Smart Wearable Device for Physical Distance and Location Monitoring

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ABSTRACT

On the 11th day of March 2020, the World Health Organization (WHO) affirmed COVID-19, as a pandemic, in response to more than 1,000,000 confirmed cases globally in more than 100 nations and the persistent danger of spreading further. As of 2022, vaccines are already available, making a significant breakthrough in fighting the catastrophe. Aside from the vaccine, health experts are advised to strictly take standard safety precautions to lessen the transmission of the virus, especially for those who haven't already been vaccinated. Physical distance, that is, maintaining a minimum distance of at least one meter (1m) between two individuals, is one of the foremost proactive measures advised by WHO.[1]

This study creates a wearable device that users can wear inside a specific indoor venue to maintain physical distancing and monitor their real-time position. It is a simple device that is easy to use and is built using Bluetooth Low Energy (BLE). The device can also be used for future data analysis, like analyzing foot traffic within a specific venue and, most importantly, for contact tracing purposes in case, COVID-19 transmission occurs. The system can be viewed online via a web application that includes the current users' indoor position, distance measurements, and activity logs to view the list of visitors inside the establishment, including their details and assigned Tag.

Keywords

Bluetooth Low Energy (BLE), COVID-19, Foot Traffic, Location Monitoring, Physical Distancing, Wearable Device

1. INTRODUCTION

As COVID-19 struck, the "new normal" arose. How people interacted seems utterly different from the indoor and outdoor routines in which people used to wear face masks and shields. Aside from that, people followed the physical distancing protocol to lessen the transmission of the virus. According to the World Health Organization (WHO), physical distancing helped reduce the spread of COVID-19; people keep a space of at least one meter (1m) between each other and avoid spending time in crowded places or groups.[2] There were some common solutions like decreasing indoor venue capacities, limiting allotted seats, and providing floor markings to observe physical distances that government agencies have mandated. Some businesses and government establishments have already implemented these preventive measures. However, due to some instances, like a lack of personnel to check and maintain those protocols, establishments failed to observe the stated protocols. As a solution to the manifested problem, the proponents developed a technology that monitored and maintained the physical distances of people within a specific indoor venue. The proposed project aimed to determine the real-time indoor location of the users within a specific venue. The proponents used an open-source electronic platform as the main processing device which consolidated and processed all the inputs sent by the sensor modules attached to it. Bluetooth Low Energy (BLE) technology has also been used; it is a Bluetooth technology that consumes less power compared to typical classic Bluetooth modules available in the market. The setup comprised Anchors that continuously scan the enrolled BLE Media Access Control (MAC) address. An algorithm identifies the Tag's indoor location based on the trilateration of each Anchor's Received Signal Strength Indication (RSSI). On other side, Tags are wearable devices equipped with a BLE module that broadcasts BLE frequency. Aside from that, the Tag also scans the BLE frequency of the other present Tags and calculates their distances based on the converted RSSI by the specific programming algorithm.

2. RELATED LITERATURE

There were related studies used as a foundation for this study. One of these is the study of Mohamed Er Rida entitled "Indoor Location Position Based on Bluetooth Signal Strength," wherein the proponent proposed an indoor position system based on BLE's Signal Strength and Trilateration technique. This study used a different number of BLE nodes in a scenario where every node was placed 6 meters away from one another, and each node provided coverage of about 15 meters. The proponent deployed nine nodes on the ceiling. Using the trilateration algorithm, a smart device collected the signal strength (RSSI) of the three nearest adjacent nodes through RSSI measurement and estimated the user location. This implementation required a minimum of three nodes for user location, which means more nodes were used to improve accuracy. This system also showed an estimation error of about 1-2 meters.[3]

Another study entitled “Bluetooth Positioning using RSSI and Triangulation Methods” was proposed by Yutian Zhuo, wherein the proponents used Bluetooth classic and triangulation methods to localize mobile devices in a room. The proponents have developed an Android mobile application that scans all nearby Bluetooth devices and stores the RSSI. The paper suggested a scenario of the square area of a classroom with one mobile device and four fixed access points. The estimation used three different propagation models, i.e., Least Square Method, Centroid, and Three Borders applied. The best results were found using the Least Square Method with triangulation to estimate the location of mobile devices in the room compared with each other. In the study "RSSI Based Bluetooth Low Energy Indoor Positioning," Zhuo used the fingerprinting technique of localization for indoor position estimation. The fingerprinting technique has two phases. First, distribute the area into sub-areas, scan BLE reference position RSSI for offline training, and store RSSI for each BLE node with reference locations at different points. The second was to rescan the tags and compare the previous RSSI values to estimate the position for online location updates. The study used a weighted sliding window to reduce fluctuations of the real-time signals to increase accuracy. Another essential feature of this method was the active learning ability of BLE nodes regarding the position, which significantly improved the system's accuracy. Experimental data showed that the probability of locating error was less than 1.5 meters, higher than 80% in the positioning method. In the study "Improving Indoor Localization Using Bluetooth Low Energy Beacons," Pavel Kris has described the basic principles of radio-based indoor localization and focuses on the improvement of its results with the addition of a new Bluetooth Low Energy technology. Their study discussed implementing a distributed system for collecting radio fingerprints by mobile devices with the Android system. This system enabled users to create radio maps and update them continuously. Additionally, BLE beacons were installed on the floor of the building in addition to existing Wi-Fi access points to archive accuracy. The compared results show that localization by Wi-Fi is improved by 23% with a combination of Bluetooth tags.[4]

