Rehabilitation monitoring prototype: Arduino Nano 35 BLE

Mad Kaidi, H.[1]*, Izhar, M.A.M.[1], Ahmad, N.[1], Dziyauddin, R.A.[1], Sarip, S.[1], and Jalil, S.Z.A.[1],
[1]Razak Faculty of Technology and Informatics, Universiti Teknologi Malaysia, Kuala Lumpur, Malaysia

*Corresponding author: hazilah.kl@utm.my, ORCID ID:0000-0001-5915-2875

Abstract. Nowadays, smart health has been developing in the healthcare system by implementing the Internet of Things. One of the implementations of smart health is remote monitoring systems for rehabilitating patients such as stroke. Today, with the rising Covid-19 pandemic, patients undergoing rehabilitation at home have difficulties meeting with their doctors due to the moving restrictions. The healthcare facilities are focused on treating Covid-19 patients. These restrictions have caused doctors and patients not to meet regularly to collect their data on the rehabilitation progress. This research suggests building a prototype to monitor a post-stroke patient's lower limb strength rehabilitation process by using embedded sensors and microcontrollers. The prototype will measure key components of the rehabilitation process and will be discussed in the later section of this paper.

1. Introduction

Industry 4.0 is a representation of the fourth revolution that occurs in manufacturing. This fourth iteration of the industrial revolution will continue the adoption of automation systems and computers that have been implemented in the third revolution and enhance the features by including data and machine learning. In addition, there are a few applications of smart machines introduced by Industry 4.0, one of which is the Internet of Things (IoT) [1].

A system of interlinked computing devices, digital and mechanical machines, objects with unique identifiers, and the capability to transfer data over a network without human-to-human or human-to-computer interaction is the definition of IoT. IoT was introduced in the early 1980s when students from Carnegie Mellon University developed the first internet-connected vending machine that notifies users if the drinks are cold enough to be sold [2]. Nowadays, IoT is considered one of the main components of developing smart systems in many organizations and fields.

The IoT ecosystem consists of embedded systems that include processors, sensors, and communication hardware. These components will be used to collect, send, or assess the data they received. These devices work without human interaction as they use smart machine learning or artificial intelligence (AI) but can be accessed by humans if needed [3].

One of the applications of IoT is in the healthcare industry. According to the statistics, more than 60% of medical companies globally have previously acknowledged, and some have adopted IoT in their systems [4-6]. Implementing the IoT in healthcare systems has significantly improved the interaction between patients and doctors. The introduction of IoT has allowed the patients to be continuously monitored by the doctor by receiving live updates of their patients' conditions. The system will make it easier for doctors to make recommendations accordingly.

The organization of this paper will continue in Section 2 as the application of the IoT in the healthcare system. Then, the detailed description and development of Arduino Nano 33 BLE in Section 3. In Section 4, a discussion of the results, analysis, and recommendations for improvement. Then, the paper is concluded in Section 5.

2. Internet of Things in Healthcare

Internet of Things is used for monitoring purposes. This technology helps humans monitor their activities by using small devices and remotely.

2.1. Remote monitoring

Remote monitoring devices in healthcare systems are the most common application of IoT. For example, hospitalized patients who need close attention can be monitored remotely using IoT-driven devices. These devices automatically collect patients' health data such as their heart rate, blood pressure, temperatures, and pain. They will be stored in the clouds to analyze the medical staff. The frequency of the recorded data for each visited patient is reduced as the process is now automated[7]. Besides being at the healthcare facilities, patients undergoing rehabilitation at home can also be monitored using the IoT-driven devices as their data can also be accessed by the doctors remotely. Any changes or disturbances can alert the doctors or the caretakers for immediate response. Thus, it will improve the efficiency and quality of care, reducing the need for the medical staff to visit the patients for data collection, especially during this pandemic.

