MTSFB TR 014:2023

TECHNICAL REPORT

MONITORING SYSTEM AND LOCALISATION OF COVID-19 PATIENT

Preface

Malaysian Technical Standards Forum Bhd (MTSFB) has awarded Universiti Malaysia Perlis the Industry Promotion and Development Grant (IPDG) to implement the Proof of Concept (PoC) of the Monitoring System and Localisation of COVID19 Patient. The duration of this PoC is for 12 months starting March 2021. The PoC is carried out in Pusat Kuarantin dan Rawatan (PKRC) at Kolej Jururawat Masyarakat Kangar (KJM).

This Technical Report outlines the objectives, benefits, scope of work, methodology and result analysis.

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Published by:

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Abbreviations

For the purpose of this Technical Report, the following abbreviations apply.

CDC	Centres for Disease Control and Prevention
COVID-19	Coronavirus disease 2019
FSS	Frequency Selective Surface
GPIO	General Purpose Input/Output
GUI	Graphical User-Interface
HQ	Headquarters
IoT	Internet of Things
KJM	Kolej Jururawat Masyarakat
MCO	Movement Control Order
PIC	Person In Charge
PKRC	Pusat Kuarantin dan Rawatan COVID-19
PoC	Proof of Concept
PUI	Person Under Investigation
PUS	Person Under Surveillance
RFID	Radio Frequency Identification
RRIS	RFID Reader Infrastructure System
SBC	Single-Board Computer
SOP	Standard Operating Procedure
UAT	User Acceptance Testing
UHF	Ultra High Frequency
VNA	Vector Network Analyser

MONITORING SYSTEM AND LOCALISATION OF COVID-19 PATIENT

Executive summary

Radio Frequency Identification (RFID) technology is an ideal data capture and sharing system in various of monitoring applications especially healthcare environment. From admissions and administration, through points-of-care to managing equipment and supplies, an RFID solution provides an efficient, cost-effective information system to support best practices in patient service.

Besides that, the secured parameter of facilities applying the RFID technology is becoming essential nowadays when the spreading of the virus COVID-19 become aggressive. Person Under Surveillance (PUS) and Person Under Investigation (PUI) were given special non-electronic wristbands to indicate that they are under quarantine. They were also monitored through the 'MySejahtera' mobile application. However, these methods cannot detect whether the PUS or PUI remained in their quarantine stations.

Thus, a localised monitoring system for PUS and PUI in the quarantine stations was developed. Frequency Selective Surface (FSS) RFID tag antenna was implemented for its capability to improve the antenna's performance and better efficiency. Monitoring and localising the web-based system using RFID technology with the application of Internet of Things (loT) and cloud technology were integrated as a RFID full system application. This system can run and monitor in real-time on multiple devices concurrently and will alert the relevant parties on any case of PUS or PUI escaping the quarantine stations.

The monitoring system and localisation of COVID-19 patient was well developed in 12 months. The new RFID wristband invented with the ability to read the user's location in the quarantine stations. With the support of sensors integrated in the RFID Reader Infrastructure System (RRIS), the quarantine stations can be more secure and easier to manage. The proposed RFID has the potential to change an organisation's ability to get real time information on the location of assets and even personnel.

Furthermore, the proposed RFID FSS wristbands can be distributed in bulk quantities at a minimal cost. This application can also be applied in monitoring the elderly needing special care, patients needing close supervision or other private or public sector requiring the surveillance service. It is believed that this technology will be an integral part of future smart healthcare components of smart cities in the post COVID-19 era and may be part of development of standards in the application of smart cities technologies.

1. Background

On May 6, 2020, there was a shocking news of 147 individuals had escaped from a COVID-19 quarantine stations after been screened for the coronavirus. Even though, Datuk Dr Noor Hisham Abdullah, the Director General of Health of Malaysia assured that these individuals were found negative during their screening, they were supposed to be quarantined for at least 14 days and then rescreened before being cleared of the virus. Thus, a monitoring system technology for PUS and PUI is essential to prevent such incidents from happening again.

Various technological approaches have been adopted by different countries. For example, Taiwan is tracing travel history and mobile phone location to observe quarantined people, and South Korea has created a database of COVID-19 patient's travel routes. The latest invention is known as CovidWatch. It is an application by Google-Apple collaboration that uses Bluetooth technology to track user's location and COVID-19 status. India has started its Aarogya Setu mobile application, where it is used to inform the user about the risk of getting COVID-19. While Malaysia, used a special tag on their wrist known as non-electronic wristbands to indicate that they are under home quarantine. They also will be monitored through the 'MySejahtera' phone application.

Besides, current practice for monitoring PUS and PUI is by having them to wear a wristband tag for identification. For example, every PUS and PUI in Sarawak will be issued a QR-coded wristband as shown in Figure 1. These wearers are placed under home quarantine or hospital quarantine and are

required to report their situation by scanning their wristband's QR code via mobile apps. Despite being required to report their location twice daily, this Standard Operating Procedure (SOP) does not provide real-time location information of the wearers and does not alert the authority if the PUI leaves the quarantine stations, as happened before (refer to Figure 2).

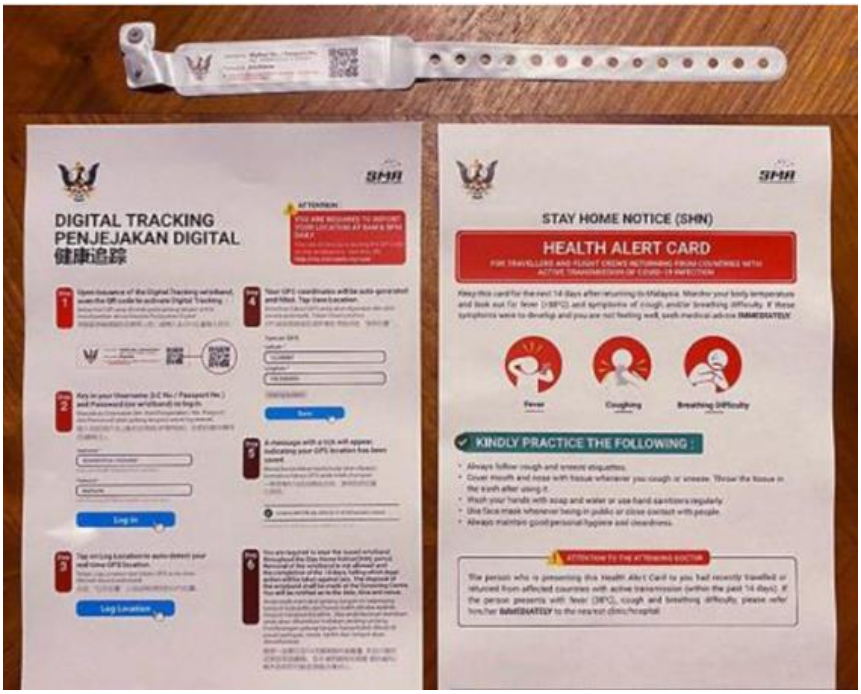


Figure 1. Sarawak rolls out QR wristbands to monitor quarantined people

Figure 2. PUI's cut off QR wristbands to go out

To curb the spread of the COVID-19 outbreak, Malaysian Government has decided which effective from 10 June 2020, all Malaysian citizens and non-citizens who had the permissions to enter Malaysia should undergo a mandatory self-quarantine period of 14 days upon arrival. Monitoring of the health progress will be made through MySejahtera application by submitting the health self-assessment throughout the 14 days. However, MySejahtera application is limited to self-health monitoring only and not supporting a continuous monitoring system including real time location of the users. Continuous monitoring is essential today as it constantly monitors for any threats, security misconfigurations or other vulnerabilities. Since home quarantine permitted due to low infection, now the PUS is all over Malaysia.

Without a real-time monitoring system, this will increase the workload of the authorities to monitor their movements.

2. Objective

The objectives of the project are as follows:

a) To integrate the sensors with single board medium performance of mini-computer for long range monitoring and with the application of Internet of Things (loT) and cloud technology.

b) To develop a new solution of PUI or PUS monitoring and detection using FSS RFID wristband prototype.

c) To test and verify the FSS RFID wristband with the RFID reader to ensure its ability to read the user's location in the quarantine stations.

d) To develop a web-based system for security and monitoring of RFID FSS, for measurement and validation.

e) To install the RFID full integrated system at *Pusat Kuarantin dan Rawatan* COVID-19 (PKRC), for PoC and validation.

f) To implement the proposed of FSS RFID wristband prototype with cloud database, that offers the possibility of highly secure monitoring services for the next waves of COVID-19.

3. Target groups and benefits

No.	Target groups	Benefits
1	Person in charge (PIC) at the PKRC	a) Easily to improve current monitoring technique through the real-time monitoring system. b) Help PIC to receive the accurate information related to inflow and outflow patients. c) Help PIC to receive alerts on multiple devices even on personal mobile phone.
2	Government authorities related to COVID-19 Centres for Disease Control and Prevention (CDC)	a) More efficient on taking action once receive alerts from the centralised system. b) Reduce human resources by replaced the securities at the access of the PKRC.
3	Ministry of Health	a) Easily to provide report with the data export feature integrated on the COVID-19 Monitoring System. b) Analyse the data from the report to strategies the execution of the Movement Control Order (MCO). c) Understanding the overall developed system features and functionalities to be implemented at other suitable facilities.
4	Researchers	a) Help the researchers to enhance the developed system from time to time. b) Analyse the result to provide more solutions on RFID technology.

4. Scope of work

The site selected for this project was PKRC under supervision of Hospital Tuanku Fauziah, Perlis at Kolej Jururawat Masyarakat (KJM), Kangar Perlis. This site is selected because of the infrastructure of KJM meet the project infrastructure requirements as well as meet the requirements of the project validation activities. The duration of this PoC is for 12 months starting 01 March 2022.

Validation exercise was conducted here as well.

The scope of work includes:

a) Design and development of disposable FSS RFID wristband using simulator tools CST MICROWAVE STUDIO including fabrication and measurement.

b) Design and integration of the FSS RFID wristband and sensors with RFID reader by using the Single-Board Computer (SBC). The phase where all hardware was programmed with Phyton language on the SBC using several modules and protocols.

c) Design and development of Graphical User Interface (GUI) for monitoring purposes on IoT web based. By using Visual Studio software, the GUI was developed to communicate and retrieve the data from the SBC.

d) Perform system testing and project implementation at KJM. Full system developed are installed and tested as well as practiced with the PIC of the PKRC.

5. Methodology

Figure 3 illustrate the overall process and activities on this development project. There are 4 main phases, which are:

a) Phase 1: Development of Wearable Metamaterial UHF RFID Tag Antenna (FSS RFID wristband).

b) Phase 2: Development of RFID Reader Infrastructure.

c) Phase 3: Development of User-Interface Management System.

d) Phase 4: Full Run Testing, Commissioning and Validation.

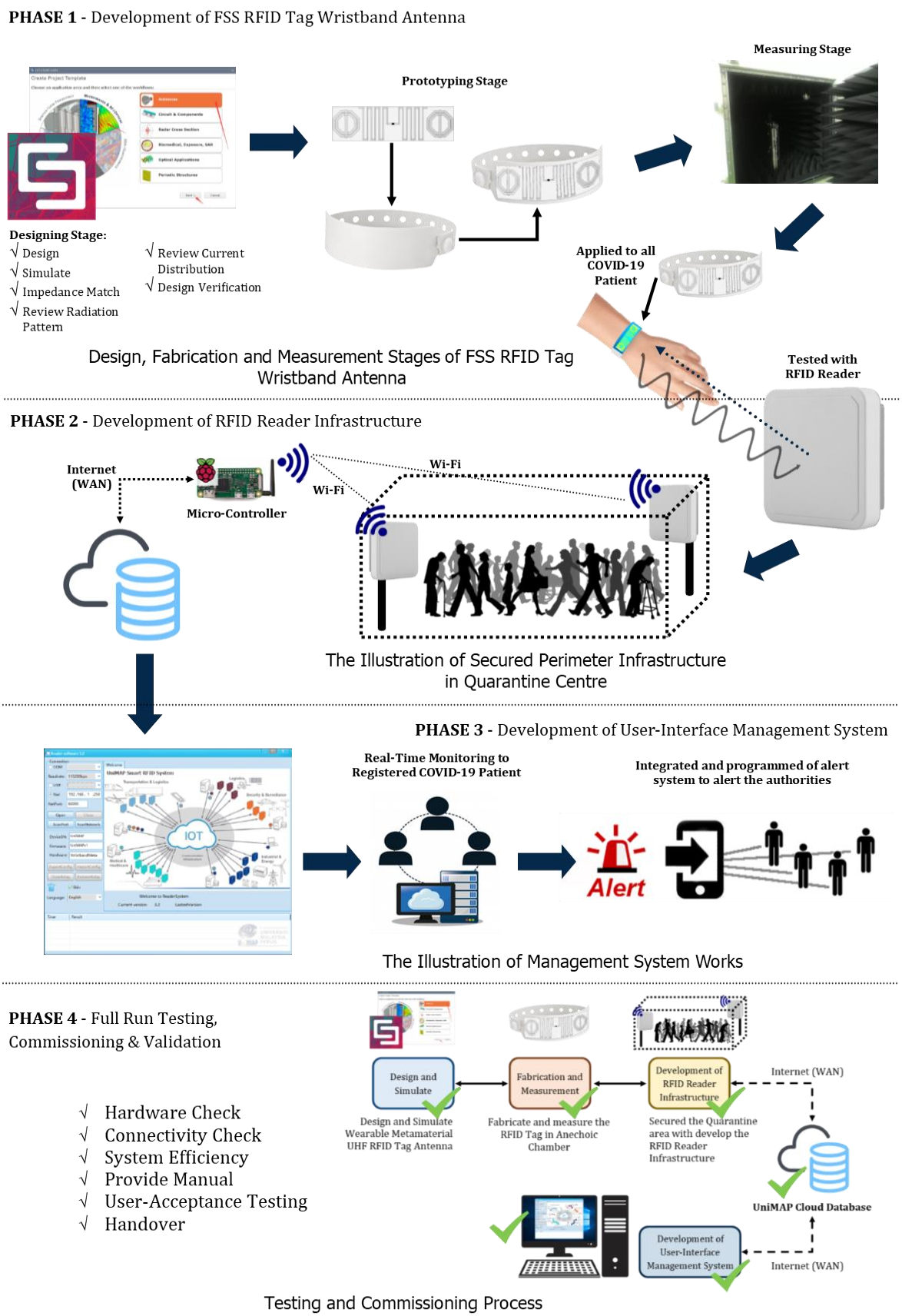


Figure 3. The overview of full illustration of the project development

5.1 Phase 1 - Development of Wearable Metamaterial UHF RFID Tag Antenna (FSS RFID wristband)

Study on RFID Tag for wearable application.