Lastly, in the study entitled "Indoor Positioning in Bluetooth Networks using Fingerprinting and Trilateration Approach," F. Subhan presented an indoor positioning based on trilateration and fingerprinting techniques of a BLE beacon with a gradient filter that removed the environmental effects. In this method, the study merged the online stage of the fingerprinting method with trilateration which enhanced the reliability of the indoor positioning of the user. The filter was used for RSSI values to increase accuracy before storing them in the database. This paper compared the results obtained without a filter with results obtained with a filter.[5]

3. PRESENTATION OF ANALYSIS OF DATA

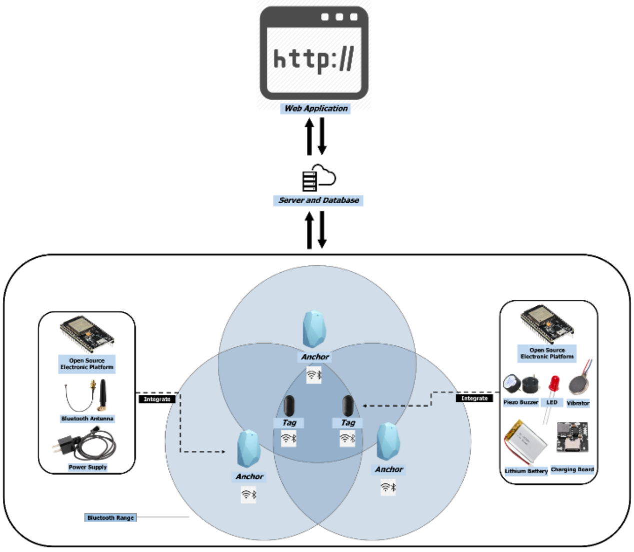

Figure 1: Operational Framework of the Project

The figure above (Figure 1) shows the operational framework the proponents used for the entire project. In developing this project, the proponents used an open-source electronic platform as the main processing device. An open-source electronic platform has been programmed based on the best algorithm the proponents can use to obtain accurate measurements for the project to become reliable. The proponents also used the Bluetooth Low Energy module, which acted as the transceiver and the receiver of BLE frequencies. Lastly, a piezo buzzer, vibration module, and Light Emitting Diode (LED) was also integrated into the project for alerting purposes.

The setup was composed of Anchors and Tags. Anchors are stationary devices that continuously scan the Tags' BLE frequencies and determine their Received Signal Strength Indication (RSSI). The placement of the anchors was determined strategically to avoid inaccuracy due to the blockage of BLE frequencies. The algorithm triangulates the Received Signal Strength Indication (RSSI) scanned by every Anchor from the Tag and converts it into coordinates that will be used for indoor location monitoring. On the other hand, Tag broadcasts simultaneously scan the Bluetooth Low Energy frequency of the other Tags present nearby and convert the Received Signal Strength Indication (RSSI) into distances using a programming algorithm. Once the algorithm determines that the Tags' distance to the other Tags is less than one meter (1m), the Tag's piezo buzzer will beep synchronously with the vibration module and LED light with an interval of 1500 milliseconds (1.5s) continuously to warn the users. The beep will only stop once the physical distance is on a range of at least one meter (1m). Manual measurement was done to determine the accuracy of the distances of the Tag to another Tag. Once inaccuracy is determined based on the manual measurement, the proponents will manually calibrate the algorithm to achieve the ±5 margin of error.

Proponents determined the project's functional and non-functional requirements based on the interview with the stakeholders and with the proponent's focus group. The project's features and qualities are considered in this phase. Based on the information gathered during the previous phase, the Functional and Non-functional Requirements describes what the project can accomplish or how its function would be carried out to satisfy the needs of stakeholders.