2.2. Stroke rehabilitation Device

There are a few rehabilitations processes that utilize the smart healthcare system, and one of them is the monitoring system for stroke rehabilitation. This paper suggests building a prototype to monitor the rehabilitation process of a stroke patient, especially for lower limb strength. Patients undergoing the rehabilitation process at home need to conduct exercises to improve their posture and mobility; hence, they need a device to record their progress. Other than that, rehabilitation progress also monitors the recovery of the patients.

This prototype requires the users to interact with it to collect data. Different sensors are attached to the prototype to collect heartbeat and leg strength monitoring data. The components and methods to test the prototype used will be discussed in detail next section.

3. Rehabilitation monitoring prototype using Arduino Nano 33 BLE

The prototype will include microcontrollers as the computing device to process the data collected by the sensors embedded in the systems. These sensors are explicitly chosen to follow the project's requirement to obtain the desired data representing the rehabilitation process of a stroke patient for heartbeat monitoring and less strength at a particular lower limb. The movement of the foot refers to general step movements. However, for details measurement consist of several phases such as heel-strike (HS), foot-flat (FF), midstance (MS), heel-off (HO) and toe-off (TO) [8]. This movement has been implemented in many gait analysis applications involving gait cycles.

The hardware prototype was assembled and programmed to receive input from sensors (pulse and accelerometer). Then the Arduino NANO 33 BLE was booted. Three subjects (Subject A, Subject B, Subject C) were chosen to undergo the testing for data collection. Table 1 tabulates the setup measurement for both procedures.

Table 1. Measurement procedure

	Heartbeat monitoring	Steps counting (accelerometer)
1	The python script (heartbeat_monitoring.py) for the pulse sensor was executed.	The python script (count_step.py) for step counting was executed.
2	The pulse sensor is tied to the thumb of Subject A.	Subject A was walking for 20 steps.
3	The heartbeat of Subject A was manually counted for 60 seconds by placing two fingers between the bone and the tendon over the radial artery.	The step counter from the script was recorded.
4	The manual reading was recorded.	Subject A repeated steps (2) until (3) two more times.
5	The beat-per-minute (BPM) of subject A from the sensor reading was recorded.	Steps (2) until (4) was repeated using 50 steps.
6	Steps (2) until (5) was repeated six times.	The python script was terminated.
7	The python script was terminated.	Steps (1) until (6) are repeated by Subject B and Subject C.
8	Steps (1) until (8) was repeated by Subject B and Subject C.	

The board chosen for the prototype is the Arduino Nano 33 BLE. This board is newly introduced and has many improvements over the regular Arduino Nano. This version of Arduino Nano is redesigned and has the features required to make this prototype. The new central part is the upgraded processor that allows higher data and programs to be stored in the memory. Other than that, the board comes with built-in Bluetooth pairing features via NFC, and it consumes less power making it more efficient to be used in the prototype. Finally, the board has built-in nine-axis internal measurement units such as an accelerometer, a gyroscope, and a magnetometer. Arduino Nano 33 BLE features and small form factor are perfect for this prototype [9].

The finger clip of the heart rate sensor is used in this prototype to measure the heart rate of the stroke patient. Heart rate monitoring for a stroke patient is very crucial. Any disturbance in the rhythm of the heartbeat will be notified to the doctors or caretakers as they will decide if the patient needs immediate action or not. This is a vital part of the prototype, so the data acquired from this sensor must be accurate.

4. Results and analysis

These results are then plotted into graphs for heartbeat monitoring. In the charts as described in Fig. 1, the results obtained from each subject are compared to analyze the accuracy of the sensor. The graph pattern of all three subjects are closely similar between 70-90 bpm.

The next part is to measure the step count of the subjects (off-patient). It is also essential for the stroke patient rehabilitation process. By implementing the built-in accelerometer in the Arduino Nano 33 BLE, a python code is written to track the steps of the subjects. The benchmark for the measures that will be compared is 20 and 50 steps. The subjects then carry the prototype while walking the steps. The result is tabulated in Table 2 and described in Fig. 2.

