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# SMART IOT SCANNER FOR COVID-19 CONTACT TRACING

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**Abstract**

The smart IoT scanner for covid-19 contact tracing project was proposed and developed to help increasing the efficiency of the contact tracing process during the covid-19 virus pandemic. As of 15th January 2021, Malaysia has recoded 151066 cases and 586 deaths [1]. The aim of this project is to develop a smart IoT scanner for covid-19 contact tracing by scanning telecommunication signal to break the chain of covid-19 virus transmission. This project digitalized the conventional contact tracing by scanning BLE beacons transmitted by any proximity devices. A custom hardware is developed in this project with the ability to advertise an anonymous ID and scanning other devices for the contact tracing purpose. BLE has been choose as the medium of communication between devices as it consumes low power. All the recorded data can be analysed by the software for the data matching and contact tracing purpose. This method reduces the time to interview covid-19 patient and find the contact by simplifying into a single click method. As the results, this project achieved 72.62% of detection rate between the devices and the average response time between each scan was recorded for 4 seconds. The distance accuracy test between the device shows that the accuracy up to 98.08% can be achieved from this system.

Keywords: Bluetooth, Coronavirus, Hypertext transfer protocol, Internet of things, Printed circuit board.

# 1. Introduction

Contact tracing has become a compulsory action for any healthcare agency tracking the infection of covid-19 pandemic. Based on CDC, contact tracing is one of the best methods to halt the virus transmission [1]. Normal patient interviewing often lead to uncomplete contact tracing that may be dangerous by infecting another person.

To reduce the risk on uncomplete data from contact tracing interview process, a digital contact tracing device is proposed for the proximity detection that may lead to the virus transmission. Digital contact tracing can be more accurate, efficient and have more reliable data.

# 2. Literature Review

## 2.1. Contact tracing

The contact tracing method is an important measure to be taken in any virus outbreak. The factor of a huge outbreak can be seen from a delay or ineffective method in the contact tracing. During the Ebola Virus Disease (EVD) in year 2014-2015, [2] found the challenges in the contact tracing process in West African. The problem that has been studied by the researcher to understand the requirement in contact tracing based on the EVD outbreak in West African.

The researchers compile the challenge of the contact tracing process that have been done by the United States Centers for Disease Control and Prevention (CDC) staff. Researchers interviewed two representatives of CDC staff that have been coming back to United Stated to collect the method use and challenge in the implementation of the contact tracing in EVD outbreak. A total of 12 interviewed have been done which is two CDC representatives from each of six countries in West African. All the six countries have been assisted by the CDC staff for the contact tracing process to control the outbreak of EVD [2].

From the interviewed, the researchers listed the five challenges in the implementation of the contact tracing process on the EVD outbreak at West African. The challenges mention by the researchers are identification of close contact, locating close contact, close contact enlistment, staff management and performance of contact tracing. The first three challenges are important in the implemented of this Smart IoT Scanner for Covid-19 Contact Tracing. The issue that has been gathered by the researchers on the first challenge in the detection of the close contact is lack of understanding about the EVD outbreak by the community. The fear and misjudgement of the EVD treatment process led to the patient not to share their close contact. In some community such as Guinean, declaring the close contact's name is assume as putting the name in "death list".

The process to locate the close contact in the West African have the issue such as logistic for transportation of staff and patient. Besides that, lack of addresses and telecommunication services limit the tracing process. Certain area using landmarks to find the close contact. The contact tracing method have been proved one of the methods to control the virus outbreak such EVD transmission in West African [1]. The limitation that can be found by the researcher from all the CDC's staff representative interview was lack of the usage in the contact tracing technology due to limited telecommunication services.

## 2.2. BLE/Wi-Fi scanning/localization

By using the current technologies, researchers perform research to find the accuracy on the indoor positioning system using BLE technologies with comparison to Wi-Fi [3]. This research is done for indoor positioning due to GPS signal cannot penetrate indoor and the new Wi-Fi Access Point (AP) power saving system change the positioning system indoor to a non-straightforward system. The researchers suggest the usage of the Bluetooth Low Energy (BLE) that consume less power from the classic Bluetooth and Wi-Fi connection.

Researchers proposed in their testing for the BLE beacon capture inside a university floor consists of 800 $m^2$ space which consist of few classes and office with wall partition. The researcher set up 45 BLE beacons and 20 Wi-Fi access point in a testbed floor.

The system utilised two Samsung J5 with an apps that have been developed by the researcher to process the signal. All the signal sampling was generated in the size of the time window to make sure all the window is in the same size for each signal analysis. The result that has been analyse conclude that the error of the location measurement from beacon increase when the real distance increases as Fig. 1. The researcher also concluded the BLE result also is better compared to Wi-Fi positioning method.

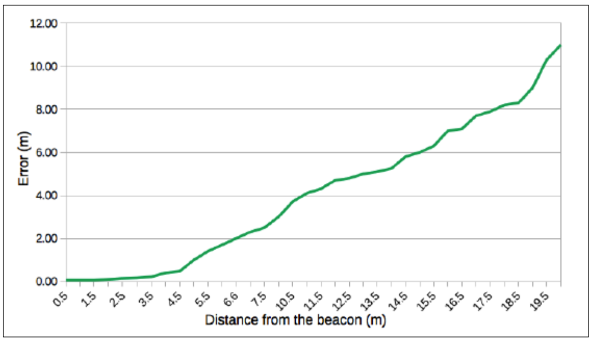


**Fig. 1. Real error vs distance from the beacon.**

The comparison that has been done by the researchers show the effectiveness of BLE technology for the indoor positioning system. As future work suggests by researchers Martins et al. [3] to construct research by collecting more data per day for few years and create an analyse system to calculate the real position of the devices.

Other researchers proposed a method using BLE Received Number of Signal Indicator (RNSI) to determine more accurate location for tracking a moving user in indoor environment especially in the healthcare facilities [4]. The normal method by using the BLE Received Signal Strength Indicator (RSSI) is simple but need to calibrate based on the environment.

The method that has been used by the researchers is to read the data of the location by the user device and store to the database to plot the movement of the user. Figure 2, the location beacon was fixed in the known location as the location transmitter. The signal transmitted by the location beacon will be stored in the wearable device and will be send the data to base station it is in range. The number that has been received by the signal was process and plot as the path when the user moving from one location to another location.

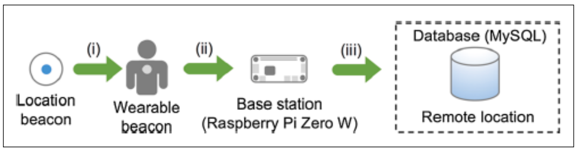


**Fig. 2. BLE RNSI detection process.**

The results from this method have more accuracy when compared to the conventional RSSI. As the experiment that have been test in the hospital, the RNSI method achieve 83.3 % accuracy which is higher than RSSI which achieve 51.9 % accuracy. The limitation from the implementation of the RNSI method that can be discovers was the wearable device will be received RNSI by two beacons at a point especially when the user was at the intersection of the beacon. The elimination technique to overcome the issue also led to some data losses for the localization.

Wireless scanning and identification using BLE become a trend due to the system capability to operate with lower power consumption. Researchers proposed to study the signal latency for BLE discoverable, and the energy consumption use during the process by android system. Researchers focus on the connection-less BLE during the evaluation [5].

The method use in this evaluation assessment was by implementing a custom program connecting android smartphone through USB to the RPI. A develop apps being deployed to the smartphone and enable Android Debug Bridge (ADB) for USB connection to the RPI. Custom python script is deployed on RPI to control, monitor and record the data from the smartphone. Data collected will be analyse using RPI with the python script.

Figure 3 shows the latency of the signal over the advertising interval of the BLE beacons. The figure concludes that higher latency will be observed when the latency will increase when the advertising interval is higher. Figure 4 shows the charge loss from the smartphone battery with respect to the number of records collected. Researchers mention that the charge loss is also dependent on the system uptime and any other background processed that run in android system. The limitation mention by the researchers was the method measuring energy consumption need to be focus on the usage of BLE only not the entire system. The developed apps are suggested to be enhance for measuring energy consumption and to mimics real world environment. Smartphone tend to have interference when Wi-Fi and BLE in operating simultaneously.

