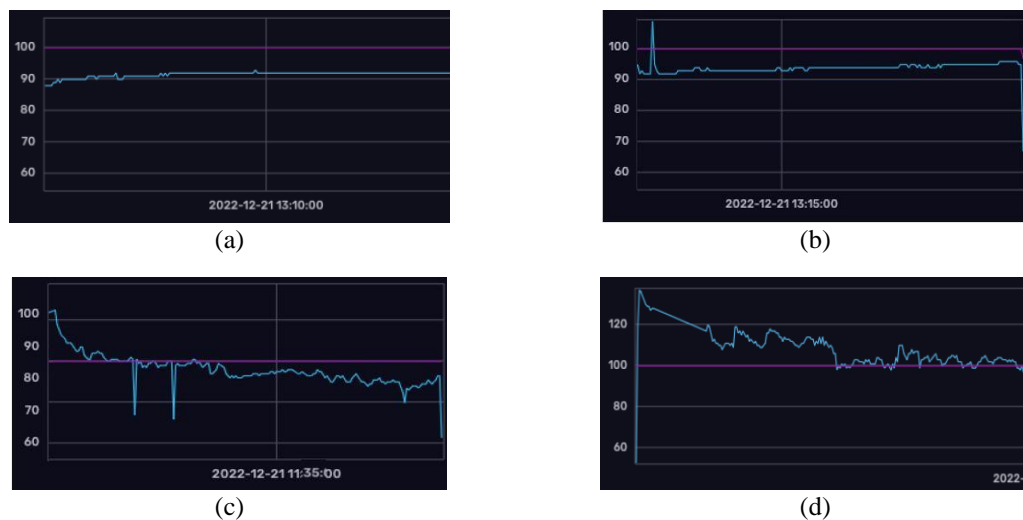| Gender	Average heart rate BPM		Average SpO2 level	
	Before	After	Before	After
Male	110	110	100	100
Female	77.5	82.5	100	100

Figure 13. Sporty and non-sporty heart rate before and after activities: (a) sporty person heart rate BPM before activities, (b) sporty person heart rate BPM after activities, (c) non-sporty heart rate BPM before activities, and (d) non-sporty heart rate BPM after activities

Table 2. Sporty and non-sporty heart rate before and after activities

Group	Average heart rate BPM		Average SpO2 level	
	Before exercise	After exercise	Before exercise	After exercise
Sporty	91.5	94	100	100
Non-sporty	90	110	100	100

4.   CONCLUSION

In conclusion, our study proposes a real-time monitoring tool that incorporates MAX 30100 sensor to collect BPM and SpO2 data and connects to a visualization platform such as InfluxDB and Grafana. Our findings show interesting differences in resting heart rates and changes in heart rate after activity between male and female participants. Specifically, some male participants had a higher resting heart rate compared to female participants, while a few female participants had a lower resting heart rate. Additionally, the average heart rate slightly increased for female participants after activities. We plan to validate these findings by conducting further research with a larger and more diverse sample population. We also aim to enhance the monitoring tool by incorporating additional sensors to provide a more comprehensive picture of the body's physiological state. Moreover, we intend to explore machine learning algorithms to analyze the collected data and provide personalized health recommendations based on individual patterns and trends.

REFERENCES

[1] S. Soon, H. Svavarsdottir, C. Downey, and D. G. Jayne, "Wearable devices for remote vital signs monitoring in the outpatient setting: an overview of the field," *BMJ Innovations*, vol. 6, no. 2, pp. 55–71, Apr. 2020, doi: 10.1136/bmjinnov-2019-000354.

[2] K. Singh, P. Thiyagarajan and S. P., "Design and implementation of IoT enabled low cost SPO2 and heart rate monitoring system," *2022 IEEE Delhi Section Conference (DELCON)*, New Delhi, India, 2022, pp. 1-6, doi: 10.1109/DELCON54057.2022.9753167.

[3] M. A. Akkaş, R. Sokullu, and H. E. Çetin, "Healthcare and patient monitoring using IoT," *Internet of Things*, vol. 11, p. 100173, Sep. 2020, doi: 10.1016/j.iot.2020.100173.

[4] M. Abe *et al.*, "A method of determining anaerobic threshold from percutaneous oxygen saturation," *Scientific Reports*, vol. 12, no. 1, p. 20081, Nov. 2022, doi: 10.1038/s41598-022-24271-w.

[5] T. Veeramanikandasamy, C. S. Vasudhaa., and A. P. Rajesh, "Smart Vital Signs Monitoring System for Covid-19 Patients in Quarantine," *in 2022 7th International Conference on Communication and Electronics Systems (ICCES)*, Coimbatore, India: IEEE, Jun. 2022, pp. 401–406, doi: 10.1109/ICCES54183.2022.9835946.