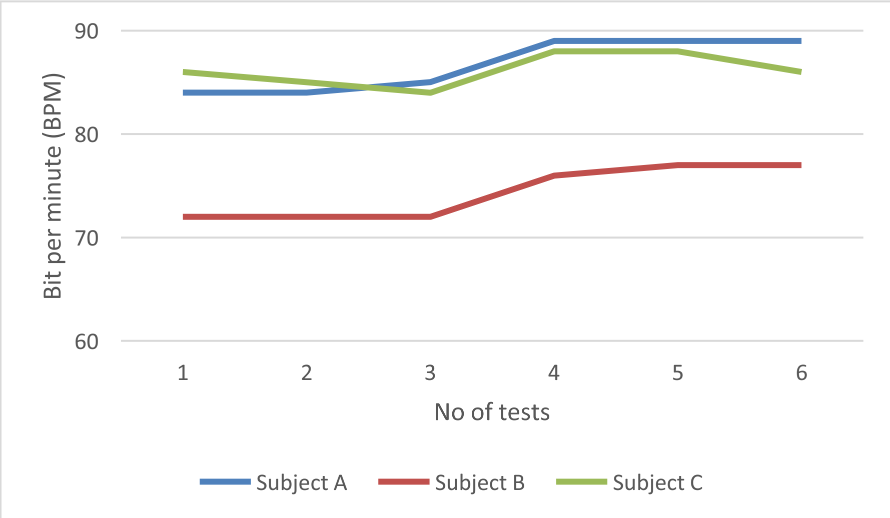

Figure 1. Heartbeat monitoring for various subjects

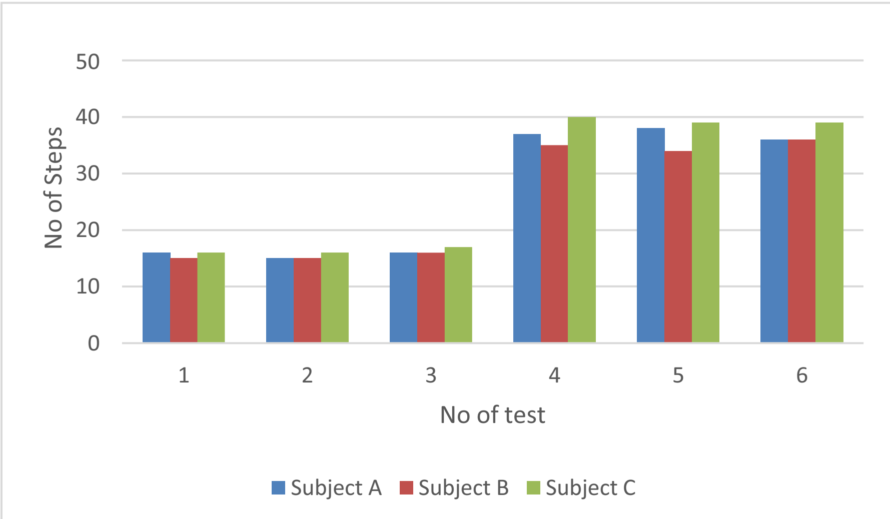

Figure2. Step counting pattern for various subjects

Table 2. Result of step tracking movement

Test #	Real Number of Steps	Accelerometer steps measurement		
		Subject A	Subject B	Subject C
1	20	16	15	16
2	20	15	15	16
3	20	16	16	17
4	50	37	35	40
5	50	38	34	39
6	50	36	36	39

The result shows that the accelerometer is working to register the steps walked by the subjects. The result was consistent throughout the test, but it was not as accurate as of the desired step numbers.

A small error is detected as the subjects walk to 20 steps, but a significant difference in steps detection compared to the 50 steps mark. It might have resulted from a precision fault in the device itself or the program written for the accelerometer. This needs to be revised and improved as the sensor is not yet ready to use in the prototype.