The 3 types of RFID are active RFID, passive RFID and semi-passive RFID. The summary of comparison is shown in the Table 1.

Table 1. Comparison between active RFID, passive RFID and semi-passive RFID

Features	Active RFID	Passive RFID	Semi-passive RFID
Lifetime	Limited by battery	Unlimited	Limited by battery-assisted and tag life
Power reliability	Continual	Reader anywhere within the area	Only external battery
Signal intensity to tag available	Low in scale	Large Scale	Moderate of (does not need to power tag, but need power backscatter)
Battery tag	Yes	No	Yes
Tag power base	External with tag	Triggered by RFID Reader via RF	Triggered by RFID Reader via RF
Read distance	Up to 100 metres	Up to 6 metres	Up to 100 metres
Functionality of sensor	Continuous sensor tracking and monitoring	Read and pass sensor information when the reader is powered by the tag	Capability to read and pass sensor values only when the tag receives a reader's RF signal
Storage capacity	Large	Small	Large
Cost	Expensive	Reasonable	Affordable

Based on summary of comparison above, the Passive RFID was selected as the disposable FSS RFID wristband, no battery needed, it can be powered by RFID reader and at reasonable cost. There are several design specifications to be considered as shown in Table 2.

Table 2. Design specification

Item	Design specification
Type of antenna	Passive RFID antenna
Frequency band for Malaysia	919 MHz to 923 MHz
Operating frequency	921 MHz
Efficiency	>80%
Radiation pattern	Omni-Directional
Realised gain	Positive Value (dB)
Physical profile	Small, low profile and compact

Besides design specification, the material properties also need to be identified in this development phase as shown in Table 3.

Table 3. RFID Wristband Antenna Material Properties

Parameter	Specifications
Substrate	Kodak Photo paper
Substrate Thickness	0.254 mm
Dielectric Constant	2.85
Conductive	Silver Trace
Reflection Coefficient S11	< -10 dB
RFID Chip	NXP SL3S1213 UCODE G2iL

The antenna design activities of FSS RFID Wristband are described in Figure 4.

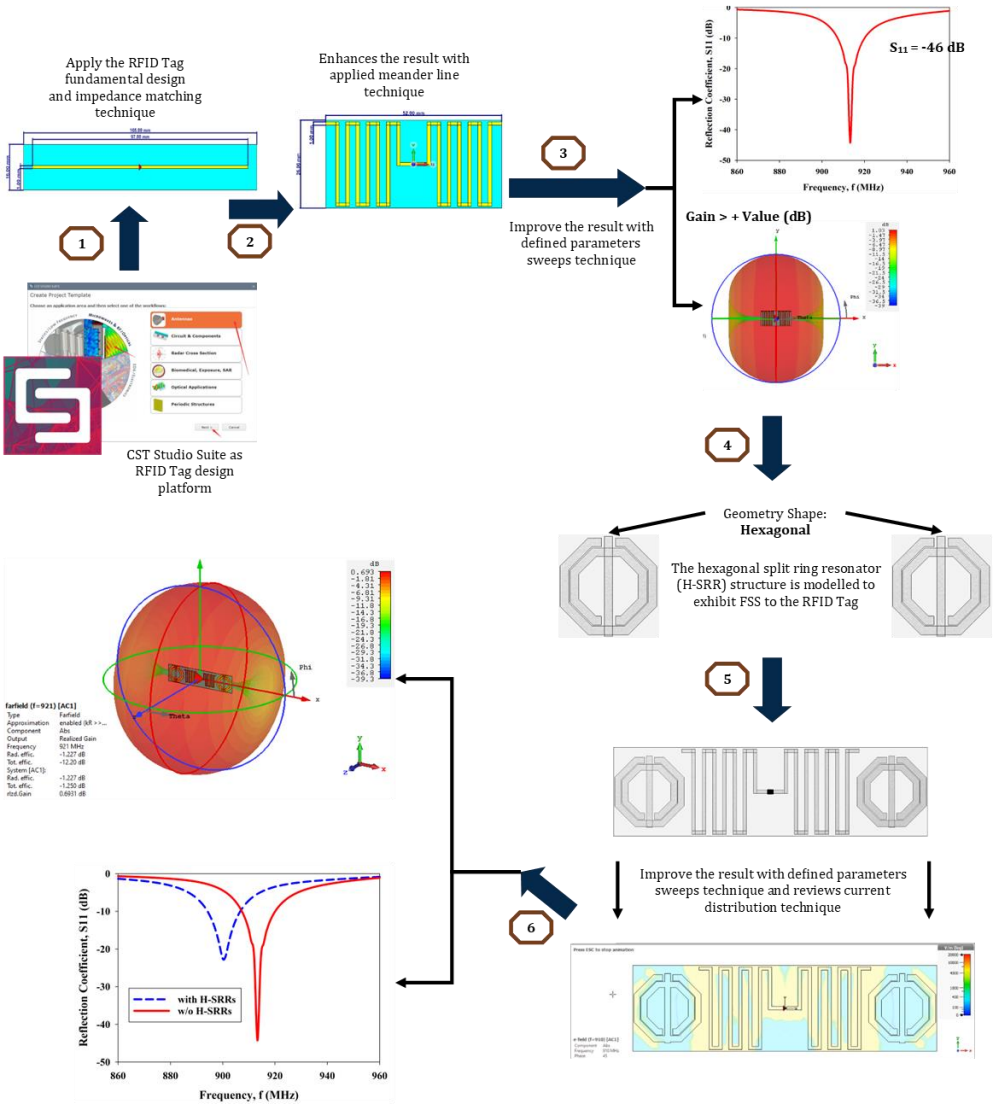


Figure 4. The FSS RFID Wristband antenna development activities

Flowchart of the overall FSS RFID Wristband development is shown in Figure 5.

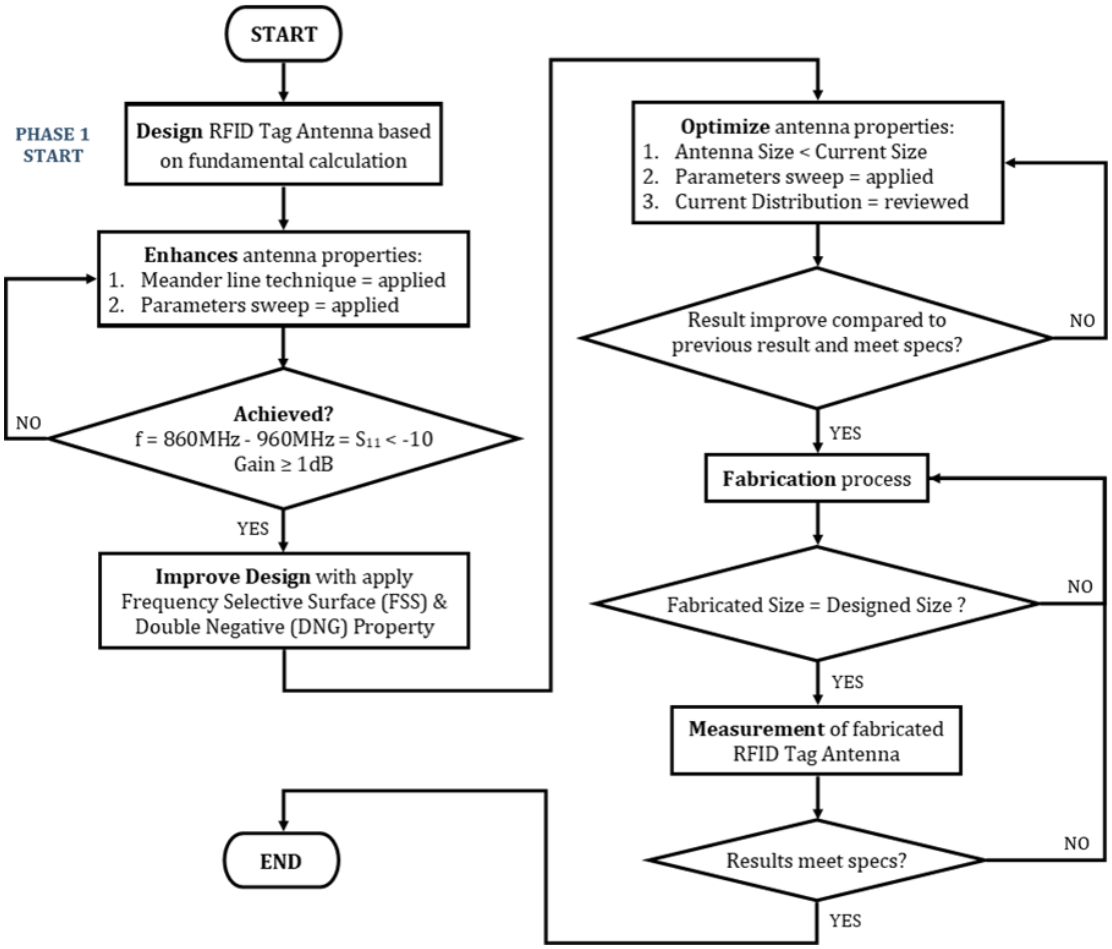


Figure 5. The flowchart of the FSS RFID Tag design and development activities

The fabrication process or Step E is shown in Figures 6 and 7 below, the process was arranged from setting the printing scale and dimension based on simulated design dimension until the printed RFID antenna seal in the FSS wristband tag.

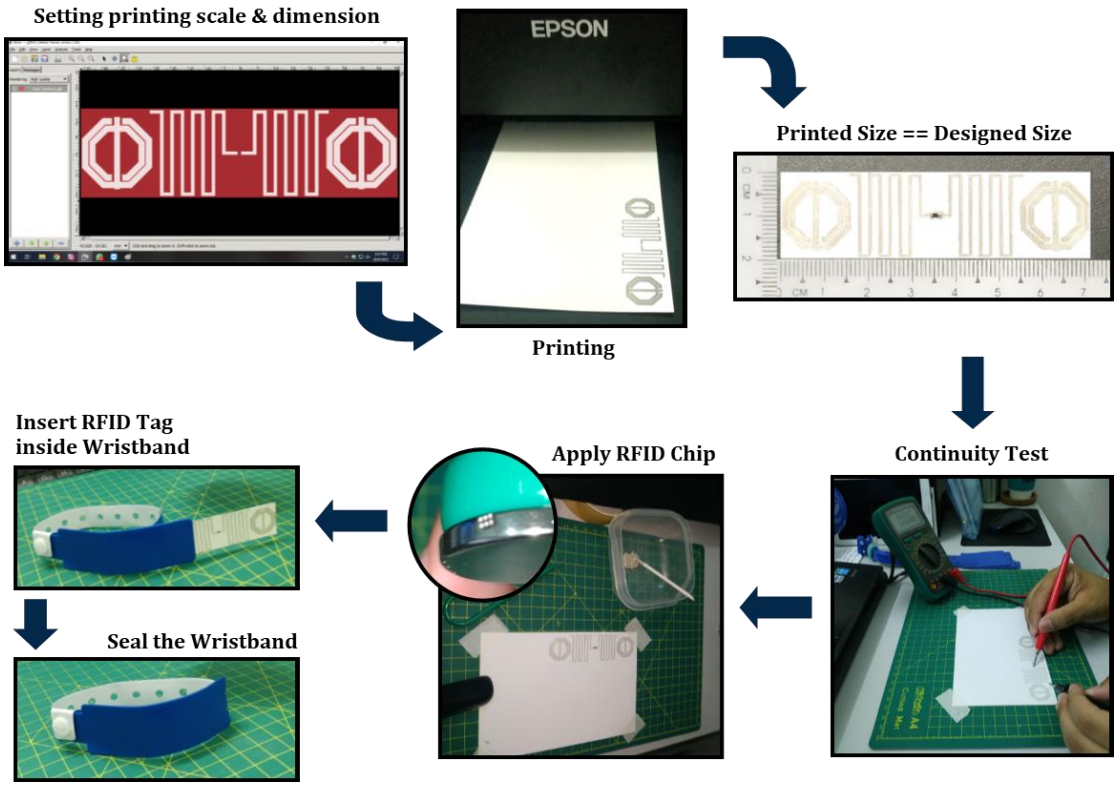


Figure 6. The fabrication activities of the FSS RFID Wristband

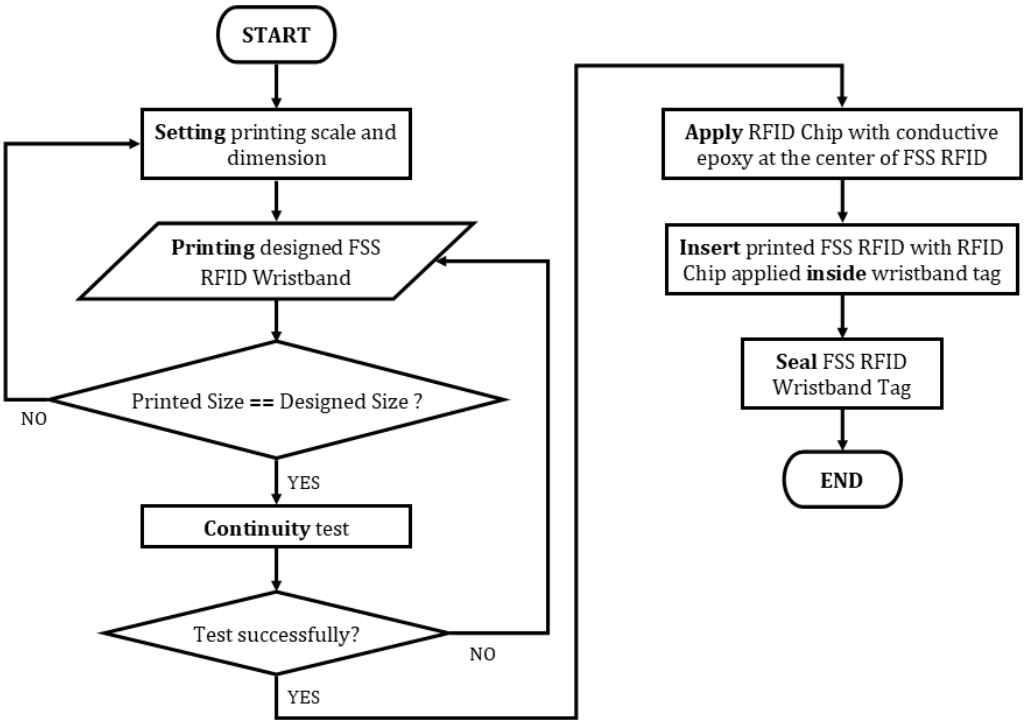


Figure 7. The flowchart of the fabrication process

a) Design and analysis of the RFID Tag Antenna

Refer to Figure 8, after applying the RFID tag fundamental design, there are several processes of design analysis with parameters sweep technique. Following figure is the part of the design transformation after made the design analysis. Besides design analysis, current distribution on antenna field surfaces also been analysed to produce the final design and meet the expected result outcome.