3.1 Functional Requirements

- The Tag can broadcast and scan the BLE frequencies of other Tags.
- The Tag can determine the distance of the other Tags.
- The Anchors can receive the BLE frequencies of the Tags.
- The Anchors can determine the indoor location of the Tags.
- The web application can display the real-time location of the tags, the activity log, user details, and Tag assignment.

3.2 Non-functional Requirements

- The web application should be simple, user-friendly, and easy to use.
- The web application should be controlled by an authorized person only.
- The web application should provide safety to the people involved inside the venue.
- The system maintains the confidentiality of information of users and the establishment.
- The Tag should be comfortable to wear.

The proponents created a schematic diagram to illustrate the placement of the microcontroller, the modules, and other electronic components. With the help of an open-source Computer-Aided Design (CAD) tool for electronics, the proponents were able to design the project's hardware, including the circuit diagrams for the project. The hardware design incorporates all the electronic components that were used.

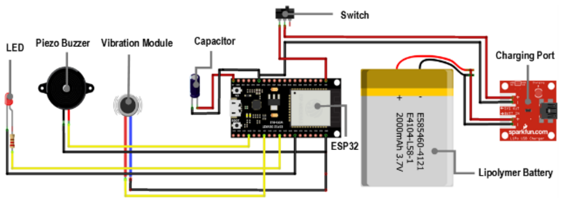

Figure 2: Schematic Diagram of Tag

In developing the Tag, the proponents used ESP32 WROOM 32-U, which has built-in WIFI and Bluetooth modules. These embedded modules have been useful for the proponents since they are one of the system's most essential features. ESP32 also served as the main processing device for the system. Other modules, such as LED, Piezo Buzzer, and the vibration module, were attached to the Input/Output (IO) pins of the ESP32. Another electronic component was the Li-polymer battery; the proponents used this component to supply current to the Tag. This also considers the need to make the Tag portable and convenient for the users. The next component used by the proponents was the charging board, an electronic component used to charge and regulate the charging voltage and current of the Li-polymer battery. Other important electronic components include capacitors and resistor, which helps to balance and regulate the voltages of the circuitry.

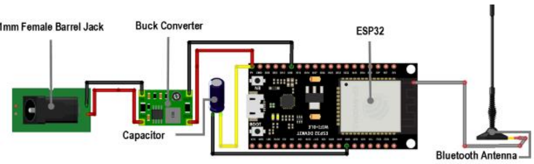

Figure 3: Schematic Diagram of Anchor

Similar to the Tag, the proponents used an ESP32 WROOM 32-U that served as the main processing device for the Anchor. It has a built-in WIFI and Bluetooth modules that sense Bluetooth RSSI within the surrounding area. A Bluetooth antenna was connected to the microcontroller to boost the sensing of the Bluetooth Low Energy (BLE) frequency. Lastly, to power up the whole device, a five volts (5v) power supply was connected to a buck converter to regulate the voltage to be distributed to the microcontroller.

The proponents were also able to render the 3D Design of the enclosure. The enclosure was vital because it protects all the electrical components that might be damaged caused by any external factors. Aside from that, it adds an aesthetic and ergonomic factor to the device.

Figure 4: 3D Design of Tag's Enclosure

Figure 4 shows the rendered 3D design of the Tag's enclosure. The design comprised holes, supports, and space where the electrical components were placed. These include a hole for the piezo buzzer, vibration module, LED light, Bluetooth antenna, and charging board. There was also a space inside where the battery, ESP32, and electrical wires were placed.

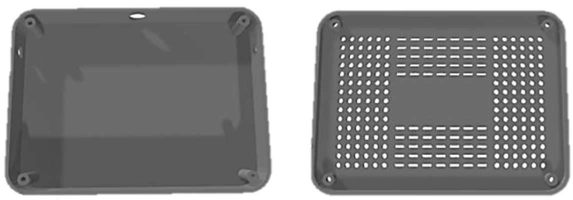

Figure 5: 3D Design of the Anchor's Enclosure

Similar to the Tag, the 3D design of the Anchors' enclosure (Figure 5) shows the realistic look of Anchor's final design. The design was composed of holes intended for the electrical components, such as the Bluetooth antennas and the power adapter. Plenty of holes are also in the back portion of the enclosure, serving as cooling vents for the device. Another thing was the space inside the enclosure; this was where the microcontroller would rest with the buck converter, capacitor, and other electrical components.

Figure 6: Final Internal Setup of Tag

After all the components had been identified and implemented, the final assembly of the Tag's prototype was done. In this setup, the proponents changed the battery from a Li-ion to a li-polymer battery to minimize space consumption and moved the entire structure permanently to the 3D-printed case to make the device intact and portable.