[6] D. Tran *et al.,* "Recommendations for exercise in adolescents and adults with congenital heart disease," *Progress in Cardiovascular Diseases*, vol. 63, no. 3, pp. 350–366, May 2020, doi: 10.1016/j.pcad.2020.03.002.

[7] A. E. Lammers, A. A. Hislop, Y. Flynn, and S. G. Haworth, "The 6-minute walk test: normal values for children of 4-11 years of age," *Archives of Disease in Childhood*, vol. 93, no. 6, pp. 464–468, Jun. 2008, doi: 10.1136/adc.2007.123653.

[8] A. K. Mahendran, D. Katz, A. R. Opotowsky, and A. M. Lubert, "Exercise Pathophysiology and Testing in Individuals With a Fontan Circulation," *CJC Pediatric and Congenital Heart Disease*, p. S2772812923000027, Jan. 2023, doi: 10.1016/j.cjcpc.2023.01.001.

[9] P. P. Ray, D. Dash, and N. Kumar, "Sensors for internet of medical things: State-of-the-art, security and privacy issues, challenges and future directions," *Computer Communications*, vol. 160, pp. 111–131, Jul. 2020, doi: 10.1016/j.comcom.2020.05.029.

[10] N. Lata, and R. Kumar "Communication Technologies, Smart Home Solution and Security Trends in Internet of Things," *Journal of Algebraic Statistics*, vol. 13, no. 1, 2022, doi: 10.52783/jas.v13i1.60.

[11] N. Nguyen, Q. C. Nguyen, and M. T. Le, "A novel autonomous wireless sensor node for IoT applications," *TELKOMNIKA Telecommunication Computing Electronics and Control*, vol. 17, no. 5, p. 2389, Oct. 2019, doi: 10.12928/telkomnika.v17i5.12811.

[12] N. A. B. Masadan, M. H. Habaebi, and S. H. Yusoff, "Long range channel characteristics through foliage," *Bulletin of Electrical Engineering and Informatics*, vol. 8, no. 3, pp. 941–950, Sep. 2019, doi: 10.11591/eei.v8i3.1489.

[13] J. S. Kazaure and U. O. Matthew, "Electromagnetic Radiation (EMR) and Human Health: A Study on the Health Effect of EMR from GSM Base Stations in North-Western Nigeria," *American Journal of Electrical and Computer Engineering*, vol. 5, no. 1, p. 14, 2021, doi: 10.11648/j.ajece.20210501.13.

[14] S. Asheer and S. Kumar, "A comprehensive review of cooperative MIMO WSN: its challenges and the emerging technologies," *Wireless Networks*, vol. 27, no. 2, pp. 1129–1152, Feb. 2021, doi: 10.1007/s11276-020-02506-w.

[15] N. B. Ahmed, S. Khan, N. A. Haque and M. S. Hossain, "Pulse Rate and Blood Oxygen Monitor to Help Detect Covid-19: Implementation and Performance," *2021 IEEE International IOT, Electronics and Mechatronics Conference (IEMTRONICS)*, Toronto, ON, Canada, 2021, pp. 1-5, doi: 10.1109/IEMTRONICS52119.2021.9422520.

[16] J. Wan, Y. Zou, Y. Li, and J. Wang, "Reflective type blood oxygen saturation detection system based on MAX30100," *in 2017 International Conference on Security, Pattern Analysis, and Cybernetics (SPAC)*, Shenzhen: IEEE, Dec. 2017, pp. 615–619, doi: 10.1109/SPAC.2017.8304350.

[17] S.u. M. Abbasi, M. Daud, S. Ali, and A. Q. Ansari, "Design of Android-Based Remote Patient Monitoring System," *International Journal of Advanced Computer Science and Applications (IJACSA)*, vol. 9, no. 6, 2018, doi: 10.14569/IJACSA.2018.090627.

[18] M. T. Tamam, A. J. Taufiq, and A. Kusumawati, "Design a system of measurement of heart rate, oxygen saturation in blood and body temperature with non-invasive method," *IOP Conference Series: Materials Science and Engineering*, vol. 403, p. 012038, Oct. 2018, doi: 10.1088/1757-899X/403/1/012038.

[19] V. D. Soni, "An IoT Based Patient Health Monitoring System," *International Journal on Integrated Education*, vol. 1, no. 1, pp. 43-48, 2018; doi: 10.31149/ijie.v1i1.481

[20] A. Das, S. D. Katha, M. S. Sadi and Ferdib-Al-Islam, "An IoT Enabled Health Monitoring Kit Using Non-Invasive Health Parameters," *2021 International Conference on Automation, Control and Mechatronics for Industry 4.0 (ACMI)*, Rajshahi, Bangladesh, 2021, pp. 1-6, doi: 10.1109/ACMI53878.2021.9528227.