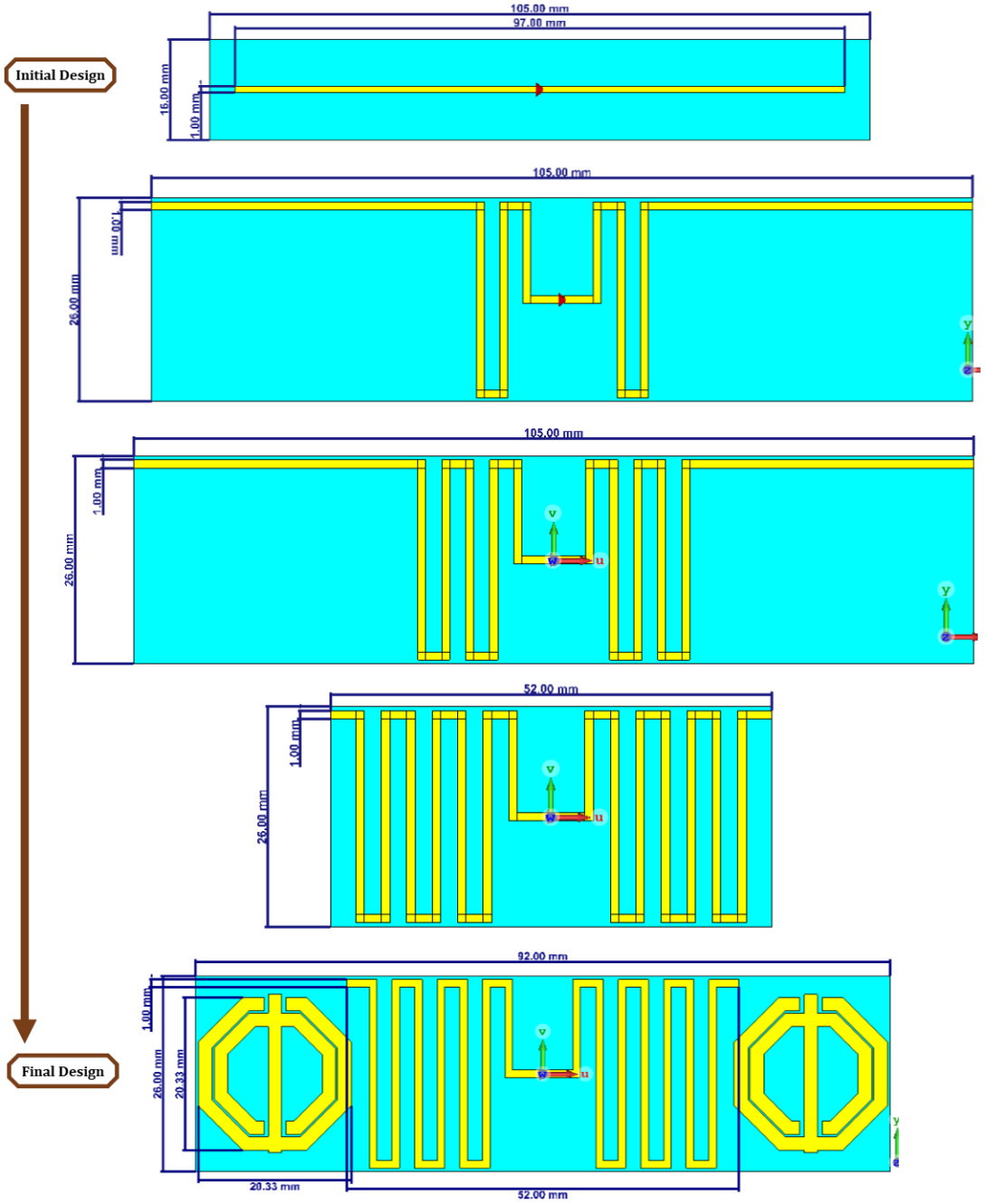


Figure 8. FSS RFID Wristband Antenna design transformation

Figure 8 demonstrated the final step which was the measurement of the fabricated FSS RFID Wristband with the Vector Network Analyzer (VNA) and RFID Reader.

Figure 9 shows the flowchart of the measurement process.

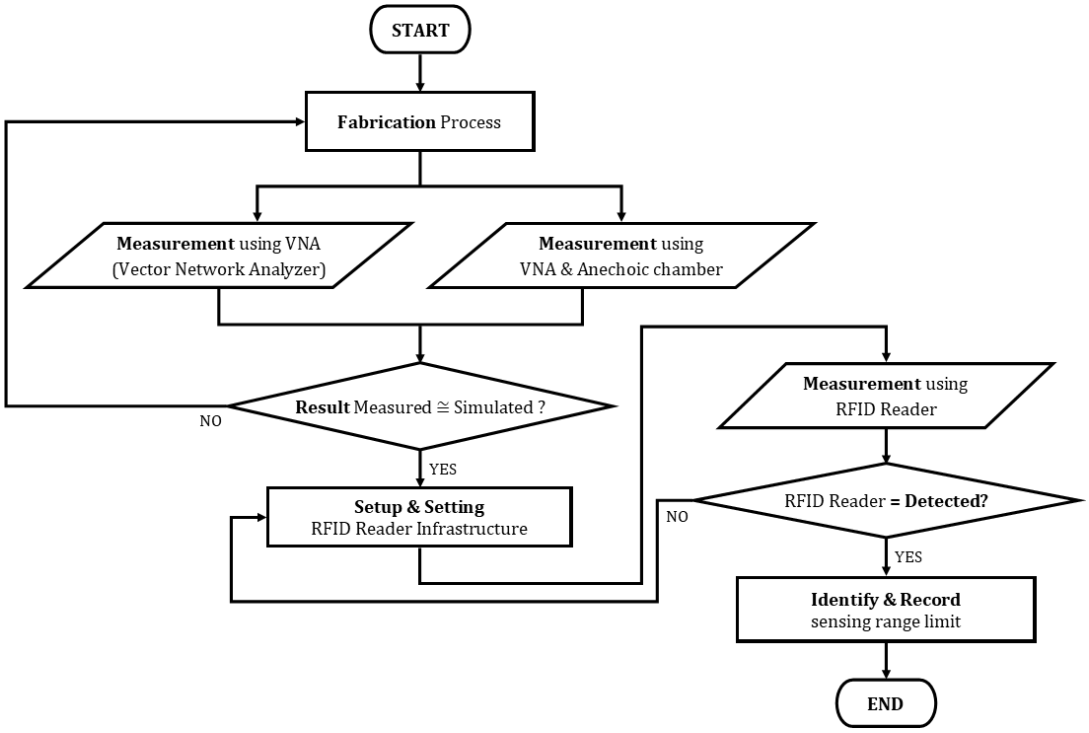


Figure 9. The flowchart of the measurement process

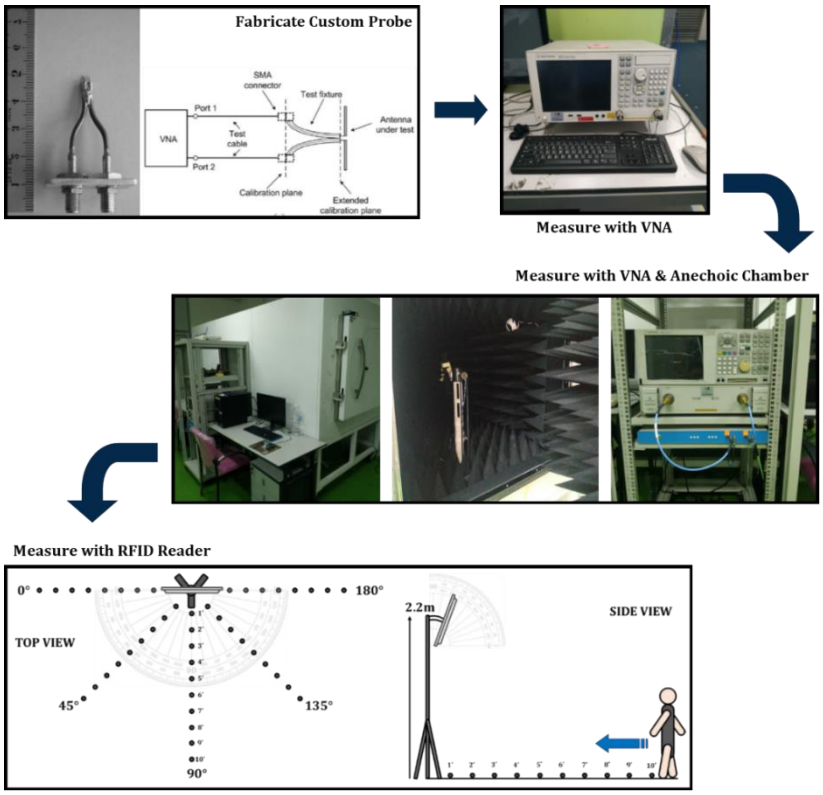


Figure 10. The measurement activities of the fabricated FSS RFID Wristband

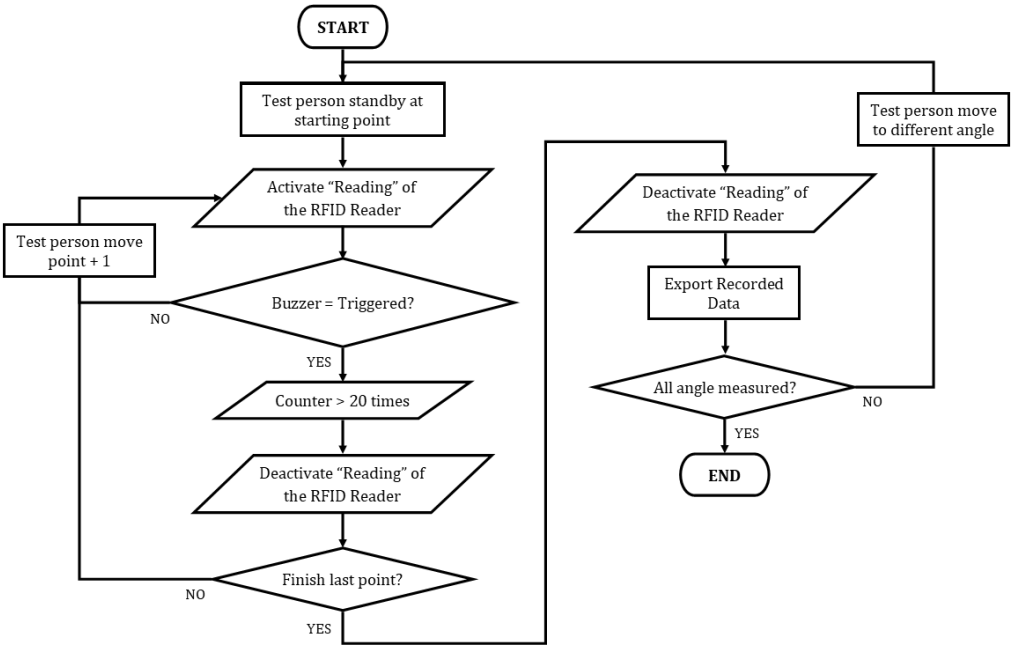


Figure 11. The flowchart of the measurement with RFID Reader

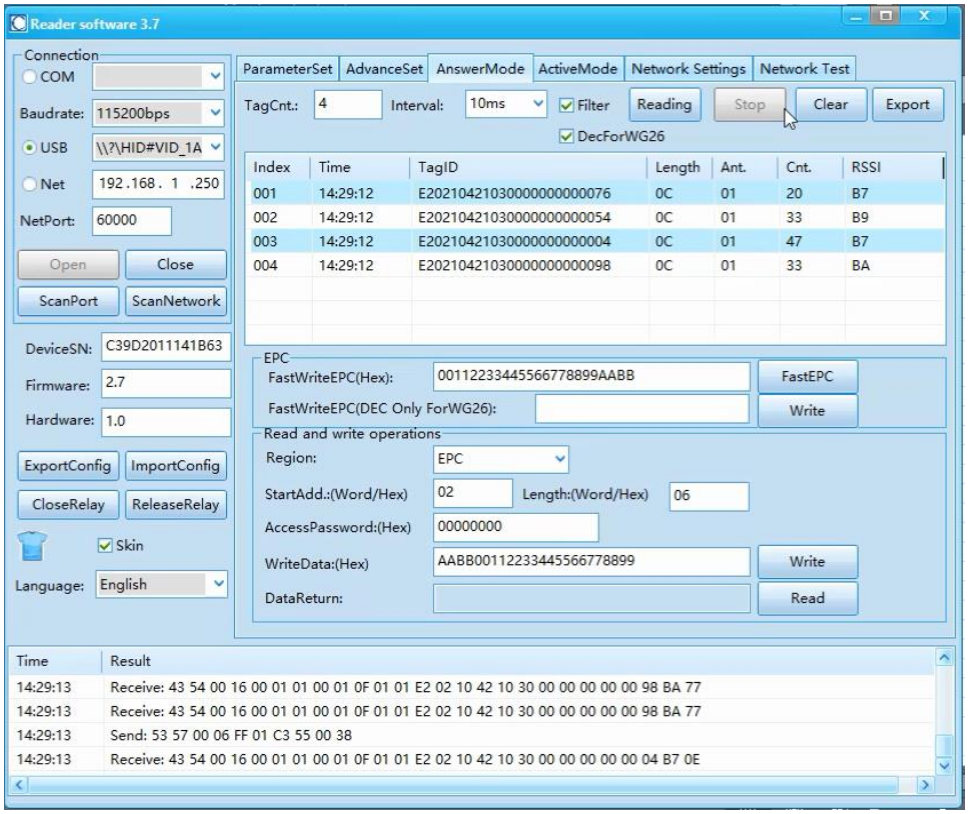


Figure 12. Reading page of the RFID Reader software

The measurement of RFID reader used to determine the limitation of the RFID reader performance. The RFID reader was placed with several degrees such as 0°, 45°, 90°, 135°, and 180°. The measurement was also tested with different of length in feet from 0 until 10 feet for every single angle. The RSSI in column G of Tables 4 until 8 is the received signal strength Indicator used to indicate the

minimum and maximum of receiving signal can be determined from RFID reader to the FSS RFID Wristband