Monitoring people movement and its behaviour can be used in many other systems such robotics to improve its performance and decision making. Tracking a social interaction between a group of people can be achieved by using a wearable device. The issue to study the interaction of people using a BLE wearable devices is intended to be evaluated by Girolami et al. [6]. Researchers intended to collect physical proximity information and evaluate the performance of the BLE detection.

Researchers proposed to use commercially available smartphones and BLE tag watch. The researchers construct a platform named SocializeME platform for the detection and analyzation of BLE beacons. This evaluation use software and hardware to determine the interaction between devices. A group of students with apps installed and wearing the tag watch are deployed to get the analyzation data by the SocializeME apps. All the devices used are set to have a specific user ID for data evaluation.

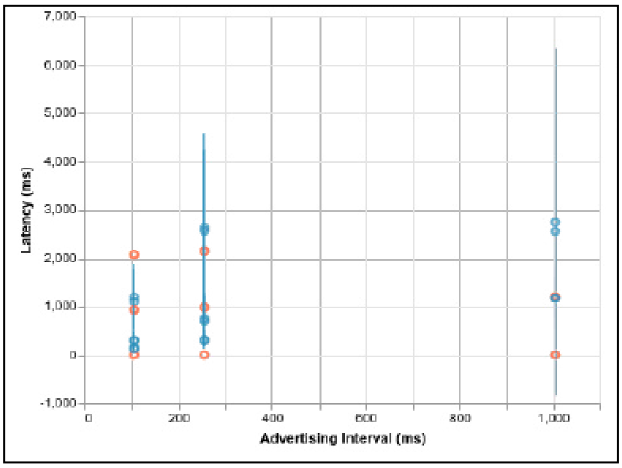


**Fig. 3. Result of latency vs advertising interval of connection-less system.**

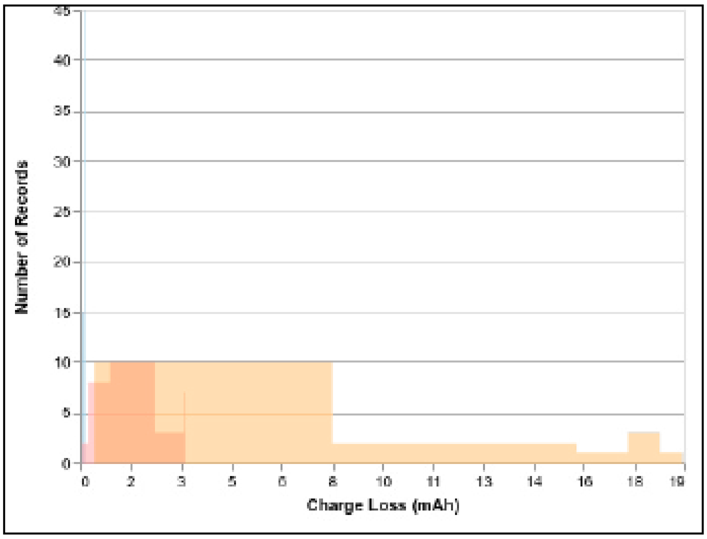


**Fig. 4. Charge loss result based on number of detected records.**

Figure 5 shows the screenshot of apps that have been install in the student's smartphone and the BLE tag watch. The smartphone will broadcast BLE beacons while scanning for other BLE peripherals. All the devices are set to be test in three different tests set to get the average detection accuracy.

Table 1 shows the results of analysis from SocializeME application that have been install. In overall 81.56% of accuracy of scanned device have been achieved by the system and have average F-score of 84.7%. The F-score shows the data precision that from the scanned device.

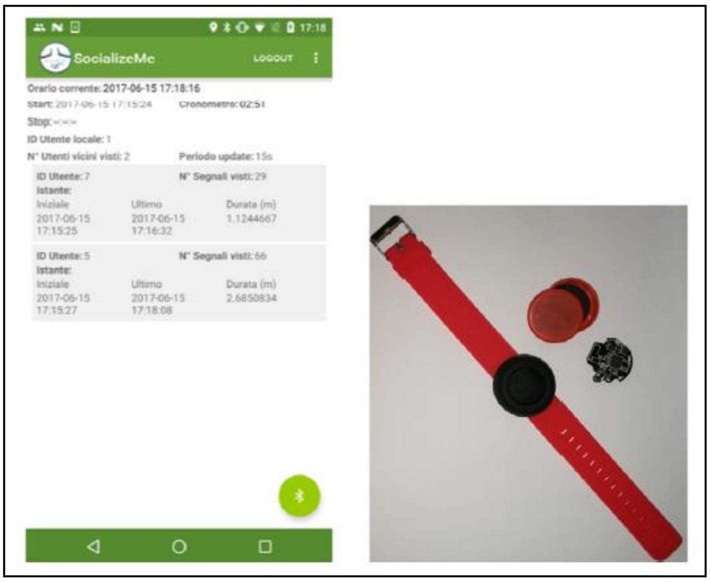


**Fig. 5. SocializeME apps and BLE tag watch.**

**Table 1. Accuracy and F-score results from SocializeME apps.**

| | Test 1 | Test 2 | Test 3 | All tests |
|---|---|---|---|---|
| Accuracy [%] | 85.32 | 87.19 | 72.21 | 81.56 |
| F-score [%] | 88.54 | 89.28 | 75.67 | 84.7 |

The limitation that has been mentioned by the researchers is android devices tend to go into deep sleep mode when the apps is not inactive use to reduce the power consumption. This will also turn off the active BLE scanning function of the device. Previous version of android also does not automatically turn on BLE advertising function when the Bluetooth in use. In iOS, the system will interrupt the BLE advertising when the apps are in background [6].

On the other hand, other researchers proposed an improve indoor positioning system by considering the signal strength of the BLE beacons to measure the distance between the beacon and the user by using new algorithm [7]. The researcher compared the results of the proposed approach with the triangulation method that is widely used to map the location of a signal [7]. Figure 6 shows the location of the beacons placed in the experiment by marking it in green colour. The users with smartphone apps were placed in the specific location marked by the pink colour dot on the floor plan. The system used by the researchers in their experiment to prove the concept of the improve algorithm to find the location of the user by placing multiple point of the beacons on a floor. The user also being set up with a smartphone installed with an application to measure the signal strength of the BLE beacons at the desire location. The signal strength and other variable was calculated by the improved formula to determine the location. The signal curve being analyse and train by the researchers to minimize error at higher distance [7].

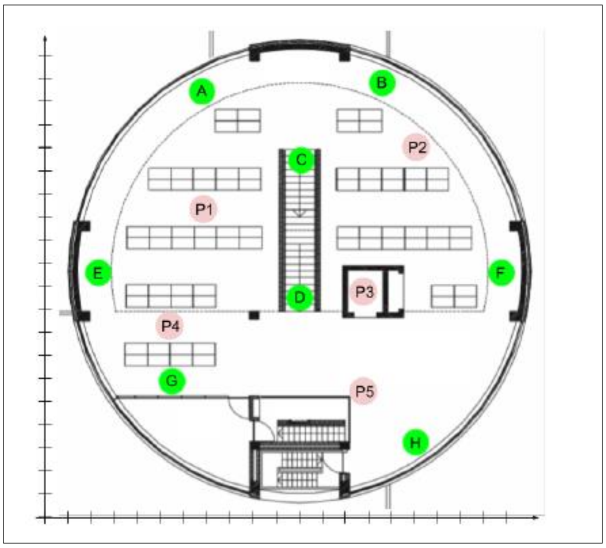


**Fig. 6. Floor plan of BLE beacons placement.**

The results achieve from the experiment that have been done shows the comparison of the effectiveness using the calculation method of the improve algorithm. The results show the proposed solution was 13.2% higher in accuracy compared to triangulation method [7].

From Table 2, the results show the comparison between the real location and the location that have been calculated by the improved formula. The results show an average accuracy of 96.9% and 98.0% for X and Y location of the user, respectively.