Figure 7: The Actual Model of Tags

Figure 7 shows the final actual model of the Tag. The device measures one hundred ten centimeters (110cm) in length, forty-five centimeters (45cm) in width, and twenty centimeters (20cm) in height.

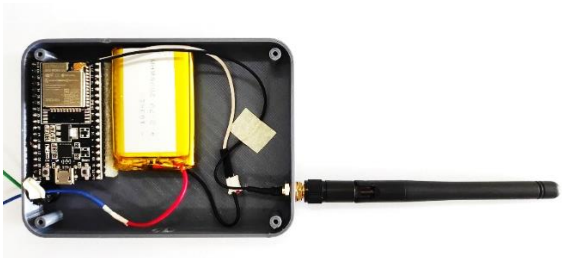

Figure 8: Final Internal Setup of Anchors

After a few modifications and finalizing the hardware components, the proponents made the final prototype for the Anchor. In this part, the proponents moved the entire setup to the 3D-printed case to make the microcontroller and Bluetooth antenna intact and avoid loose connections. Due also to the lack of power bricks in the stakeholder's establishment, the proponents integrated a li-polymer battery temporarily to supply energy during the deployment of the project.

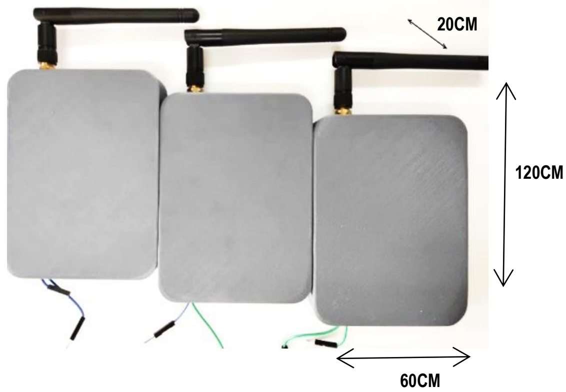

Figure 9: The Final Actual Model of Anchors

The figure above (Figure 9) shows the final actual model of the Anchors. The final setup measures one hundred twenty centimeters (120cm) in length, sixty centimeters (60cm) in width, and twenty centimeters (20cm) in height. The Bluetooth antenna was also attached to the antenna ports in this setup.

Programming of the devices was primarily started with a simple code that scans the other BLE frequencies nearby. The next thing done was to filter different Bluetooth frequencies and only display the registered BLE name. After these, the proponents started getting further BLE details, such as the BLE MAC address and, most importantly, the RSSI and the TX Power. RSSI values scanned are converted into distance. The proponents used the RSSI to Distance formula to convert the RSSI values into distances as follows:

$$\boldsymbol{d} = 10\frac{txPower - RSSI}{10 * FreeSpaceFactor}$$

Equation 1: Formula of the RSSI to Distance

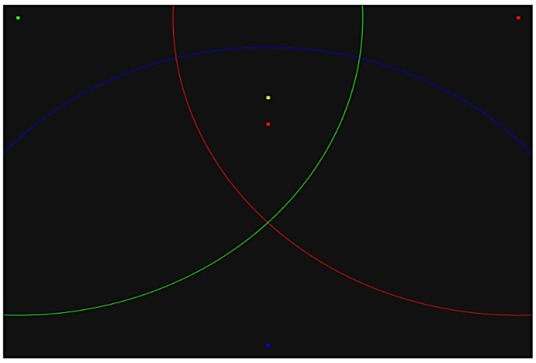

Figure 10: Simple Web Application Utilizing Triangulation

Figure 10 shows a simple web application to test indoor location monitoring. The web application was created using JavaScript, where the MQTT subscription happens with the triangulation formula. A simple canvas represented each Anchor's radius range, and a few HTML and CSS were embedded for visualization.

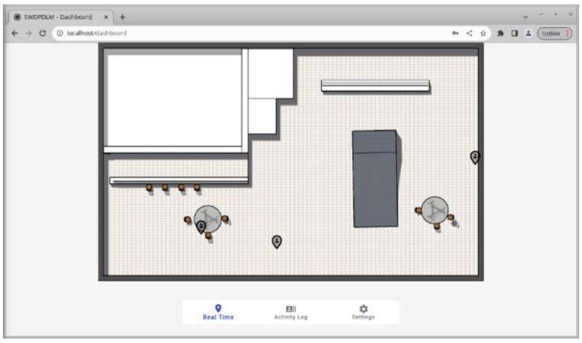

Plate 1: Real-Time Monitoring Page of SWDPDLM

The proponents started to render a simple floor plan of the locale of the study (Figure 11). The floor plan was used to visualize the equivalent indoor location of the Tags.