Table 4. The exported data of the 0-degree angle

	A	B	C	D	E	F	G
1	0 Degree						
2	**Label**	**Time**	**TagID**	**Length**	**Ant**	**Cnt**	**RSSI**
3	A1	14:01:27	E2021042103000000000000098	17	01	12	1B
4	A1	14:01:58	E2021042103000000000000098	32	01	18	24
5	A1	14:02:16	E2021042103000000000000098	48	01	07	5B
6	A1	14:02:33	E2021042103000000000000098	69	01	26	9B
7	A1	14:02:57	E2021042103000000000000098	82	01	34	A1
8	A1	14:03:19	E2021042103000000000000098	95	01	32	B0
9	A1	14:03:24	E2021042103000000000000098	AF	01	19	63
10	A1	14:03:41	E2021042103000000000000098	C8	01	17	3E

Table 5. The exported data of the 45-degree angle

	A	B	C	D	E	F	G
1	45 Degree						
2	**Label**	**Time**	**TagID**	**Length**	**Ant**	**Cnt**	**RSSI**
3	A2	14:08:29	E2021042103000000000000054	18	01	11	35
4	A2	14:08:51	E2021042103000000000000054	33	01	15	42
5	A2	14:09:10	E2021042103000000000000054	49	01	13	6A
6	A2	14:09:30	E2021042103000000000000054	6A	01	29	8F
7	A2	14:09:57	E2021042103000000000000054	83	01	37	93
8	A2	14:10:09	E2021042103000000000000054	96	01	35	96
9	A2	14:10:15	E2021042103000000000000054	B0	01	41	9E
10	A2	14:10:25	E2021042103000000000000054	C9	01	44	A0

Table 6. The exported data of the 90-degree angle

	A	B	C	D	E	F	G
1	90 Degree						
2	**Label**	**Time**	**TagID**	**Length**	**Ant**	**Cnt**	**RSSI**
3	A3	14:13:34	E2021042103000000000000004	19	01	07	1E
4	A3	14:13:50	E2021042103000000000000004	33	01	11	23
5	A3	14:14:12	E2021042103000000000000004	4D	01	19	C7
6	A3	14:14:37	E2021042103000000000000004	66	01	29	D6
7	A3	14:14:59	E2021042103000000000000004	7F	01	37	DA
8	A3	14:15:11	E2021042103000000000000004	99	01	35	DC
9	A3	14:15:29	E2021042103000000000000004	B2	01	41	D9
10	A3	14:15:41	E2021042103000000000000004	CC	01	44	B7
11	A3	14:15:57	E2021042103000000000000004	E4	01	25	B4
12	A3	14:16:18	E2021042103000000000000004	FB	01	29	BA

Table 7. The exported data of the 135-degree angle

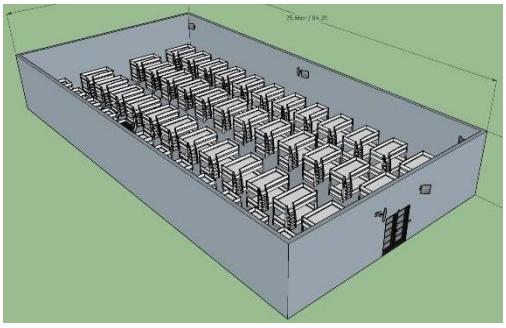
	A	B	C	D	E	F	G
1	135 Degree						
2	**Label**	**Time**	**TagID**	**Length**	**Ant**	**Cnt**	**RSSI**
3	A4	14:17:31	E2021042103000000000000076	19	01	11	5E
4	A4	14:17:42	E2021042103000000000000076	34	01	19	61
5	A4	14:18:25	E2021042103000000000000076	4A	01	34	9A
6	A4	14:18:37	E2021042103000000000000076	6B	01	12	23
7	A4	14:19:35	E2021042103000000000000076	84	01	38	C5
8	A4	14:19:51	E2021042103000000000000076	93	01	36	C8
9	A4	14:20:27	E2021042103000000000000076	AD	01	42	D0
10	A4	14:20:45	E2021042103000000000000076	C6	01	42	D2

Table 8. The exported data of the 180-degree angle

	A	B	C	D	E	F	G
1	180 Degree						
2	**Label**	**Time**	**TagID**	**Length**	**Ant**	**Cnt**	**RSSI**
3	A5	14:25:29	E2021042103000000000000077	18	01	09	37
4	A5	14:25:42	E2021042103000000000000077	33	01	15	3B
5	A5	14:25:57	E2021042103000000000000077	49	01	18	40
6	A5	14:26:12	E2021042103000000000000077	6D	01	25	A0
7	A5	14:26:35	E2021042103000000000000077	86	01	33	AC
8	A5	14:26:55	E2021042103000000000000077	99	01	11	46
9	A5	14:27:17	E2021042103000000000000077	AC	01	15	4E
10	A5	14:27:35	E2021042103000000000000077	C5	01	19	5C

5.2 Phase 2 - Development of RFID Reader Infrastructure

This phase is related with the RRIS where these RRIS was designed based on the existing PKRC in Malaysia. Design A is suitable for a hall or spacious room and Design B is suitable for a dorm or small room (refer following example of the PKRC shown in Figure 13.



Design A

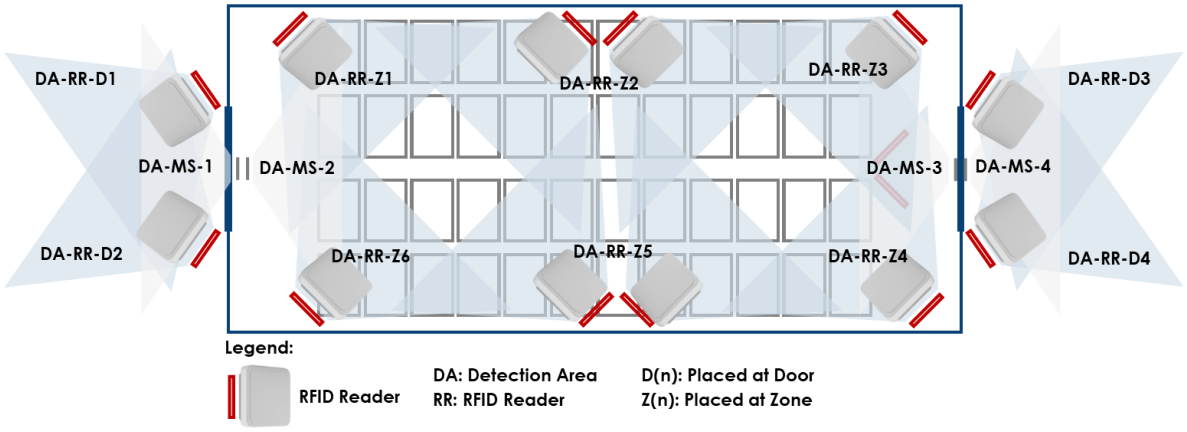
Design B

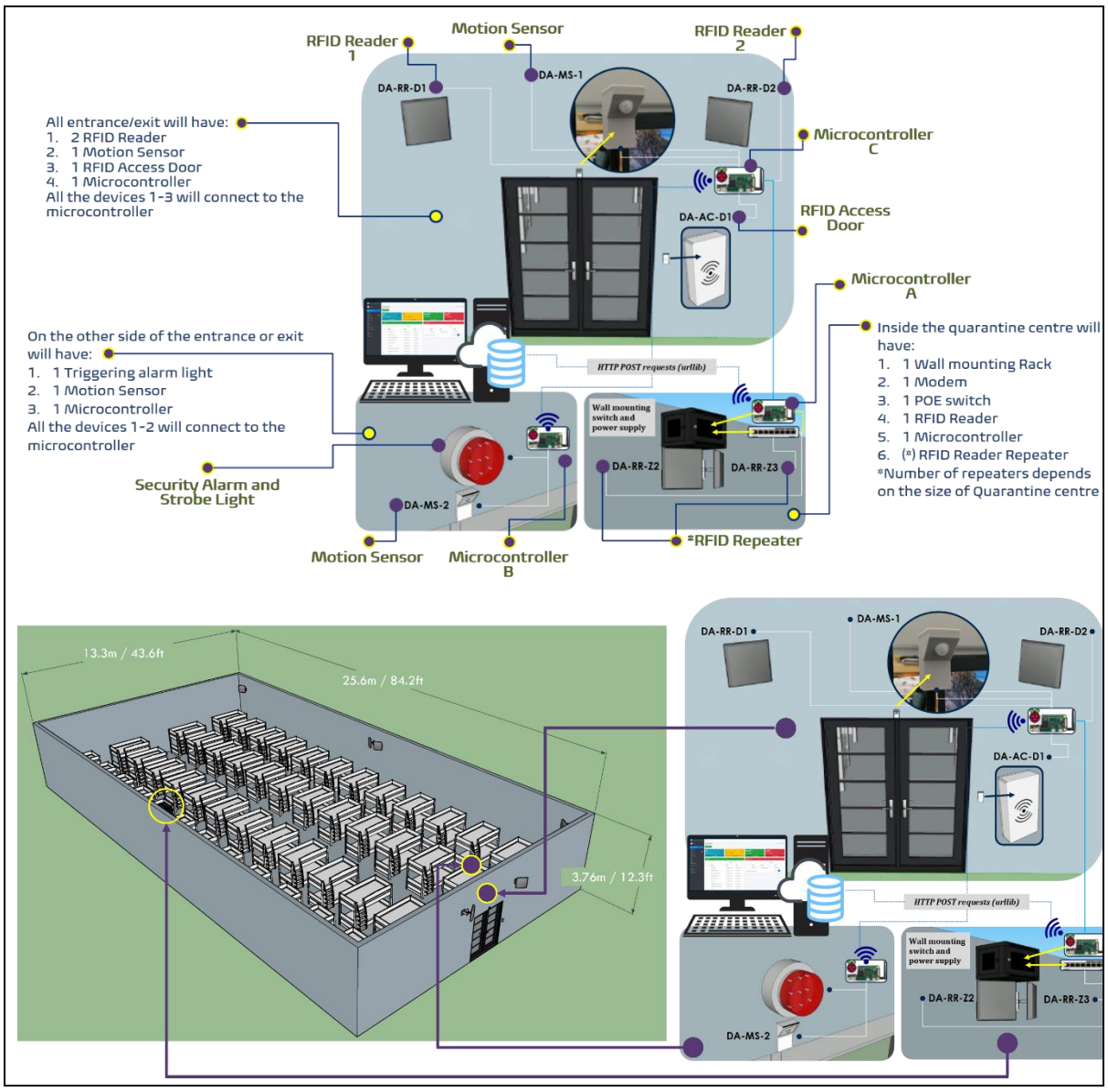
Figure 13. Left image is the PKRC Design A and right image is the PKRC Design B

a) RFID Infrastructure study and analysis

Based on the study of the RRIS, hardware setup and installation are shown in Figure 14.

Design A




RFID Reader 1
Motion Sensor
RFID Reader 2
DA-RR-D1
DA-MS-1
DA-RR-D2
All entrance/exit will have:
1. 2 RFID Reader
2. 1 Motion Sensor
3. 1 RFID Access Door
4. 1 Microcontroller
All the devices 1-3 will connect to the microcontroller
Microcontroller C
DA-AC-D1
RFID Access Door
Microcontroller A
Inside the quarantine centre will have:
1. 1 Wall mounting Rack
2. 1 Modem
3. 1 POE switch
4. 1 RFID Reader
5. 1 Microcontroller
6. (*) RFID Reader Repeater
*Number of repeaters depends on the size of Quarantine centre
HTTP POST requests (urllib)
Wall mounting switch and power supply
DA-RR-Z2
DA-RR-Z3
On the other side of the entrance or exit will have:
1. 1 Triggering alarm light
2. 1 Motion Sensor
3. 1 Microcontroller
All the devices 1-2 will connect to the microcontroller
Security Alarm and Strobe Light
DA-MS-2
Motion Sensor
Microcontroller B
*RFID Repeater
13.3m / 43.6ft
25.6m / 84.2ft
3.76m / 12.3ft