[21] S. Bakhri, E. Rosiana, and R. C. Saputra, "Design of Low Cost Pulse Oximetry Based on Raspberry Pi," *Journal of Physics: Conference Series*, vol. 1501, no. 1, p. 012003, Mar. 2020, doi: 10.1088/1742-6596/1501/1/012003.

[22] E. Susana and H. Tjahjadi, "Handheld pulse oximeter based on single board computer raspberry Pi B+," *2017 15th International Conference on Quality in Research (QiR): International Symposium on Electrical and Computer Engineering*, Nusa Dua, Bali, Indonesia, 2017, pp. 141-145, doi: 10.1109/QIR.2017.8168470.

[23] O. Y. Tham, M. A. Markom, A. H. A. Bakar, E. S. M. M. Tan and A. M. Markom, "IoT Health Monitoring Device of Oxygen Saturation (SpO2) and Heart Rate Level," *2020 1st International Conference on Information Technology, Advanced Mechanical and Electrical Engineering (ICITAMEE)*, Yogyakarta, Indonesia, 2020, pp. 128-133, doi: 10.1109/ICITAMEE50454.2020.9398455.

[24] O. B. M. Magtibay, R. H. Cabrera, J. P. Roxas, and M. A. D. Vera, "Green switch: an IoT based energy monitoring system for mabini building in De La Salle Lipa," *Indonesian Journal of Electrical Engineering and Computer*, vol. 24, no. 2, p. 754, Nov. 2021, doi: 10.11591/ijeecs.v24.i2.pp754-761.

[25] I. González, F. J. Folgado, and A. J. Calderón, "Visualisation and Analysis of Digital and Analog Temperature Sensors in PV Generator through IoT Software," *Engineering Proceedings*, vol.27, no.1, Nov. 2022, p. 59, doi: 10.3390/ecsa-9-13283.

BIOGRAPHIES OF AUTHORS

Siti Fatimah Abdul Razak 🆔 � SC 🔵 is an Assistant Professor at the Faculty of Information Science and Technology, Multimedia University. She graduated from Multimedia University (MMU) with a Doctor of Philosophy (Ph.D.) in Information Technology in 2018 and a Master of Information Technology (Science and System Management) in 2004. She is also an active member of the Centre for Intelligent Cloud Computing. Her research interest includes vehicle safety applications, the internet of things, rule mining, information systems development, and educational technology. She can be contacted at email: fatimah.razak@mmu.edu.my.

Yap Jia Wee 🆔 🔲 SC 🔵 is a Bachelor of Information Technology (Hons) student in Faculty of Information Science and Technology, Multimedia University (MMU), Melaka, Malaysia, majoring in Security Technology. His research interests include internet of things, mobile and wireless network, sensor technology and embedded device. He can be contacted at email: 1181200628@student.mmu.edu.my.

Sumendra Yogarayan 🆔 🔲 SC 🔵 is a senior lecturer at the Faculty of Information Science and Technology, Multimedia University (MMU), Melaka, Malaysia. He is an active member of the Centre for Intelligent Cloud Computing (CICC), Multimedia University (MMU). He graduated from Multimedia University (MMU) with a Master of Science (Information Technology) in 2019 and a Bachelor of Information Technology (Security Technology) in 2015. He completed his Doctor of Philosophy (Ph.D.) in Information Technology at Multimedia University (MMU) in 2022. His research interests include intelligent transportation systems, vehicular ad hoc networks, wireless communication, and mesh networks. He can be contacted at email: sumendra@mmu.edu.my.

Sharifah Noor Masidayu Sayed Ismail 🆔 🔲 SC 🔵 received her Bachelor of Information Technology (Hons) (Data Communication and Networking) in 2019 and Master of Science (Information Technology) in 2022 from Multimedia University (MMU). She is currently pursueing her Doctor of Philosophy (Information Technology) at Multimedia University (MMU). Her research interests include signal processing, machine learning and deep learning. She can be contacted at email: sharifahayuismail@gmail.com.

Mohd Fikri Azli Abdullah 🆔 🔲 SC 🔵 has been a lecturer in the Faculty of Information Science and Technology at Multimedia University (MMU), Melaka, Malaysia, since 2005. He graduated from the University of Melbourne, Australia, with Master in Software System Engineering. He was a researcher at Advance Network Lab at Chonnam National University, South Korea, in 2010. His research interests include mobile computing, image processing and pattern recognition. He can be contacted at email: mfikriazli.abdullah@mmu.edu.my.