**Table 2. Improved algorithm detection result.**

| User Location | Real Location | | Results | | Precision (%) | |
|---|---|---|---|---|---|---|
| | X | Y | X | Y | X | Y |
| P1 | 7 | 13 | 7.6 | 12.8 | **91.4** | **98.5** |
| P2 | 16 | 15.5 | 15.9 | 16.1 | **99.4** | **96.1** |
| P3 | 13.5 | 10 | 13.1 | 10 | **97.0** | **100.0** |
| P4 | 5.5 | 8 | 5.4 | 7.8 | **98.2** | **97.5** |
| P5 | 13.5 | 5 | 13.3 | 5.1 | **98.5** | **98.0** |
| Average Accuracy | | | | | **96.9** | **98.0** |

The researchers conclude the experiment by acknowledging this method was more accurate for indoor positioning system compared to the conventional triangulation method. One of the researchers also proposed the future works for this research to train the beacons signal on more affected distances and develop a mobile apps specific with experiment layout [7].

Radio Frequency (RF) device detection research has been widely done especially for indoor positioning. One of the researchers proposed an accurate occupancy estimation system for more efficient system such as Heat, Ventilation and Air Conditioning (HVAC) control [8]. The proposed solution is to use the unlicensed band of 2.4 GHz from the Bluetooth and Wi-Fi technology with the compliance of IEEE 802.11 standard. The researchers compared their result with previous work that using standalone RF technology and other method such as environment sensor as present detection [8].

The method use by the researchers in the implementing experiment on the proposed problem are using Wi-Fi, Bluetooth and BLE sniffing. The packet data captured by the experiment such as the unique identification of the device in terms of MAC address and the Received Signal Strength Indicator (RSSI) from any RF devices [8]. The captured data was display in the dashboard constructed as Fig. 7.

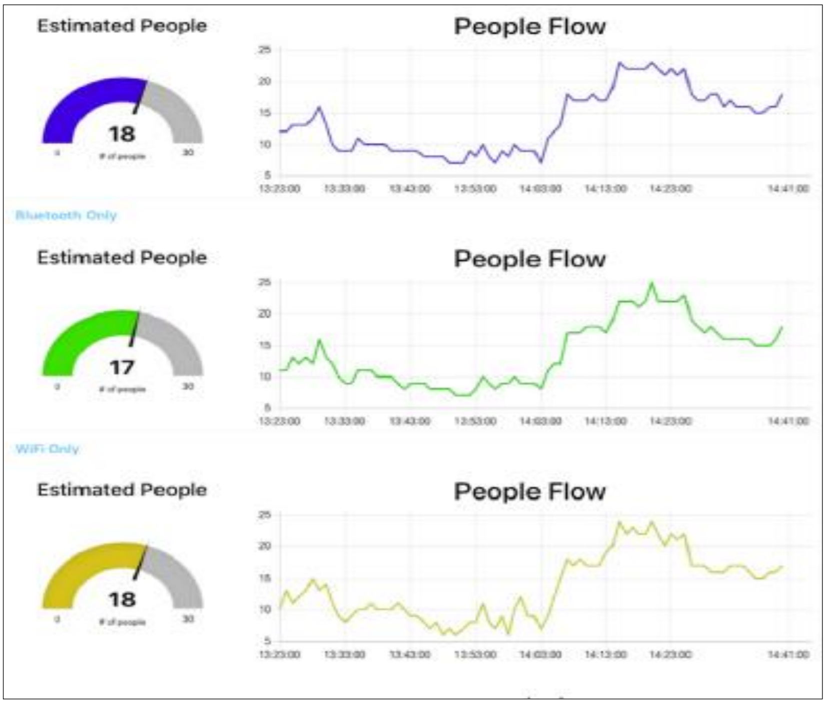


**Fig. 7. Occupancy estimation system dashboard.**

From all the captured data, researchers train the data to get the occupancy estimation and compared with the real cases for the improvement. The researchers test the constructed system indoor and outdoor in the uncontrolled situation to train the system accuracy [8]. The results from the research can be referred to Table 3. The results show the combine system give more accurate result compared to independent system.

The gap found from the implemented system is the system only depends on the calculation to estimate the occupancy of a place. The system does not have any method to detect the owner of the device that is important for contact tracing. The

MAC address randomization attack from the smartphone devices affects the accuracy of the system built by the researchers.

**Table 3. Accuracy result on Wi-Fi + Bluetooth system.**

| Testbed | Combine System (%) | Wi-Fi Only (%) | Bluetooth Only (%) |
|---|---|---|---|
| IS1 | 88 | 82 | 81 |
| IS2 | 74 | 68 | 53 |
| IS3 | 97 | 95 | 97 |
| IS4 | 93 | 93 | 81 |
| OS1 | 87 | 84 | 54 |

Egress monitoring for the cognitive disability have used multiple technology. The problem intended to be solved by the researchers in this study was the Alzheimer's Diseases (AD) elderly people that have limited memory to remember their address by suggesting a BLE monitoring device to monitor the movement. The proposed idea was to monitor and alert the caretaker of the patients when the patients is going out from the set [9].

The method use by the researcher was creating a BLE wearable device system that will monitor the movement of the AD's patients with automatic alert system. The RSSI will be used to compute the location using the raspberry pi and triggered the alert when the condition set achieve. Figure 8 shows the location of the receiver and the beacons of the wearable device.

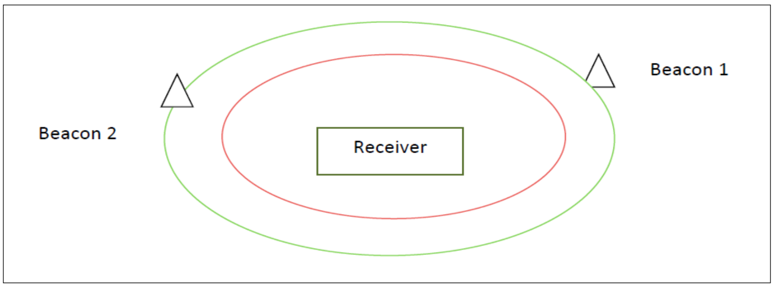


**Fig. 8. Proposed layout of the AD's detection system.**

The result from this research shows a positive impact in the monitoring of the AD's patients. This system successful to alert the caretaker when the patients are outside alone or going out from the indoor places. The limitation from the BLE tracker for the AD's patients by the researchers was to develop an algorithm that can help to detect more accurate indoor location with the system can learn the pattern of the patient's movements to trigger the alert before any dangerous events [9].

The traffic volume of the Origin-Destination (OD) from a moving Bluetooth device such a vehicle has been challenging since the first implementation. The problem stated for the probability of scanning Bluetooth MAC address was the intended problem to be solved by the researchers by considering the scanning angle and the speed of the object passing through the scanner [10].

In this research, the researchers set up a scanning device for the Bluetooth on the middle of road with the length of 120 meter. The scanner was capable to detect with the radius of 60 meter. Figure 9 shows the testing set up that have been done by the researchers. The angle of the Bluetooth scanner was changed few times during the testing period to test the best possible angle for the detection through the scanner. The data collected by scanner was evaluate by the Logistic Regression Model to determine the probability of the MAC address detection. From the test that have been done, the researchers found out the angle and height of the scanner affected the detection. The main parameters that affect the scanning process was the scanner timeout for the next scan. The lower the timeout of the scanner will give more frequent scanning process and increase the detection rate.

The detection rate of the slowest timeout set by the researchers of 3 second shows as Table 4. The results show that only small error have been achieve from the testing that ranging from 6.5% to 11.8%. The smaller timeout will give bigger sample size of the data for the Logistics Regression Model for evaluation. The limitation from this research mention was to implement data validation for the calculation model with implementation on more realistic environment.