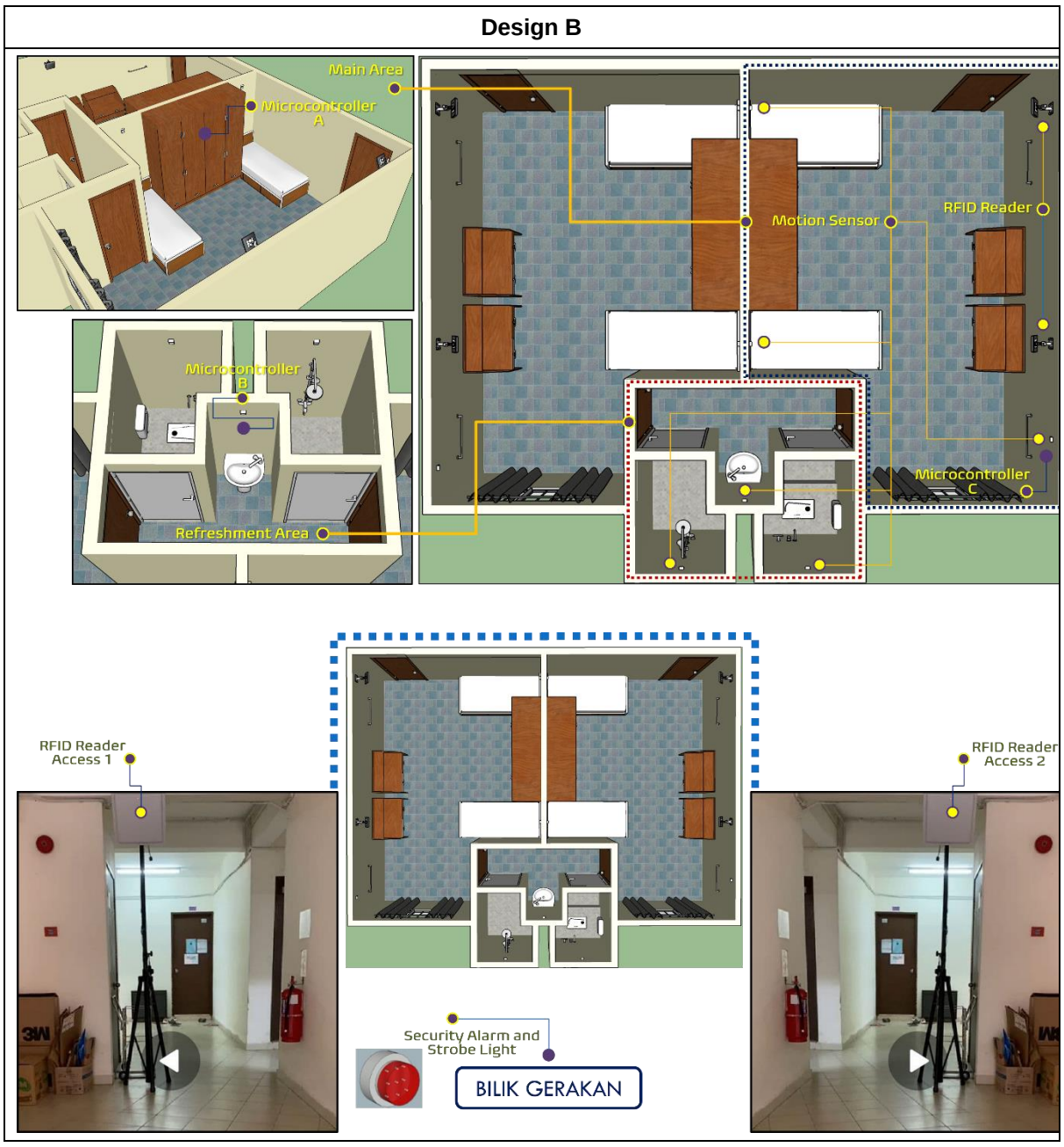


Figure 14. The hardware setup and installation for Design A and Design B

b) Hardware specification

The hardware used is based on their specification and performance testing result. Table 9 shows the specification of the hardware.

Table 9. The hardware specification details

No	Hardware	Specification
1	Groove Motion Sensor	• Voltage range: 3V - 5V • 2.0cm x 4.0cm twig module • Detecting angle: 120 degree • Detecting distance: max 6 m (3 m by default)
2	SBC (Raspberry Pi 3 B+)	• Processor Broadcom BCM2837B0, 64-bit ARM Cortex-A53 Quad Core Processor SoC running @ 1.4 GHz, with metal body for better heat dissipation. • 1GB LPDDR2 SDRAM • 4 x USB2.0 Ports with up to 1.2 A output • Expanded 40-pin GPIO Header • Video/Audio Out via 4-pole 3.5mm connector, HDMI, CSI camera, or Raw LCD (DSI) • Storage: MicroSD • Gigabit Ethernet over USB 2.0 (maximum throughput of 300 Mbps) • Power-over-Ethernet (PoE) support (requires separate PoE HAT) • 2.4 GHz and 5GHz IEEE 802.11.b/g/n/ac wireless LAN, Bluetooth 4.2, BLE • Low-Level Peripherals: • 27 x GPIO • UART • I2C bus • SPI bus with two chip selects • +3.3 V • +5 V • Ground • Power Requirement, 5 V / 2.5 A via Micro B USB connector. • Supports Raspbian, Windows 10 IoT Core, OpenELEC, OSMC, Pidora, Arch Linux, RISC OS • Dimensions: 85mm x 56mm x 17mm

Table 9. The hardware specification details *(continued)*

No	Hardware	Specification
4	Magnetic Door	• Holding force: 60 kg • Voltage input: 12 V DC, 280 mA to 300 mA. • Magnet dimension: 8 cm x 3.8 cm x 2.9 cm • Plate dimension: 7.5 cm x 3.3 cm x 1.1 cm
5	Buzzer	• Operating voltage: 2 - 6 V DC • PCB type • Diameter: 1.2c m
6	Strobe Light	• Height: 10 cm Diameter: 12.3 cm • Solar panels: 5 V 69 MA 53 * 53 MM • Solar charging light control mode, automatic flash at night, during the day and automatically turn off • Baoshan way: lights flash, the white flash of red and blue cross • Charge Time: 15 h or more
7	RFID Reader Long Range	• Frequency: 919 – 923 MHz • Protocol: ISO 18000-6C • Antenna: 12 dBi UHF antenna • Reading Distance: 10~15 m • Communication: WG26/34, RS-485/232, TCP/IP, Wi-Fi • Status indicator: Buzzer/LED light flashes • Power Supply: 12 V • Working Mode: Trigger mode • Working temperature: -20 ℃ ~ +70 ℃ • Dimension: 445 x 445 x 35 mm
8	RFID Reader Medium Range	• Frequency: 919 - 923 MHz • Protocol: ISO 18000-6C • Antenna: 8 dBi UHF antenna • Reading Distance: 6~10 m • Communication WG26/34, RS-485/232, TCP/IP, Wi-Fi • status indicator: Buzzer/LED light flashes • Power Supply: 12 V • Working Mode: Trigger mode • Working temperature: -20 ℃ ~ +70 ℃ • Dimension: 227 x 227 x 60 mm
8	RFID Reader Medium Range	• Frequency: 919 - 923 MHz • Protocol: ISO 18000-6C • Antenna: 8 dBi UHF antenna • Reading Distance: 6~10 m • Communication WG26/34, RS-485/232, TCP/IP, Wi-Fi • status indicator: Buzzer/LED light flashes • Power Supply: 12 V • Working Mode: Trigger mode • Working temperature: -20 ℃ ~ +70 ℃ • Dimension: 227 x 227 x 60 mm

Table 9. The hardware specification details *(concluded)*

No	Hardware	Specification
9	RFID Reader Desktop Version	• Frequency: 919 - 923 MHz • Protocol: ISO 18000-6C • Communication: USB and Wi-Fi • Built-in antenna: 1 dBi Antenna
10	Access Door Board	• Operating Current :13-26 mA/DC 3.3 V • Idle Current :10 - 13 mA/DC 3.3 V • Sleep Current: less than 80 uA • Peak Current: less than 30 mA • Operating Frequency: 13.56 MHz • Supported card types: mifare1 S50, mifare1 S70, mifare UltraLight, mifare Pro, mifare Desfire and mifare Classic • Environmental Operating Temperature: -20 - 80 degrees Celsius • Environmental Storage Temperature: -40 - 85 degrees Celsius • Relative humidity: relative humidity 5 % -95 % • Data transfer rate: maximum 10 Mbit/s • Size: RFID-RC522 Module:3.9 x 6 cm The Standard S50 Blank Card :8.5 x 5.4 cm • Diameter of S50 special-shaped card: 3.1(max)

5.3 Phase 3 - Development of User-Interface Management System

This phase is related with the GUI or also known as application or software. The GUI displays objects that convey information and represent actions that can be taken by the user. To real-time monitoring and localising the COVID-19 patients, the need to communicate with the SBC continuously and real-time. Besides monitoring and localising the patients, the system also will integrate with the alert features where system alert will be triggered the alarm and notify the authorities if there is a patient escaped without their permission. For the compatibilities feature, the system is compatible for all devices that have browser installed.

a) GUI design planning and study

Direction of the GUI development is the monitoring web-based system and has different role of the accessibility. The main role known as Admin were allocated at the Quarantine Centre Headquarters (PKRC HQ). Another role is the one who appointed to be as a Person in Charge (PIC) at the sub-PKRC. Figure 15 shows the proposed concept to be implemented.

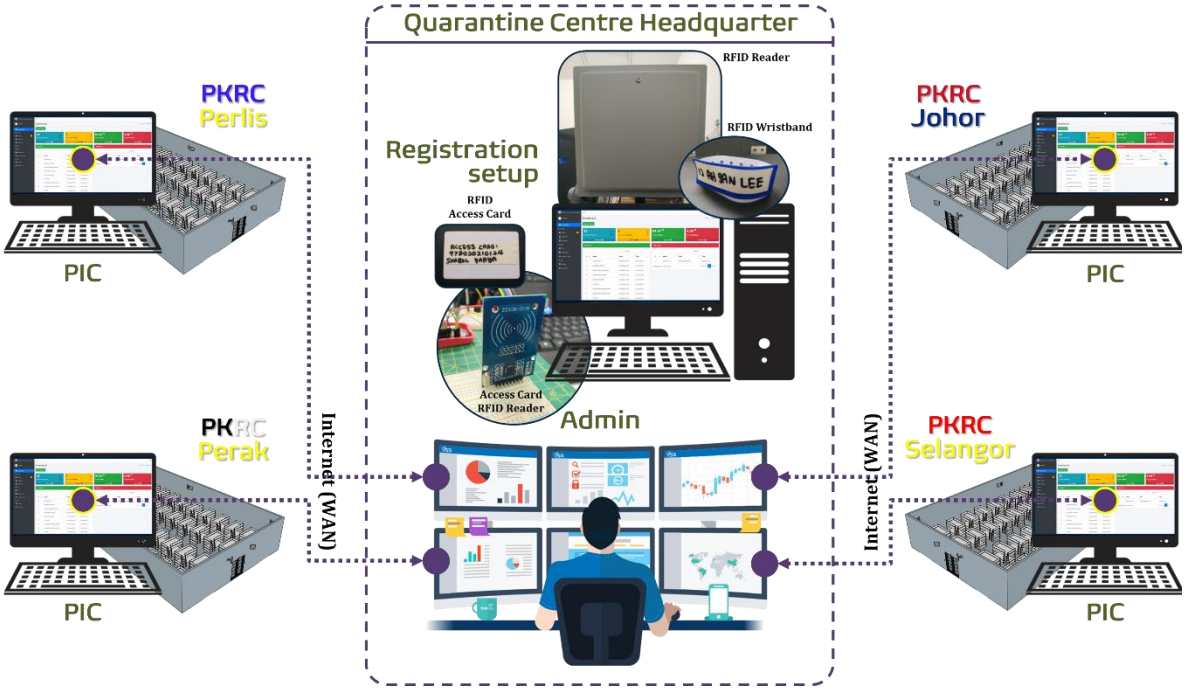


Figure 15. Direction of the GUI Development for RRIS

The reason role is divided into 2 roles which is Admin and PIC, because to reduce redundant data created, reduce the possibility for system error, give more focus to the PIC to monitor their patients, 2 level of alerts and security and reduce management procedure. Table 10 describe the main role for both roles created.

Table 10. Role Activity

Admin	Role Activity	PIC
O	Create the sub-PKRC	**X**
O	Register Access Card	**X**
O	Register PIC	**X**
O	Register Wristband	**X**
O	Register Patient	**O**
O * Receive alerts from all registered patients from all PKRC, in case the PIC un-noticed the alerts	Receive Alerts	**O** * Only can receive alerts from registered patients under his supervision
O * Can monitor from all registered patients from all PKRC	Monitor Patients	**O** * Only can monitor from registered patients under his supervision
O	Hardware Control	**X**
Legend: O = YES | X = NO | * = Notes		

5.4 Phase 4 - Full run testing, commissioning, and validation

a) Testing execution plan

There are 4 stages of testing, commissioning, and validation where in stage 1 is testing of the performance of the hardware part such as connection between RFID Tag and RFID Reader as well as connection between RFID Reader and SBC. Stage 2 is the connection between SBC and cloud database server. Stage 3 will be the expected results in GUI system applications and last stage is validation in User Acceptance Testing (UAT) and compliances through site visit outcome.

b) Testing flow process

For this phase for full run testing, commissioning, and validation, the PKRC type assigned is Design B (refer to Figure 14) but still the testing was conducted for Design A at the research laboratory. Figure 16 shows the block diagram of the testing activities for Design A. For the Design B, the different is only at Test C where the condition scenario is different.