4.1 Recommendation

Based on the obtained result of the experiment conducted using the current prototype, the results are analyzed, and there are a few recommendations made to improve the prototype. The recommendation is to change or add components to the prototype and change the testing methodology. This will be explained in detail in this section.

The lower limb part of the prototype needs to be improved. The result shows that the step counter sensor has produced a less desired output where the steps taken by manual count and the accelerometer are different. In addition, it shows inaccuracy, so this part of the prototype needs to be improved.

Other than that, another sensor can improve the lower limb strength data collection. Here, the force-sensing resistor might be implemented to detect the pressure exerted by the subjects during their walk. It can improve the data analysis of the lower limb strength. If the pressure measurement is high, the subject might progress better in the rehabilitation process. By having this sensor, the pressure imbalance can also be determined to see if the lower limb strength of the subject has imbalances. The force-sensing resistor can be combined into a design to sense the pressure points where the feet touch the floor. Combining these sensors can improve detection, thus providing lower limb strength data accuracy.

5. Conclusion

In conclusion, the lower limb prototype was successfully made, improving from the earlier iteration. It uses less cost and has many improvements from the past model. Based on the result, some parts of the prototype need to be revised, such as adding the pressure sensor and the step tracking sensor, as they did not provide the desired output. Hopefully, this prototype will be ready and available with other sensors such as for upper limb strength, sleep study, etc., to be tested as it will be a good product that can help many people recover from a stroke. This prototype can also inspire others to explore the Internet of Things in the health care system.

References

[1] L. Atzori, A. Iera, and G. Morabito, “The Internet of Things: A survey,” Computer Networks, vol. 54, no. 15, pp. 2787–2805, Oct. 2010.
[2] S. Madakam, “Internet of Things: Smart Things,” International Journal of Future Computer and Communication, vol. 4, no. 4, pp. 250–253, 2015.
[3] A. Ghosh, D. Chakraborty, and A. Law, “Artificial intelligence in Internet of things,” CAAI Transactions on Intelligence Technology, vol. 3, no. 4, pp. 208–218, 2018.
[4] S. Selvaraj and S. Sundaravaradhan, “Challenges and opportunities in IoT healthcare systems: a systematic review,” SN Appl. Sci., vol. 2, no. 1, p. 139, Dec. 2019.
[5] H. M. Kaidi, A. H. Abdullah, H. Abdullah, S. Z. A. Jalil, S. Sarip, M. A. M. Izhar, N. A. Bani, “Internet Of Things Devices And Issues In IoT System Development For Healthcare,” Turkish Journal of Physiotherapy and Rehabilitation, vol. 32, no. 2, pp. 2836-2843, Mar. 2021.
[6] N. A. Mashudi, H. M. Kaidi*, S. Sarip and L. A. Latiff, “The modelling and simulation of IoT system in healthcare applications,” International Journal of Advanced Technology and Engineering Exploration, vol 8, no. 74, 2021.
[7] B. S. Babu, K. Srikanth, T. Ramanjaneyulu, and I. L. Narayana, “IoT for Healthcare,” Int. J. Sci. Res., vol. 5, no. 2, pp. 322–326, 2016.

[8] Kharb, A., Saini, V., Jain, Y.K., & Dhiman, S. (2011). A Review Of Gait Cycle And Its Parameters, International Journal of Computational Engineering & Maangement, Vol13, July 2011, 2230-7893.
[9] A. Kurniawan, "Arduino Nano 33 BLE Sense Board Development," in IoT Projects with Arduino Nano 33 BLE Sense: Step-By-Step Projects for Beginners, A. Kurniawan, Ed. Berkeley, CA: Apress, 2021, pp. 21–74.

Acknowledgement

Universiti Teknologi Malaysia supports this work under research University Grant Q.K130000.3556.06G45 for the financial support provided throughout this research project.