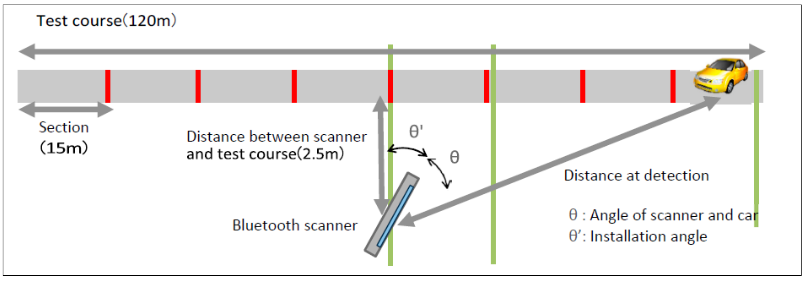


**Fig. 9. Probability bluetooth scanner layout.**

**Table 4. Detection results of bluetooth MAC address.**

| | Observed | Expected | Error (%) |
|---|---|---|---|
| Not detected | 42 | 47.6 | 11.8 |
| Detected | 144 | 135.0 | -6.5 |

The implementation of scanning and identification technology have led to multiple application including contact tracing process. This research has proposed a study to analyse the application that have been develop by others [11]. Researchers intended to find the usability, scalability and possible threat that can happen towards the implementation of mobile contact tracing.

This research is proposed by installing few apps such as TraceTogether (Singapore), Private Tracer (Netherland) and more. This research does not require any special setup. The implementation only uses few smartphones with the apps install. Researchers categorised the observation of the electronic contact tracing into five different main different such as technology, architecture, and data analyzation method.

Table 5 shows the observation of researchers on the available system that can be use on any supported smartphone. Most system implemented BLE, and some system have Wi-Fi or GPS. The architecture showed where the proximity data was stored, and role of server describe the task that will be handled by the server. Different data analyzation method has been implemented to the entire system.

**Table 5. Available solution analysis.**

| Available solution | Technology | Architecture | Role of Server | Data analyzation method |
|---|---|---|---|---|
| EPIC | Wi-Fi + BLE | Centralized | Stores encrypt data | Weight based method |
| TraceTogether | BLE | Centralized | Stores collected pair device | Match stored data point |
| Reichert's MPC based solution | GPS | Centralized | Stores geolocation and data matching | Secure binary search |
| CAUDHT | BLE | Decentralized | Blinded postbox | Pooling mechanism |
| DP-3T | BLE | Decentralized | Matching Platform | Data matching |
| ROBERT | BLE | Centralized | Store local proximity list | Risk score calculation |

The general limitation of all the develop system is it have a threat for cyber-attacks. As BLE system can have proximity attack from illegal apps that can be developed by hacker to fetch any proximity data or identity. System using GPS tend to have massive number of close contact due to lower accuracy and it based on localization in the area. BLE and Wi-Fi only received the real-time data during the scanning. However, BLE system tend to enter sleep mode on android device after few minutes of activity in background.

Digital contact tracing requires data and analysis to consider another device that is in the proximity. Identification of other device with its distance estimation is important. Alonso-Martin et al. [12] intended to evaluate the identification and distance estimation of social robotics using BLE. Researchers mention that BLE is the most suitable option for identification of other device with its approximate distance.

Identification of user is crucial in the implementation of social robotics. Researchers proposed of using BLE beacons as the communication method between the robot and user or object. From the scanned beacon, social robots can determine the dialogs or task need to be executed in certain range that have been programmed. The robot will evaluate RSSI received and calculated the estimate distance between the users [12].

Figure 10 shows the result that have been captured by the robot named “Mini”. Researchers classify the distance of users with the robot by “Immediate” as nearest detection, “Near” is within the selected range and “Far” when the user is out of range. The system successful react with the user within the selected range. Researchers also used to test the system by implementing treasure hunt game to see the reaction of the robot and the scanning of beacons. The robot successfully congratulates players when the player found the selected item with beacon installed.

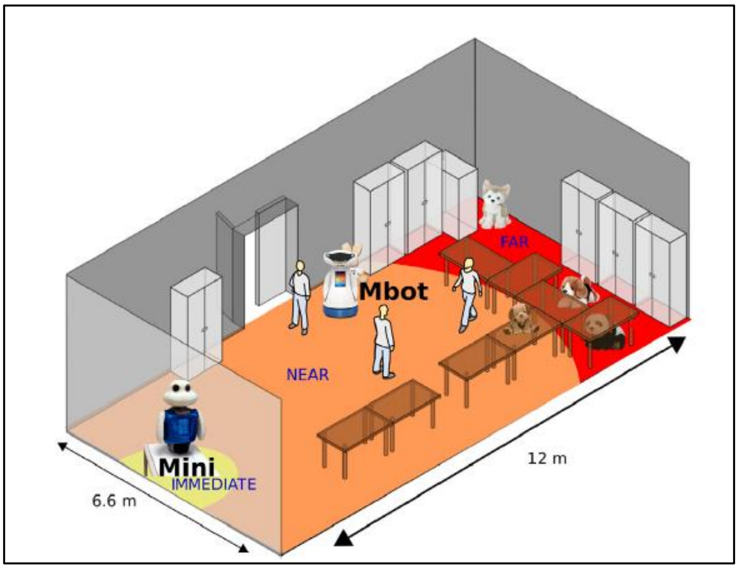


**Fig. 10. Distance estimation results of social robotics.**

The limitation from the implementation of BLE beacons scanner for identification and distance estimation is both users and objects need to have it device with BLE enable. The system does not detect any user that does not carry the device. Researchers also mention that the distance estimation still not precise due to interference of devices [12].

On the other research, the study of the main process in packet data collection of Wi-Fi network system. The study that has been done was to extract more data from the packets on the passive Wi-Fi scanning system. The management data frame based in the IEEE 802.11 standard was captured and analysed in the research. From the research that have been done by Redondi and Cesana [13], the data captured were analysed into three different parts with the data training method into user localization, user profiling and device classification.

The experiment that has been done by the researchers was by setting up nine nodes of raspberry pi 3 as Fig. 11 equipped with an additional Wi-Fi dongle for better performance. All the nodes using t-shark programs to collect the Wi-Fi data packet and save it into the MySQL database for analysis [13].

The first process that have been done by the researchers was to train the data for the user localization. Redondi and Cesana [13] use the triangulation method to detect the location of the user device in the testbed area. The results achieve by the researchers was an accuracy of 43% when the device is detected by six Raspberry Pi nodes.

The second analysis was to train the data for few days to learn the behaviour of the user. The data was processed using existing datasets for the analysis and the results shows expected behaviour of the user. The last analysis was to differentiate the type of the device such as laptop and smartphone. The researchers analyse the traffic pattern transmit from the device to define the type of the device. The researcher also successful to determine the brand of the device based on the Organizational

Unique Identifier (OUI) from the MAC address. The accuracy from this process ranging from 83% to 95% based on the data captured.

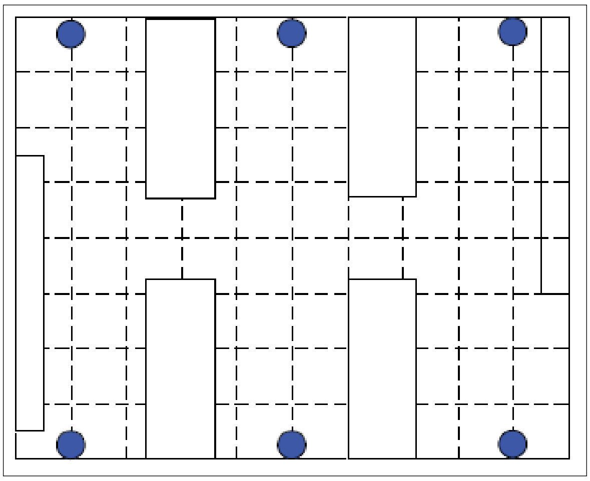

**Fig. 11. Raspberry Pi 3 nodes location.**

The limitation from the implemented research is the randomization MAC address issue. The proposed solution by probing HTTP headers become not efficient method as new secure network in the MAC address randomization and HTTPS security certificate being implemented.