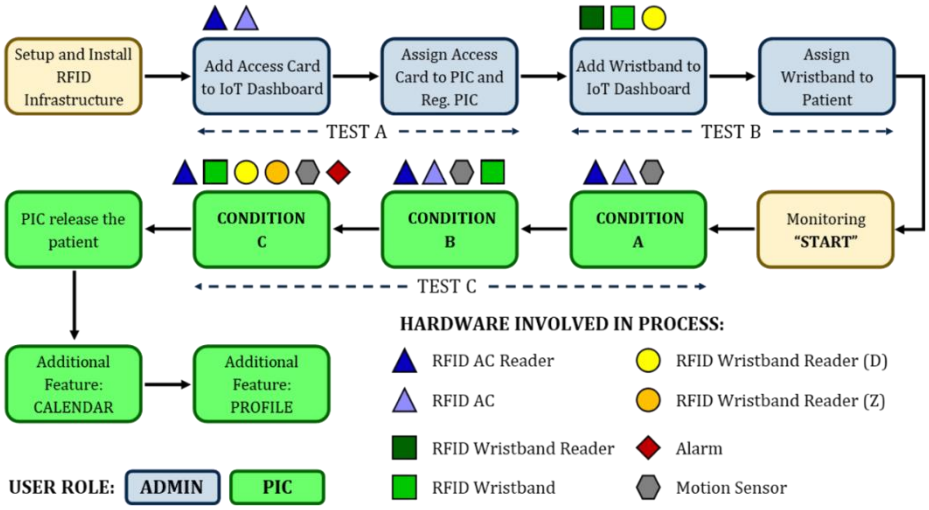


Figure 16. Block Diagram of the testing activities

6. Findings

6.1 Finding from Phase 1 - Development of Wearable Metamaterial UHF RFID Tag Antenna (FSS RFID wristband)

The comparison results between simulation and fabricated antenna shows in Figure 17.

a) Result measured with Vector Network Analyzer (VNA)

S11 (Reflection Coefficient)

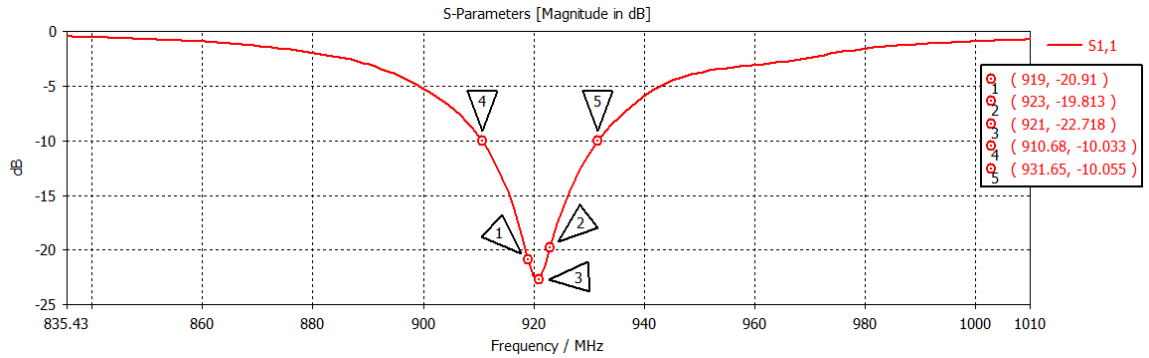


Figure 17 (a). S11 result for the simulated design

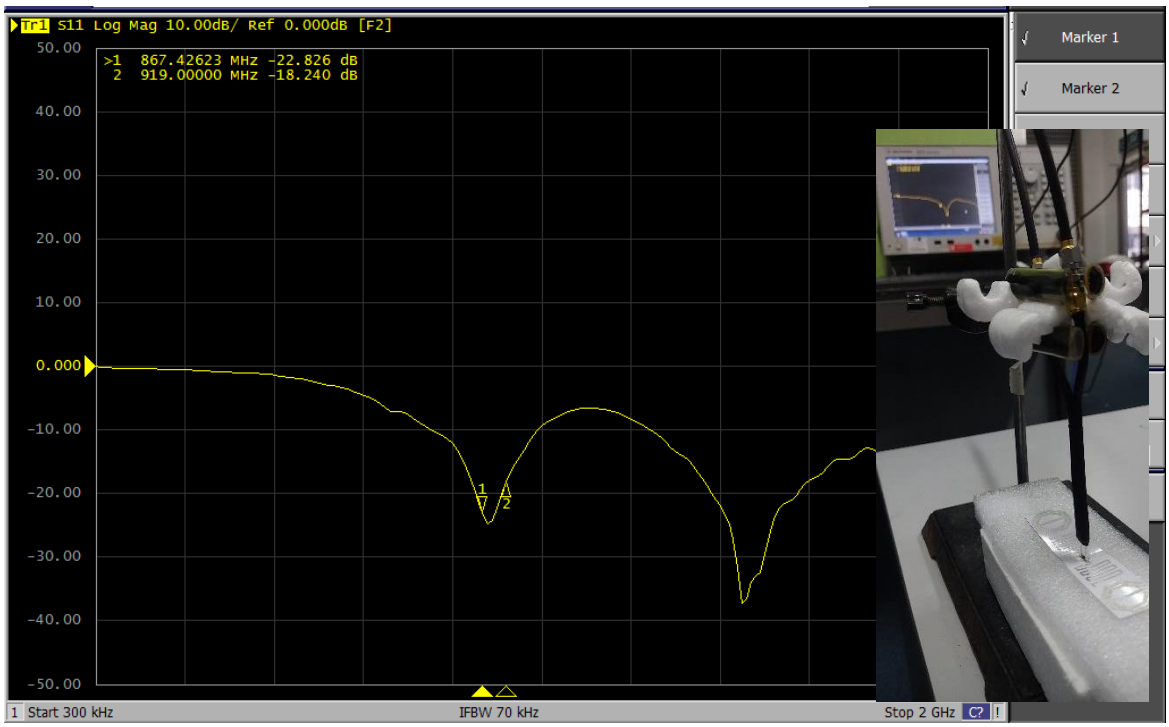


Figure 17 (b). S11 result for the fabricated antenna measured via VNA

Figure 17. Comparison results between simulation and fabricated antenna

The minimum value of the S11 or also known as reflection coefficient is -10 dB. As shown in Figure 17, from the result of the simulated design, the S11 value is -22.692 dB at 921 MHz and ranged captured below than -10 dB is from 910.68 MHz until 931.65 MHz. For the fabricated antenna measured via VNA, the S11 value are higher compared to the simulated design which is -19.876 dB and the ranged captured below than -10 dB also wider compared to the simulated design which from 845.54 MHz until 926.87 MHz. Both of the result, the antenna was successfully developed in frequency band of Malaysia

which in range from 919 MHz until 923 MHz. Although the antenna covers the frequency of other bands, it has been limited through the manufactured RFID reader.

b) Result measured with Anechoic Chamber
Farfield: Realized Gain

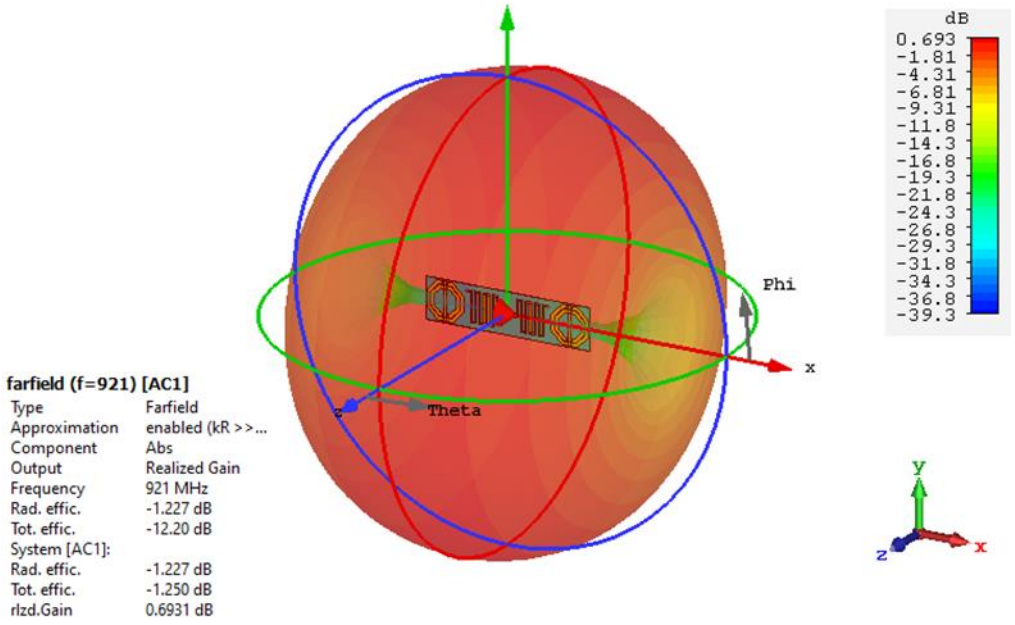


Figure 18 (a). Gain result for the simulated design

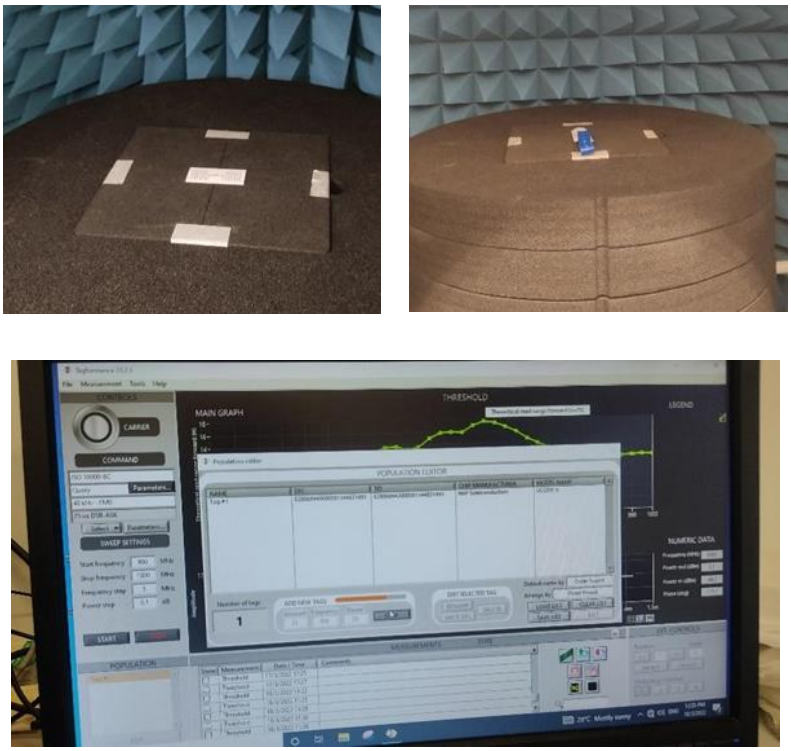


Figure 18 (b). Gain result for the fabricated antenna measured via Anechoic Chamber

Figure 18. Gain result for simulated design and fabricated antenna

Another antenna performance factor was measured is the realised gain where the goal of this factor is to produce antenna the gain in positive value. Figure 18 shows the result from the simulated design

with the value of the realised gain is 0.6931 dB at 921 MHz and the realised gain for the fabricated antenna measured via anechoic chamber is 1.371 at 921 MHz. Even if the realised value varies significantly, the crucial point is that the value remains positive and surpasses the realised gain value. This outcome is vital for achieving an improved transmitting signal from the antenna.

ANGLE (Degree °)	LENGTH (Feet')									
	1	2	3	4	5	6	7	8	9	10
0	X	X	X	O	O	O	X	X	-	-
45	X	X	X	O	O	O	O	O	-	-
90	X	X	X	O	O	O	O	O	O	O
135	X	X	O	X	O	O	O	O	-	-
180	X	X	X	O	O	X	X	X	-	-

Legend

X : Not Detected O : Detected - : Not Measured

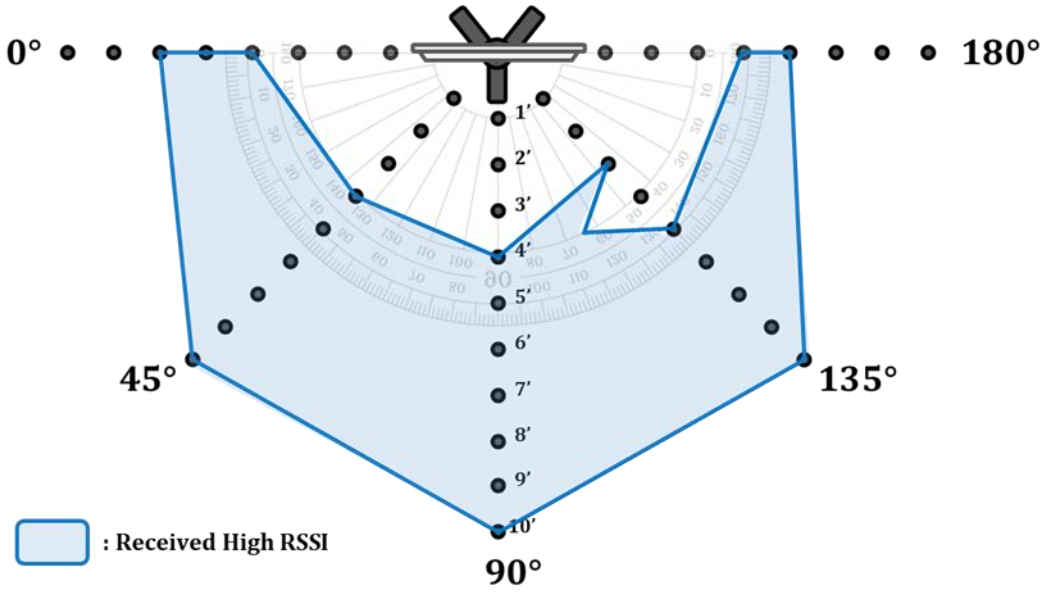


Figure 19. Result measured with RFID reader

Several testing and method were conducted to identify the optimum detection area (refer to Figure 19 and following figure). The optimum detection area was found with several criteria which there are:

a) Counter > 20 in 30 s reading with the 10 ms of interval
b) 78 < RSSI ≤ FF (RSSI reading number is in HEX Format)
c) RFID Reader Power = 26 dBm
d) Reader located at 2.0 m to 2.2 m
e) Reader angle 60° to 70°

6.2 Findings from Phase 2 – Development of RFID Reader Infrastructure

The connection setup testing result

Referring to Figure 20, every single connection of the hardware has been tested to make sure there is no bug or error existed. The test was start with Test A, Test B and Test C as explained below.

Test A - Access door and access card testing

The RFID access card to be used by PIC to access the door of the quarantine stations. The test was validated with two layers where the first layer (hardware test) test is reading output at General Purpose Input/Output (GPIO) of SBC and the second layer test (hardware and GUI test) is successfulness uploaded at display output at GUI. Referring to Figure 20 (b), at left side is the output for layer 1 and at right side is the output for layer 2.