Figure 11: Testing of the Tags in a Distance of Less than One Meter (1m)

The proponents had already undergone a testing series to ensure the prototype worked well. It all started in the pilot testing of Tags. Using a meter stick, the proponents determined the current distances of the Tags. The figure below (Figure 11) shows a less than one-meter distance between users. In this scenario, the warning components such as the piezo buzzer, LED, and vibration module have been triggered as a sign that the distances of the users are less than suggested.

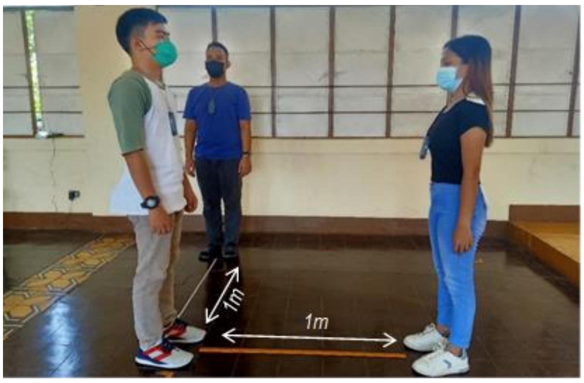

Figure 12: Testing of the Tags in a Normal Distance

After the proponents tested the Tags' distances of less than one meter (1m), the proponents also tried the normal distance. In Figure 46, the testing shows the actual manual measurement of the distance of a Tag from other Tags. Two proponents face each other while the other faces the additional proponent's left side. All of the proponents have a one-meter physical distance from each other. During this point, warning devices are not triggered to indicate that the distances are within the safe measurement.

The accuracy of the distance of a Tag from other Tags was met based on the actual manual measurement. The equation below determines the margin of error in percentage listed in Table 1.

$$\textbf{Margin of Error} = \frac{\text{Difference}}{\text{Actual Measurement}} \text{ x } 100$$

Equation 2: Formula of Getting the Margin of Error in Tag

Table 1: Testing Results of the Distances

Actual Measurement	**Gained Measurement**	**Difference**	**Margin of Error** *(in Percentage)*
50cm (0.50m)	51cm (0.51m)	1cm (0.01m)	2%
75cm (0.75m)	77cm (0.77m)	2cm (0.02m)	2.6%
100cm (1.00m)	103cm (1.03m)	3cm (0.03m)	3%
125cm (1.00m)	129cm (1.29m)	4cm (0.04m)	3.2%
150cm (1.50m)	155cm (1.55m)	5cm (0.05m)	3.33%
175cm (1.75m)	182cm (1.82m)	7cm (0.07m)	4%
200cm (2.00m)	210cm (2.10m)	10cm (0.10m)	4.5%

As shown in Table 1, the testing got a 2% margin of error or 1cm difference at 50cm (0.50m), 2.6% or 2cm at 75cm, and 3% or 3cm at a safe distance of 100cm (1m). The proponents also tested distances more significant than one meter (1m), and the accuracy base is within the targeted margin of error up to a distance of 200cm (2m)

4. RESULT AND CONCLUSIONS

Smart Wearable Device for Physical Distance and Location Monitoring helped the community to lessen the risk of COVID-19 transmission by keeping a safe distance from people inside indoor venues accurately based on the actual manual measurement.

Utilizing this project within the stakeholders' establishment helped monitor the foot traffic of the people inside their premises, having 91.67% accuracy for indoor location monitoring.

The proponents concluded that Bluetooth Low Energy Device has enormous potential in proximity and Indoor Positioning Systems (IPS) but needs further algorithm calibration for better results. This made the proponents calibrate the distances within ±5 margin of error.

After the project had been developed and tested, the proponents deployed the project to the stakeholders' establishment. After the deployment, the project was evaluated using a survey where the project got a one hundred percent (100%) level of satisfaction based on the interpreted results of the evaluation. This gave proponents that Smart Wearable Device for Physical Distance and Location Monitoring helped the establishment to reinforce the implementation of safer distance and monitor people's indoor location inside their establishment.

5. RECOMMENDATIONS

It is recommended that the establishment that wants to implement the Smart Wearable Device for Physical Distance and Location Monitoring to their premises should utilize more advanced and quality hardware components to prevent undesirable circumstances. In addition, to access the web application in their establishment, the administrator should have a personal computer and host it to make it accessible anytime and anywhere.

This project still has room for improvement. Future researchers of the same topic should broaden the scope of this study. In another way, future researchers can use the foundation of this project for other applications, specifically in proximity and indoor location systems.

6. REFERENCES

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