The energy consumed while performing device scanning can affect the battery life of a device tremendously. Researchers intended to solve the Wi-Fi scanning system which consumes significant amount of energy that affected the user experience [14]. Researchers also proposed more efficient system of Wi-Fi scanning in the application of the localization services and maintain the Quality of Service (QoS) of the transmission.

The proposed method used by the researchers to test the energy consumption of the Wi-Fi scanning was by setting up multiple APs in the test area. The researchers also utilise an android device (Samsung Galaxy S4) with installed localization apps for the transmission and parameters setting for the scanning [14]. The localization apps used in the experiments was set with fixed QoS and tested the transmission with the dwell time for scanner to communicate with the APs. The data collected was analysed for the localization of the devices.

The results achieve shows that the scanning app with constant QoS set can achieve lower error rates down to 15.6%. The accuracy of the results depends on the number of APs in the area and the environment such as indoor and outdoor as mentioned by [14]. Figure 12 shows the energy saving ratio based on the QoS set in the localization apps with different APs density in the testing area. The result shows the energy can be save up to 52.9 % from the conventional Wi-Fi scanning process with lower QoS. The limitation mention by [14] for future enhancement to the energy saving Wi-Fi scanning is to optimize the system for a place that have lower number of APs. As shown in Fig. 12, higher density of APs gives more energy saving especially for higher QoS compared to a place in lower density.

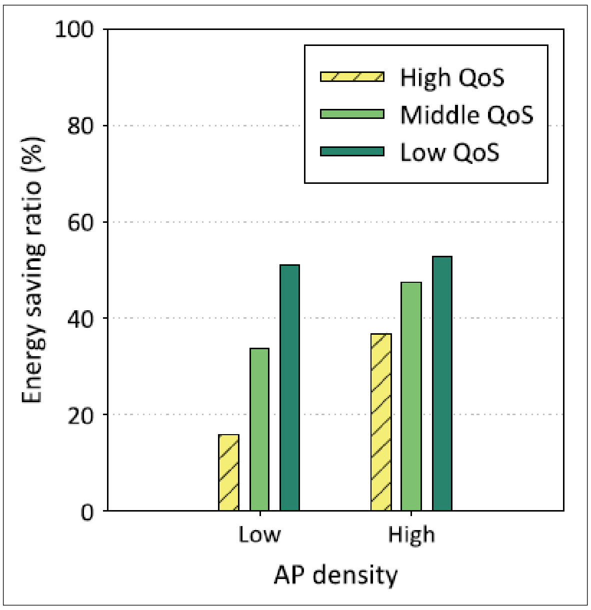


**Fig. 12. Energy saving ratio results.**

## 2.3. Antenna gain

The monitoring process in transportation research to find the travel behaviour and crowd data analytic have been done and can be incorporated the system as added value for contact tracing purpose. Abedi et al. [15] suggest a study for the effect of different gain antenna for the evaluation of capturing MAC address of the pedestrian and cyclist travel at a certain time. This study has been done to know the effect of the antenna of different gain for the suitable implementation focusing on the pedestrians and cyclist behaviour.

The placement of the scanner label in the Fig. 13 as S1 is the starting point and S2 is end point. The system calculates the time different between two scanners to get the time travel by the pedestrians and cyclists. The orange and blue circle shown on the Fig. 13 represented the 2dBi and 16dBi antenna used, respectively. The collected data by the scanner was compared by the manual data collection by the volunteer for the experiment.

As the results shown on Fig. 14, the rate of detection of Wi-Fi is higher than Bluetooth scanner as Wi-Fi has higher range and more devices using the connection as mentioned by the researchers. The successful detected devices compared to the real data collected is only 12% as shown in Fig. 15.

The usage of the two different gains of the antenna concluded by the researcher that smaller gain is a suitable usage to monitor the movement of pedestrians and cyclists. The higher gain antenna covered more area and some of the area is not for the monitoring purpose. The gain of antenna can be determine based on the project scale. The limitation found from this research compared to the target of contact tracing is the detection of the system is anonymous and all the address is not linked to any database to detect the owner or devices.

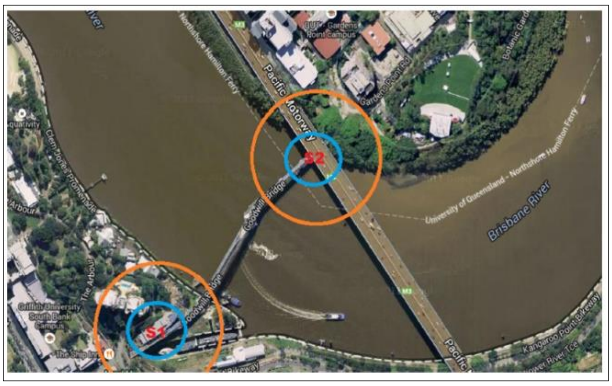


**Fig. 13. Scanner location on the bridge at Brisbane, Australia.**

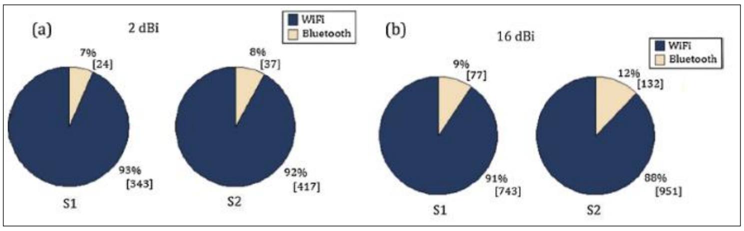


**Fig. 14. Detection rate of both antennas.**

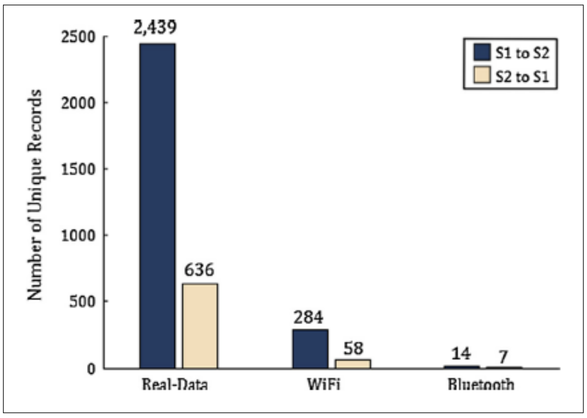


**Fig. 15. Scanning result of both antennas.**

## 2.4. Contact tracing

Contact tracing is categorised as one main strategy to prevent and help flatten the curve of any outbreak disease. However, the efficiency of this process plays important roles to avoid massive outbreak. Researchers proposed an evaluation of the effectiveness of using Real-time Location System (RTLS) method compared to the reviewing process of Electronic Medical Record (EMR) during pertussis outbreak [16]. The reviewing EMR of patients is considered as conventional method that consume lot of time and workforce needed.

Researchers proposed to track the indoor location of the staff in emergency department of a hospital by utilising Radio Frequency Identification (RFID) technology. The proposed evaluation use 734 passive RFID scanner to cover all 212 locations in the emergency department. All staff in the department are required to wear a specific RFID enabled tag. This will allow the scanner to detect which staff is attending the patient or being close with the patient [16].

As the results from this research, the researchers found out RTLS have higher efficiency than EMR in terms of time taken to list all the close contact. Conventional EMR reviewing consume 60 minutes on average for the staff to list out the close contact and RTLS system only need less than 5 minutes to generate the list. Almost 90% of the time is reduce by using the proposed method [16].

Figure 16 shows result of the close contact that have been detected by both evaluation method. From the total of 90 close contact, 32 persons was detected by both methods. Only 13 unique IDs are not detected by RTLS, and 45 IDs were not in the EMR list. The result also shows RTLS have a total of 77 unique IDs listed rather than 45 IDs in using the EMR. This conclude RTLS have higher efficiency in terms of detection and time needed to generate the data.