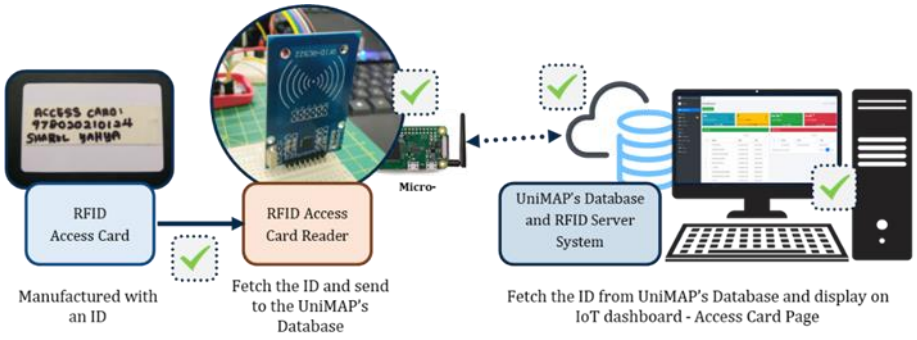


Figure 20 (a). The hardware

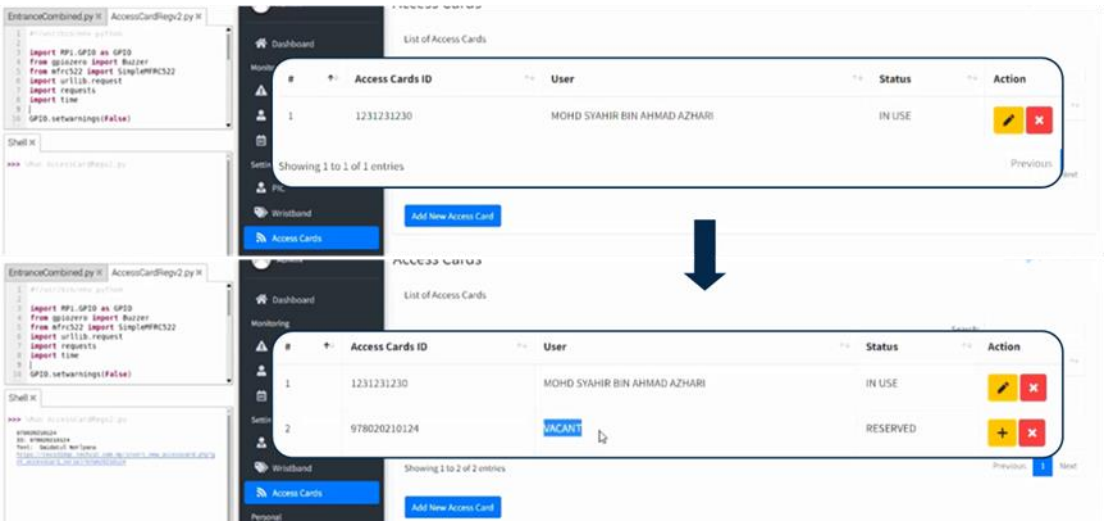


Figure 20 (b). The output for Layer 1 and 2

Figure 20. Testing result of the access card registration

Test B - FSS RFID wristband tested with the RFID reader long range, medium range, and desktop version.

The FSS RFID wristband to be used by patients at the during quarantine period before assign the wristband to the patient. The wristband must be uploaded to the IoT monitoring system portal. The test was validated with same as access card before, where has 2 layers of test. The first layer (hardware test) test is reading output at GPIO of mini-computer and the second layer (hardware and GUI test) test is successfulness uploaded at display output at GUI. Referring to first Figure 21 (b) is the output for layer 1 and Figure 21 (c) is the output for layer 2.

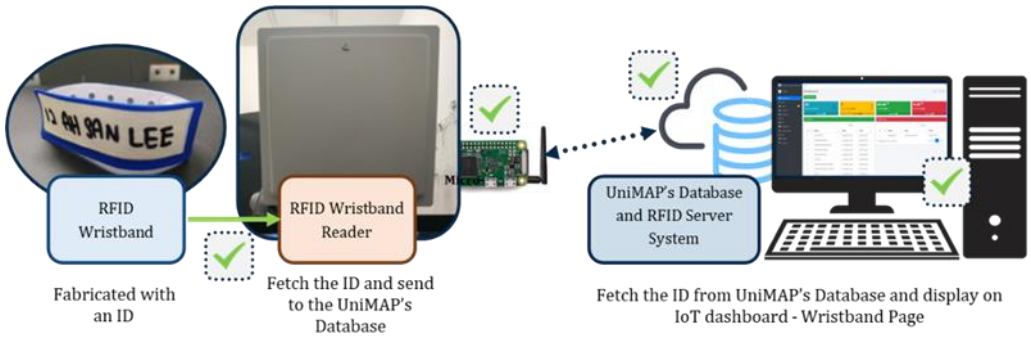


Figure 21 (a). The setup

Figure 21 (b). The output for Layer 1

Figure 21 (c). The output for Layer 2

Figure 21. Testing result of the FSS RFID wristband upload on the portal

Test C – run test with 3 conditions to proof the functionalities of the connection between installed hardware and IoT Monitoring System Portal.

All hardware shows in Figure 22 (a) and IoT monitoring system portal connection was tested with 3 conditions as referring to Figure 22 (b); Condition A (Left), B (middle) and C (right), the results was tabulated in Table 11 below.

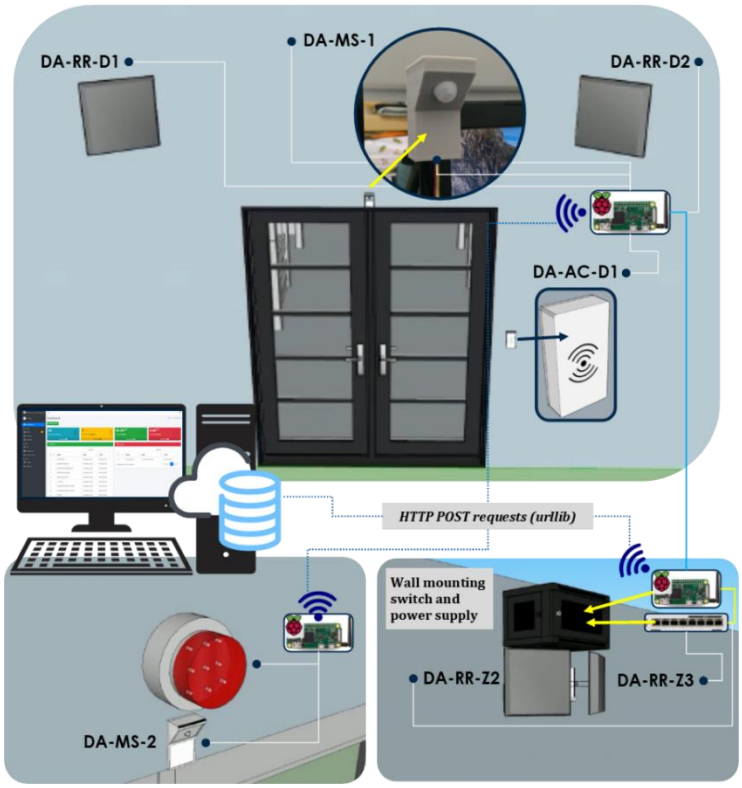
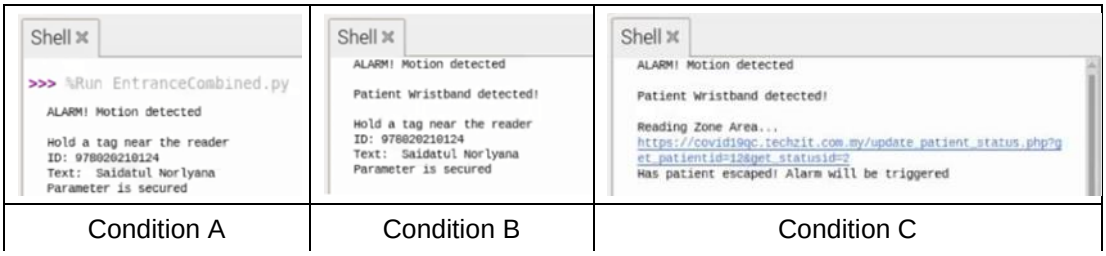


Figure 22 (a). The installed hardware and the IoT Monitoring System Portal

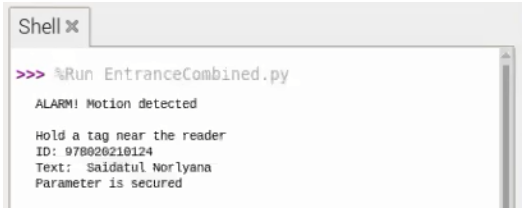
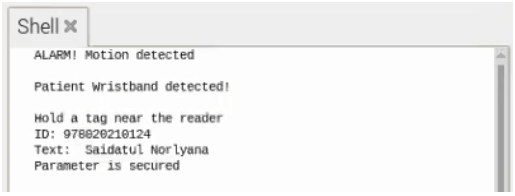


Condition A	Condition B	Condition C

Figure 22 (b). The 3 conditions

Figure 22. The proof the functionalities of the connection between installed hardware and IoT monitoring system portal

Table 11. The result with different conditions

Condition	Test result
Condition A: 	✓ Motion Detected ✓ PIC prompted to access with registered access card ✓ No interrupt for RFID Reader in The Zone needed ✓ No alarm, the parameter is secured
Condition B: 	✓ Motion detected ✓ Patient wristband detected ✓ PIC prompted to access with registered access card ✓ No interrupt for RFID Reader in The Zone needed ✓ No alarm, the parameter is secured ✓ The PIC may bring the patient wristband
Condition C: 	✓ Motion detected ✓ Patient wristband detected ✓ No prompted to access with registered access card ✓ Instantly interrupt the RFID Reader in The Zone to read the patients inside The Zone ✓ Lost registered wristband detected, alarm triggered

The quarantine stations previously were conducted in infrastructure of the hall, after some factors the quarantine stations was moved to infrastructure of the dorm. Because of these changes, additional components and sensors need to be added such as 6 motion sensors, 3 SBC and middle-range RFID reader as shown in Figure 23.

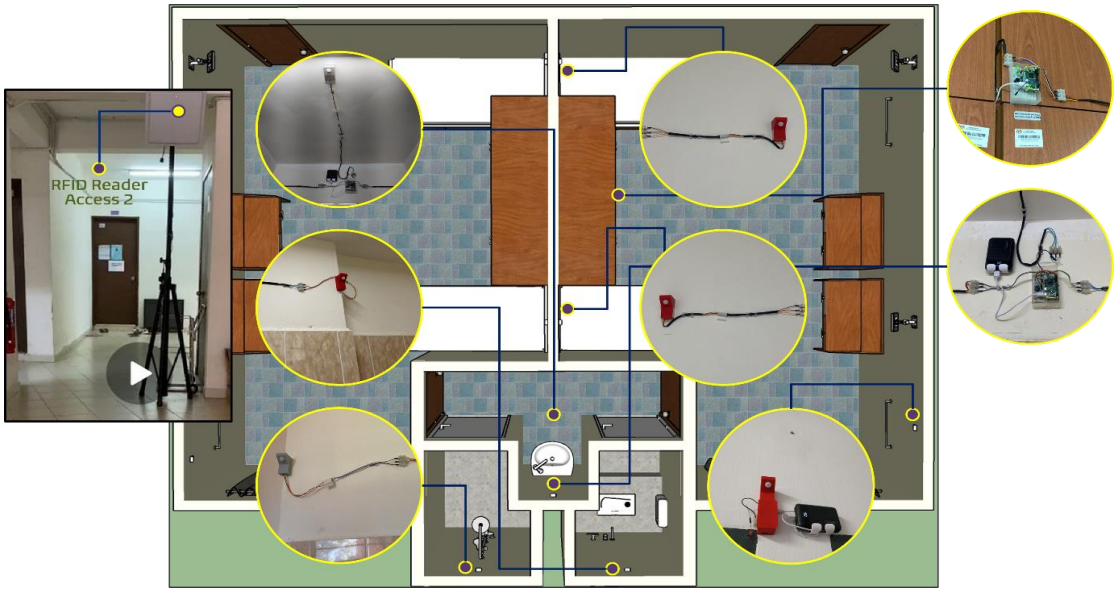


Figure 23. The additional components and sensors

The additional components and sensors are used to upgrade the security of the dorm's room where have more partition and sensing obstacle as shown in Figure 24.

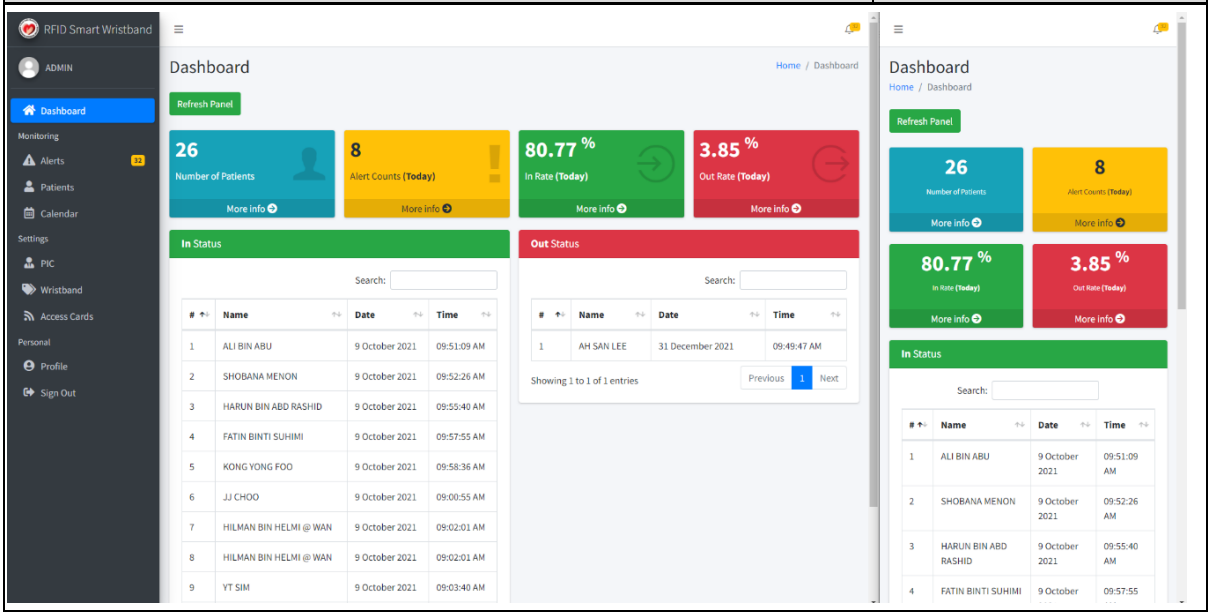
Figure 24. View of the patients' quarantine room

6.3 Findings from Phase 3 – development of user-interface management system

GUI development outcome and features

Based on planning mentioned in sub-section Phase 3 and 5.5, Table 12 is the result of the responsive display that been developed to make sure the IoT monitoring system is compatible with many devices.