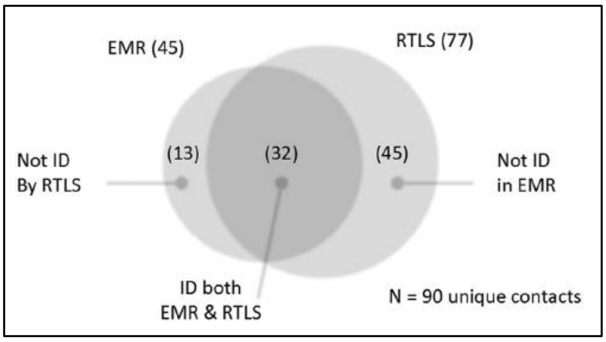


**Fig. 16. RTLS vs EMR results of close contact.**

The limitation that can be observed from the implemented research was this system suitable to be use in a specific indoor location as this system needed a specific antenna to be set up. This method will not be suitable to be implemented for mass use in large open area.

## 3.Proposed Methodology

The proposed system for the smart IoT scanner for Covid-19 contact tracing consists of the hardware implementation as a wearable device for the scanning of close contact devices. Figure 17 shows the block diagram of the proposed project that will include the RTC module and SD card module. The module used to scan nearby device is embedded inside the MCU. The MCU will call the BLE to get the device data. The return value from the BLE scanning process is timestamped by the RTC module. The timestamping will return the data when it is requested by MCU and allow user to refer specific time when another device is detected. All the unique devices will be saved on the SD card to prevent from the data losing if the MCU accidently restart. All the data from the hardware device will be send to the Node-red as the filtration software to detect all the user based on the user database as the contact tracing process. Node-red will be used to show all the close contact with their info for further health screening process by the related agencies.

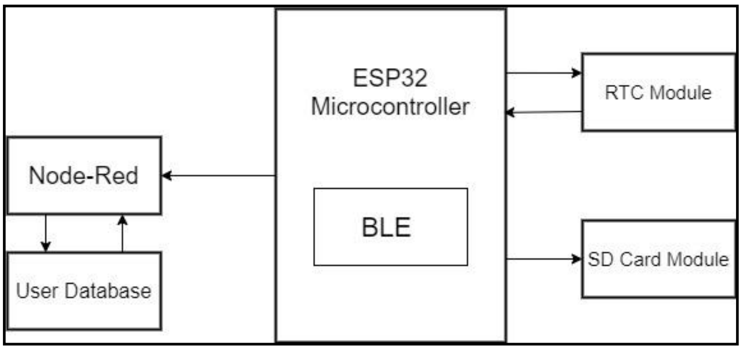


**Fig. 17. Proposed block diagram.**

## 4. Program Design

The working principle of the final implementation of this project have been improvised from the initial proposed idea. The improvement that has been implemented is done to make all the system work in most efficient way while achieving the objectives.

Figure 18 shows the finalize flowchart for the main program to be executed by the designed prototype. The system execution will mainly focus on the BLE scanning and advertising process as the main concern for the contact tracing purpose.

The process starts by fetching all configuration including saved SSID and password for the Wi-Fi connection. After all the configuration is loaded, external peripherals including SD card and RTC system is initialized to make sure all the system can be used accordingly for specific task.

The system continued by starting BLE advertising function. The system will advertise a unique ID for each user. This ID is used for data matching during contact tracing. This ID will advertise with a specific UUID of 0x1010 for the system identification method as the of contact tracing process. Then, BLE scanning function will be started to scan any other device in proximity. This system also capable to scan myTrace apps that have been install in any smartphone.

The system will check if user is pressing the configuration button for five seconds. If the user pressed the button, the system would call subprogram A. This subprogram is used as a webpage for the configurations. If the button is not pressed, the system will check if the system needs to upload the database to the cloud service. If the system needs to upload the data, subprogram B is called to execute the task. If none of the condition was met, the system will process to fetch any nearby device for contact tracing.

From the nearby detected nearby devices, the system will check if the new device is detected. If new device detected, the system would check the device UUID to make sure the device is also a contact tracing device. The system will end to start new scanning process if none of these two conditions is met and will proceed to next process if both conditions met.

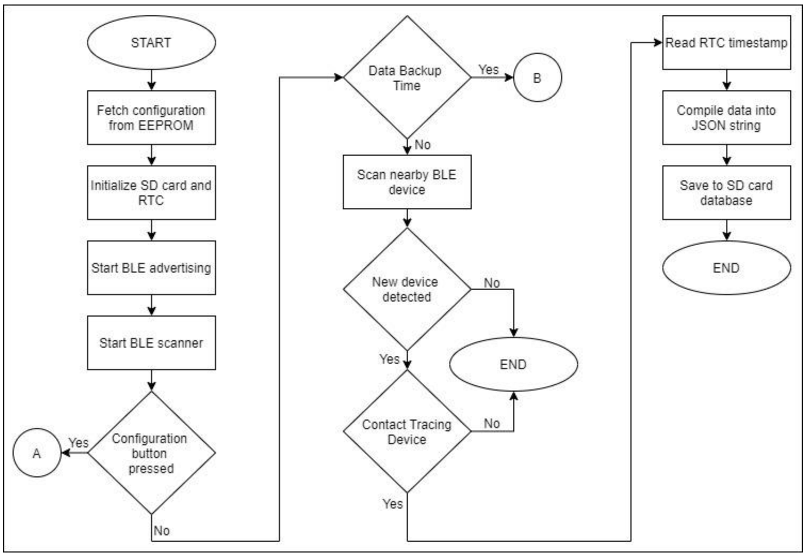


**Fig. 18. Final main program flowchart.**

The system will communicate with RTC system to get the real-time date and time of the detected devices. This timestamping process is important in the contact tracing process for further evaluation by healthcare staff. All the data collected from the scanned devices and RTC were compiled into a single JSON string. This string is used to be save to the onboard storage in the SD card. SD card is used to avoid any data losses if the system down or being reset.

The connection to A in Fig. 19 was program to allow the user when to input their Wi-Fi credentials into the system by pressing the programmable button on the hardware. The Wi-Fi credentials will be saved in EEPROM to allow the system to utilise for the B program. The program in B as Fig. 20 was to back up all the existing data in the devices towards the cloud backup database. This program will try to connect to the Wi-Fi based on the EEPROM and upload the data through SMTP server to the cloud system.

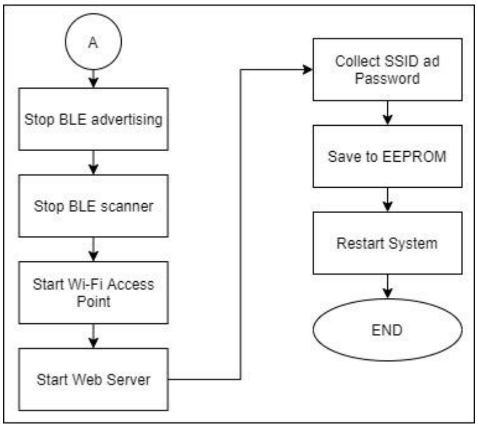


**Fig. 19. Wi-Fi setting flowchart.**

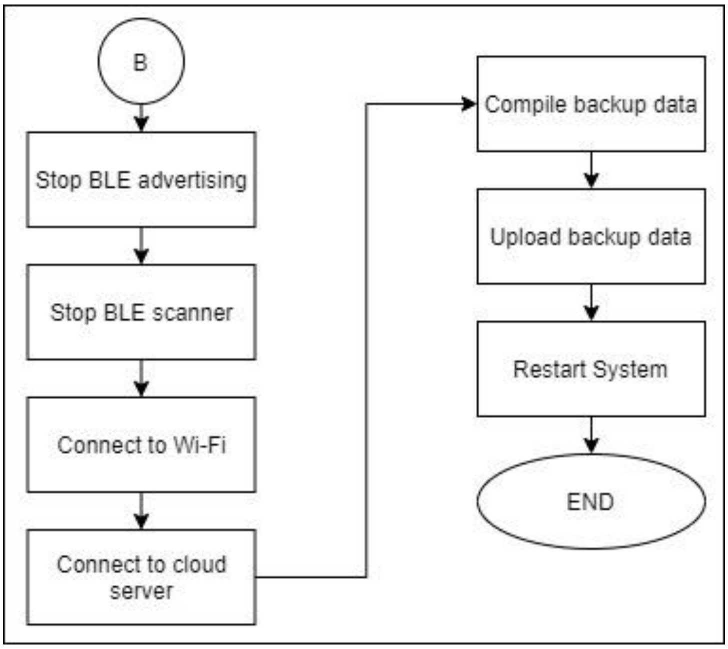


**Fig. 20. Subprogram B for data backup flowchart.**

## 5. System Implementation

A custom design PCB was made for this implementation of the system. This custom PCB integrate all the necessary component into a single board for compact and small design. This system also encloses using a watch design for user to wear during the testing. The outcome of this development as Fig. 21.

The system design also come together with a custom contact tracing software that can be used for the contact tracing process (Fig. 22) and user management system (Fig. 23). This software integrated with the MySQL database to keep the record of the user.

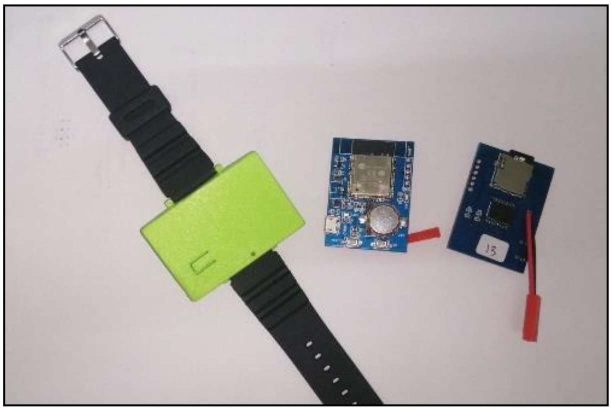

**Fig. 21. Final hardware and customize PCB (front & back).**

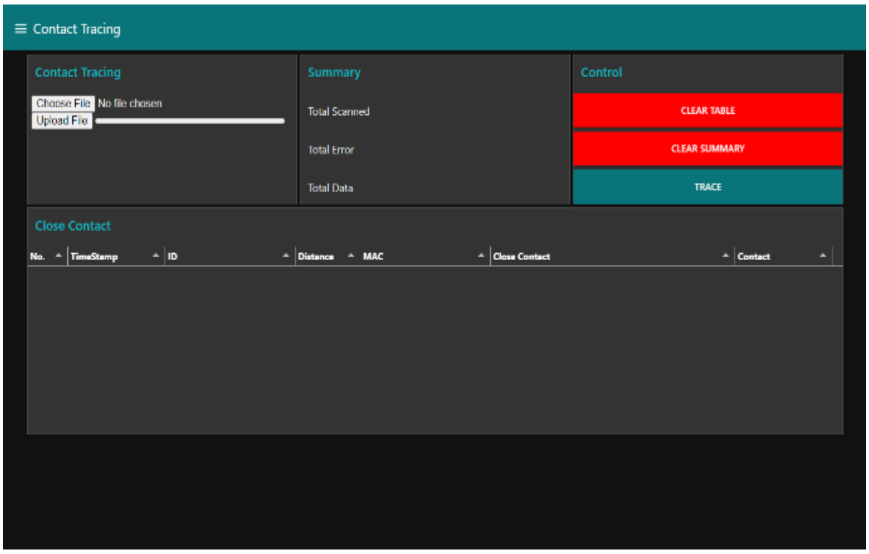


**Fig. 22. Contact tracing system.**

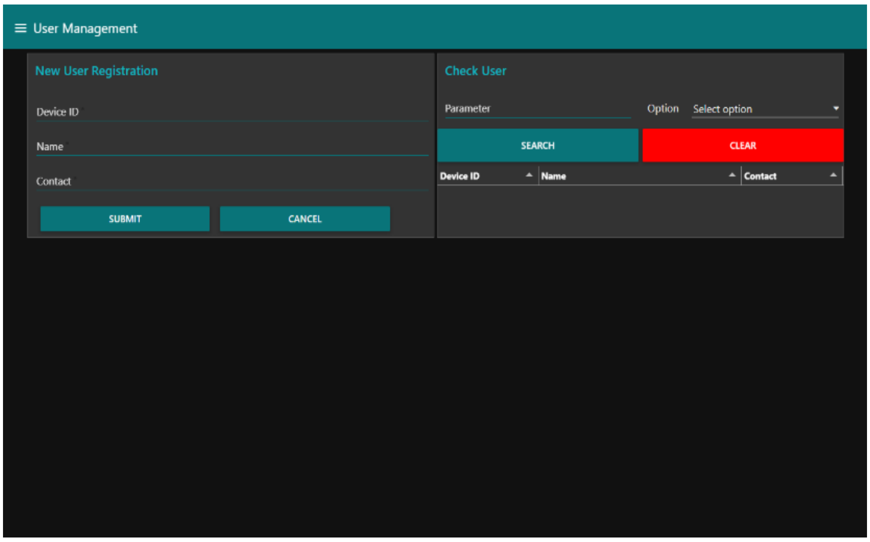


**Fig. 23. User management system GUI.**

## 6. Results and Analysis

Few tests have been done to check the efficiency and the working of this system. The testing is compulsory to get the data for future improvement and implementation.

### 6.1. Scanner detection rate

Scanner detection rate testing is implemented to see the ability of the hardware scanner detecting any other contact tracing devices which in the proximity of the scanner. This test will show the efficiency of the system to detect other devices and record all the data in the device memory. This test will be comparing the number of available devices and number of detected by the scanners.

This testing has been set up with the collaboration with Hospital Canselor Tuanku Muhriz (HCTM). 9 units of the prototype was distributed to volunteers that will wear the prototype and walk away and will meet others volunteer randomly. This device will log all the meeting between the volunteer with it timestamp and the proximity distance between the volunteer. Five devices were taken into data collection and analysis.

Table 6 shows the data tabulated form five devices that have been used for testing at HCTM. The maximum number volunteer can meet is eight persons and the meeting location can be anywhere within HCTM area. The number of volunteer meet is recorded manually by the volunteer and compare with the devices data to observe the detection rate.

**Table 6. Detection rate result.**

| Device | Number of volunteer meet | Number of devices detected | Detection rate (%) |
|---|---|---|---|
| 1 | 3 | 2 | 66.67 |
| 2 | 7 | 5 | 71.43 |
| 3 | 8 | 6 | 75.00 |
| 4 | 8 | 7 | 87.50 |
| 5 | 8 | 5 | 62.50 |
| Average detection rate (%) | | | 72.62 |

The detection rate and number of devices analysis can be observed. The table shows highest number of volunteer meet was eight persons as at the maximum during the testing and the lowest only three persons. This tests purposely used open ended method to simulate real implementation. The volunteer can decide how many persons will meet and recorded the data. The detections results show all the devices has undetected device due to some meeting by the volunteer was not meet up to the contact tracing criteria which must be in proximity of 1.5 meter and meet more than 1 minute. The detection rate has an average of 72.62% from all five devices. This average can be acceptable due to previous reasons and one of the devices show up an error during the data collection. Based on the device log, the device enters an error mode after could not initialize the BLE system during the testing.

## 6.2. Average response time

Scanner response time testing is a testing for the system to see the response time by the scanner to detect any contact tracing devices in proximity. The return rate on the response time in this testing including all the detection process that include scanning, filtering, and saving the data.

This testing is done by allocating a scanner as a data plotter on the middle of system with five devices on various distance to be detected by the scanner. The maximum distance was set to 1.5 meter within the circle as shown in the Fig. 24. The scanner is connected to a computer via UART to debug all the log in real-time with time stamping of each detection. The time taken to detect between each device were observed and tabulated.

Table 7 shows the response time by the scanner to detect, filter and save the proximity devices. The minimum response time was 2 seconds and the highest was 6 seconds. The average response time for this system to detect a device was observed as 4 seconds per device.

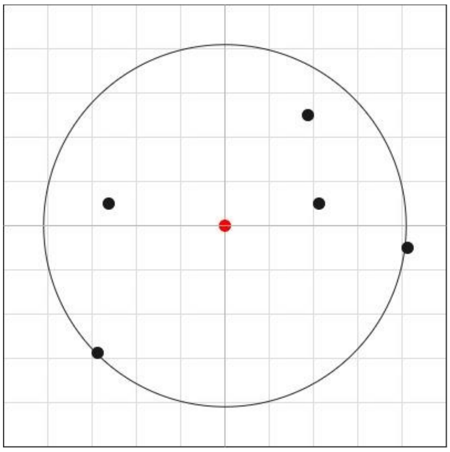

**Fig. 24. Scanner response test device mapping.**

**Table 7. Response time result.**

| Device | Response time (s) |
|---|---|
| 1 | 2 |
| 2 | 2 |
| 3 | 4 |
| 4 | 6 |
| 5 | 6 |
| Average response time (s) | 4 |

The first scanned need 2 seconds and the fifth device require 6 seconds for the same process. This issue is observed, and few outcomes has been recorded. The system requires more time for filtering the devices as more devices was scanned on the same time and avoiding data duplication in the storage unit. This issue also being affected by other BLE smart devices which also in proximity during the testing that need to be filtered out from the classification of contact tracing devices. As the results, 4 seconds is the average of the scanner to response and process other proximity devices. The average response time is suitable for the contact tracing project due to requirement of at least 1 minute in detection of another devices.

## 6.3. Distance test

Scanner distance test is done to measure the relation between RSSI and the distance between the devices. This testing was important to measure the effective distance due to contact tracing must be in the proximity range of 1 meter. The relation of the distance and RSSI will be used as software limiter to analyse is another device can be considered as close contact or vice versa.

This testing was done by setting a scanner on a fix location and a scannable device straight with line of sight from the scanner on multiple distance. The testing starts with range of 0.5 meter and increasing with 0.25-meter range between each test. The RSSI of the signal was recorded by nRFConnect application which is provided by Nordic Semiconductor and tabulated.

Table 8 shows the RSSI value that have been recorded based on the distance between the scanner device with the nRFConnect device. The RSSI become lower as the device was move farther than the signal recorder for the RSSI.

**Table 8. Distance test result.**

| Set | Distance (m) | RSSI (dBm) |
|---|---|---|
| 1 | 0.50 | -65 |
| 2 | 0.75 | -69 |
| 3 | 1.00 | -78 |
| 4 | 1.25 | -81 |
| 5 | 1.50 | -82 |
| 6 | 1.75 | -84 |
| 7 | 2.00 | -88 |

This table shows the relation between the distance and RSSI which is inversely proportional. The higher the distance between the devices the lower the RSSI reading can be observed as proof in the test. At distance of 0.5 meter, the recorded RSSI was -65dBm and at 2 meter it was -88dBm. The signal was inversely proportional due to system will have lower signal strength when the distance increases. The accuracy of the distance was 98.08% when compared to the calculation of conventional RSSI to distance equation.

$$d = 10^{\left(\frac{P-RSSI}{10n}\right)} \quad (1)$$

## 6.4. Average receiving rate

Server receiving rate is a testing to see the efficiency of the backup data IoT server. This will test the ability of the system to receive all the backup data from multiple scanners at the same time. This test comparing the number of transmitted data and number of received data at the server to calculate the efficiency.

This testing was set with five scanners devices loaded with Wi-Fi setting on different location. The device has been set to send data to the backup system on the cloud with one hour interval. All the data send from the devices will be check at the server side and compare with the number of data being send. This test was run for five hours to record three different sent of testing.

Table 9 shows the number of data packet that have been send by 5 scanners from different places into the backup cloud server and its respective receiving packet. The number of data was plot on primary axis and the receiving rate was based on secondary axis All the data send by all devices has been successfully retrieved at the server without any data losses. The average receiving rate at the server was 100% for all the 5 sets of testing. The hosted server on the google can be conclude as stable for the project implementation for mass project. The server use also can be scale based on the number of the devices needed.

**Table 9. Server receiving rate result.**

| Set | Send data | Receive data | Receiving rate (%) |
|---|---|---|---|
| 1 | 5 | 5 | 100 |
| 2 | 5 | 5 | 100 |
| 3 | 5 | 5 | 100 |
| 4 | 5 | 5 | 100 |
| 5 | 5 | 5 | 100 |
| Average receiving rate | | | 100 |

## 6.5. Performance test (processing time)

Contact tracing performance test is done to monitor the efficiency and ability of the contact tracing software that have been developed for this project. This testing will compare the scanned devices data with the database. This testing will return the efficiency of software to process all the data by comparing the number of data input and the data matching at the system. This testing also will check the accuracy of the data matching in the contact tracing system.

The setup of this testing was by taking a scanned data from a device and split the data into few sections of dataset. Each dataset will consist of difference number of data as shown in Table 10. The system efficiency will be calculated by comparing the number of input data and output data. Besides that, the time taken to process each dataset also will be recorded as the performance evaluation process.

Table 10 shows the results from the contact tracing performance test on the developed software. The number of inputs on each set is difference and the output was the input that have been successfully analyse and data match with the database by the system. The efficiency was calculated between the output and input and the processing time for each set was recorded accordingly. The result shows the system capable to do massive data matching process with 100% efficiency without data miss and processing the mass close contact information within few seconds. The average processing time for 1 data was recorded 0.03 second in average.

**Table 10. Contact tracing performance test result.**

| Dataset | Number of data (input) | Data match (output) | Data match efficiency (%) | Processing time (s) |
|---|---|---|---|---|
| 1 | 100 | 100 | 100 | 3 |
| 2 | 200 | 200 | 100 | 5 |
| 3 | 300 | 300 | 100 | 8 |
| 4 | 400 | 400 | 100 | 11 |
| 5 | 500 | 500 | 100 | 13 |
| Average processing time for one data (s) | | | | 0.03 |

## 6.6. Comparison with previous research

The testing outcome from this project also can be compare with previous research that have done a similar concept experiment. The testing for scanner detection rate can be compared with few research. Only research that have use Bluetooth/BLE is compared.

Based on Table 11, the detection rate between devices was compared to previous research. The outcome recorded from this project was 72.62% which can be categorised as on the same range of the detection rate from another research. However, the results can be higher and lower due to all research used difference method and setup including antenna gain form their respective research.

Table 12 shows the comparison of the distance or range test between the devices. This project shows the highest accuracy when compared to another research. This different due to system design that have been improve for the prototype. However, the accuracy was affected by signal interference that is difference on every research.

**Table 11. Detection rate comparison.**

| Author | Detection rate (%) |
|---|---|
| Afiq (Current project) | 72.62 |
| Longo, Redondi & Cesana [9] | 73.20 |
| Abedi et al. [7] | 12.00 |
| Tsubota & Yoshii [11] | 93.75 |
| Girolami, Mavilia & Delmastro [6] | 81.56 |

The processing time needed for the close contact system also can be compared to previous research that have been done by another researchers. [12] shows their result take below 5 minutes to process 90 data of the close contact. However, from the test on Performance Test (Processing Time) shows that this project only required less than 30 seconds to process 500 close contact data using the software that have been developed.

**Table 12. Distance accuracy test.**

| Author | Accuracy (%) |
|---|---|
| Afiq (Current project) | 98.08 |
| Morgado, Martins & Caldeira [8] | 98.00 |
| Redondi & Cesana [15] | 43.00 |
| Surian et al. [4] | 83.30 |

## 7.Limitation

The limitation that has been recorded during this project implementation was the better battery lifetime that affecting the uptime of the system. To overcome this issue, the system can be optimizing the power management system to reduce power consumption. On the other hand, the detection rate of this design was only 72.62% which is consider low. This can be improved by the power delivery towards the microcontroller and avoid the system to reset due to lack of power.

## 8. Conclusion

As conclusion, the custom system and software have been successfully done and tested. Based on the testing, this system achieved the detection rate of 72.62% which can be improve further. The response time for the scanning is 4 seconds on average which is as expected by the system. The distance test between the device shows that the accuracy up to 98.08% when compared to the theoretical calculation. This shows this system have high accuracy to process and analyse the close contact exposure rate.

## Acknowledgments

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