Table 12. Responsive result for multiple devices compatibility

Desktop View	Mobile Phone View
	

Based on Table 10, this IoT monitoring system was developed with different roles of user. The different features or accessibilities as shown in the following figure. Role as admin is responsible to make sure, access card and RFID wristband are available on the system, create quarantine branches, assign access card to PIC and monitor alerts. For role as PIC, the pages can be access are limited because of to give focus for PIC to monitor alerts of active patient's occupancy status and register patient. Figure 25 shows the pages that can be access by admin (HQ) and PIC.

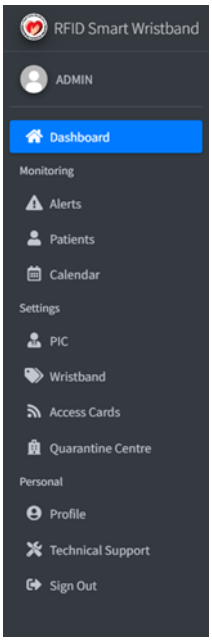


Figure 25 (a). Pages can be access by admin (HQ)

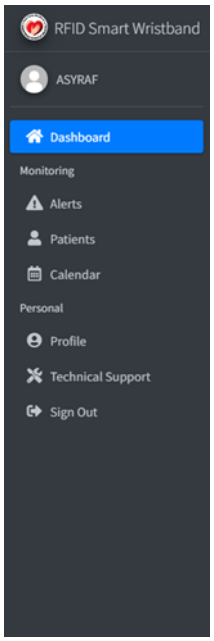


Figure 25 (b). Pages can be access by the PIC

Figure 25. Pages can be access by admin (HQ) and PIC

Every page has their own features to assist user on manage the quarantine stations. Total of pages is 11 and separated into 3 divisions, monitoring, settings and personal for admin. 2 divisions for PIC, monitoring and personal. Shown in Table 13 is the description of the pages.

Table 13. Developed pages and pages description

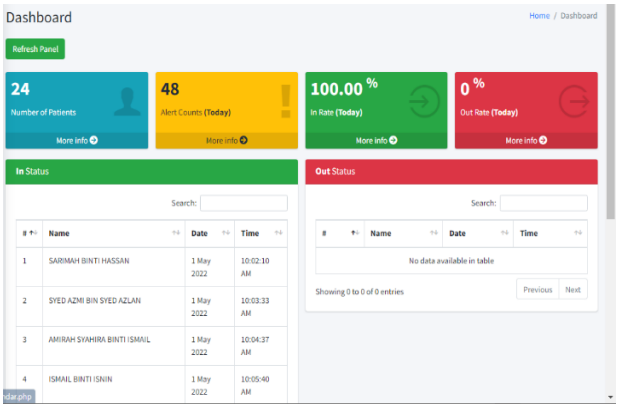
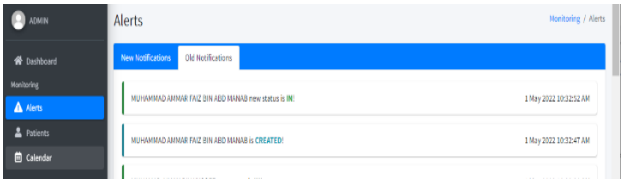
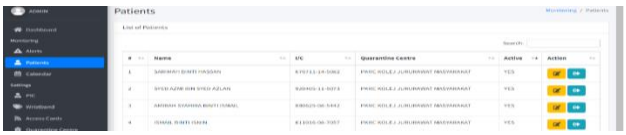
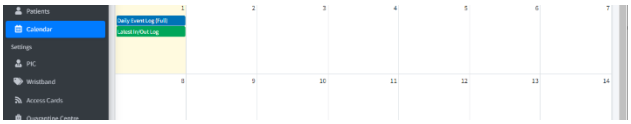
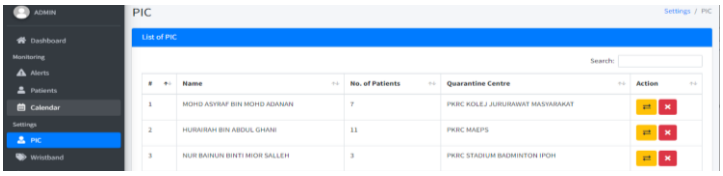
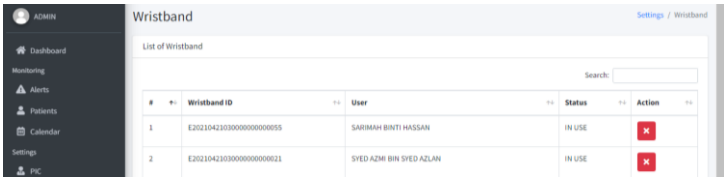
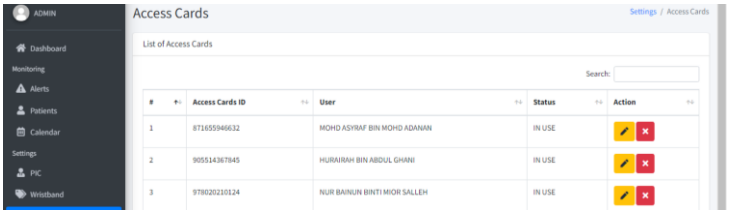
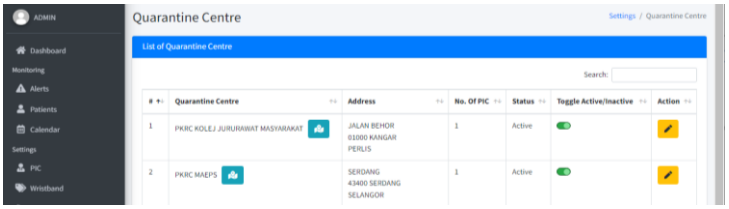
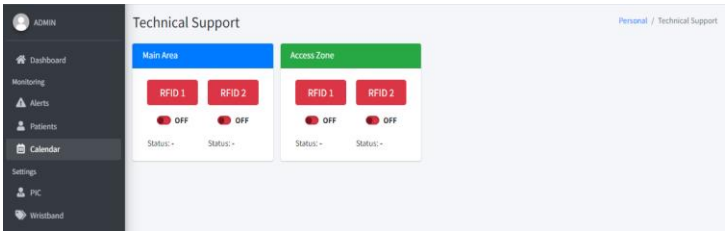
Developed pages	GUI	Pages description
DASHBOARD		From above: b) **Refresh Panel** To manually refresh the page. c) **Number of Patients (Blue box)** Shows the total number of registered and active patient(s). c) **Alerts Count (Yellow box)** Shows the number of counting alerts of the day where consists of cumulated patient was created, IN and OUT. d) **In Rate (Green box)** The percentage of active patient(s) of the day. e) **Out Rate (Red box)** The percentage of active patient(s) of the day escaped from the quarantine stations. f) **In Status (Green table)** The main information of the active patient(s). g) **Out Status (Red table)** The main information of the escaped patient(s).
ALERTS (Monitoring)		a) **New Notifications** The latest log of the activities on the day (Created, In, Out and Released). b) **Old Notifications** The old log of the activities after the alert(s) was viewed (Created, In, Out and Released).
PATIENTS (Monitoring)		The table of List of Patients was registered in the IOT Monitoring System. For column Action, the yellow button is to edit the Patients details and the blue button is to release the patient.

Table 13. Developed pages and pages description *(continued)*

Developed pages	GUI	Pages description
CALENDAR (Monitoring)		a) **Daily Event Log** Exported file in excel format for log event of the day. b) **Latest In/Out Log** c) Exported file in excel format for cumulative log event of a month.
PIC (Settings)		The table of List of PIC was registered in the IOT Monitoring System. For column Action, the yellow button is to edit the PIC details and the red button is to terminate the PIC from the system.
WRISTBAND (Settings)		The table of List of Wristband was registered in the IoT Monitoring System. For column Action, the red button is to remove the wristband from the system.
ACCESS CARD (Settings)		The table of List of Access Cards was registered in the IOT Monitoring System. For column Action, the yellow button is to edit the Access Card details and the red button is to remove Access Card from the system.
QUARANTINE CENTRE (Settings)		The table of List of Quarantine CENTRE was registered in the IOT Monitoring System. For column Quarantine centre, user can view QC location using Google Maps, for column Toggle Active/Inactive, the user can use radio button to change the status of the QC, Column Action, the yellow button is to edit the QC details.
TECHNICAL SUPPORT (Personal)		This page was developed based on infrastructure design type and the total number RFID Readers installed at the quarantine zone. As shown in figure above, the box labelled as RFID 1 and RFID 2 is the indicator the mode of the RFID Reader either OFF (Red), ON (Green: Standby Mode) or ON (Yellow: Reading). The toggle button used to turn on or off the RFID Reader remotely.

6.4 Findings from Phase 4 – full run testing, commissioning, and validation

Testing result of the UAT

Referring to Figure 16, the UAT was conducted where covered all monitoring and management procedures of quarantine stations as well as covered testing for hardware setup and installation. Additional procedure that has added which is role as Admin must create the branches for quarantine stations before executing all procedures in Figure 16. Shown in Table 14 is the checklist of the conducted testing and demonstration.

Table 14. UAT checklist

No.	Testing Activity	Tick (√)
Role: **ADMIN**		
1	Quarantine Centre Page	
	a. Add	√
	b. Edit/Modify	√
	c. View QC location thru integrated Google Maps link	√
	d. Enable/Disable	√
	e. Terminate/Remove	√
2	Access Cards Page	
	a. Add	√
	b. Edit/Modify	√
	c. Terminate/Remove	√
3	PIC Page	
	a. Add	√
	b. Edit/Modify	√
	c. Terminate/Remove	√
4	Wristband Page	
	a. Add	√
	b. Edit/Modify	√
	c. Terminate/Remove	√
5	Technical Page	
	a. On/Off RFID Reader	√
	b. Indicator Bar	√
	c. Status description	√
Role: **PIC**		
1	Patients Page	
	a. Add	√
	b. Edit/Modify	√
	c. Terminate/Remove	√

Table 14. UAT checklist *(continued)*

No.	Testing Activity	Tick (√)
	--- Monitoring Start ---	
2	Condition A	
	● One of motion sensor = Have Detection ● One or both **RFID Reader Access** = Wristband detected ● Alarm Triggered ● Status patient on dashboard updates *Scenario:* Patient tries to escape	√ √ √ √
3	Condition B	

	● All motion sensor = No Detection
	● RFID Reader Main Area
	  ○ Sensing
	  ○ One or both wristbands **missing**
	● Alarm Triggered
	● Status patient on dashboard updates
	Scenario: Patient tries to escape
		√
		√
		√
		√
		√
		√

4	Condition C	

	● All motion sensor = No Detection
	● RFID Reader Main Area
	  ○ Sensing
	  ○ One or both wristbands **not missing**
	  ○ **Re-sensing** after *1 minutes
	● Alarm Triggered
	● Status patient on dashboard updates
	Scenario: Patient may collapse
		√
		√
		√
		√
		√
		√
		√

5	Condition D	
	● One of motion sensor = Have Detection ● RFID Reader Main Area ○ Sensing every *30 seconds ● Status patient on dashboard updates *Scenario:* Normal operation	√ √ √ √
*Duration set for demonstration; it can be changed based on PIC request		
	--- Others ---	
6	Profile Page	
	● All details well displayed ● Change Password	√ √
7	Calendar Page	
	a. Calendar Display b. Export Daily Event Log c. Export Latest In/Out Log	√ √ √

Based on checklist as in Table 12, figures below are some of the results captured during demonstration session held on 31st March 2022.

Figure 26 (a). Mock-up patient wears the FSS RFID Wristband

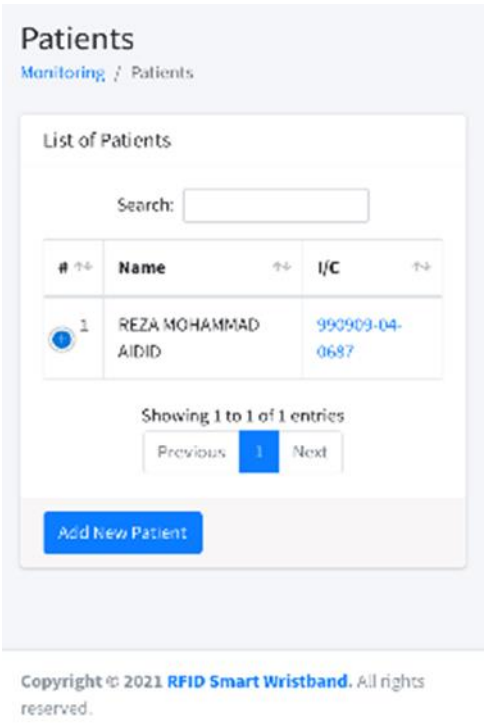


Figure 26 (b). Uploaded wristband was successfully assigned to the mock-up patient

Figure 26. The patient was successfully registered as active patient with the registered wristband

Once the patient was assigned with the FSS RFID Wristband and which quarantine stations, the IoT Monitoring System will automatically monitor the existence of the patient inside the quarantine room. Figure 27 shows the monitoring dashboard.

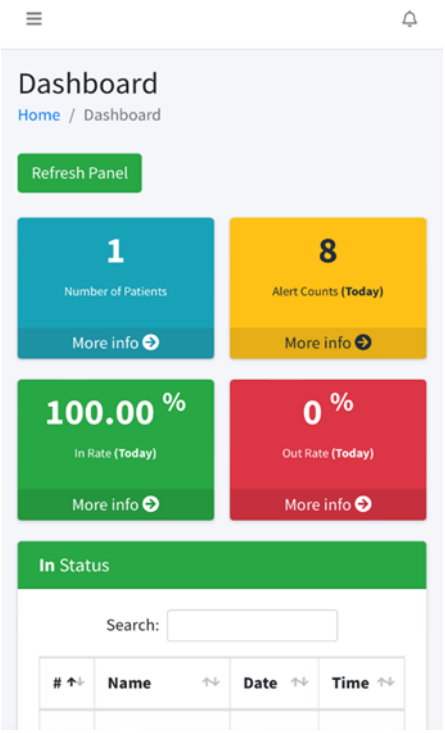


Figure 27 (a). Dashboard of the IoT monitoring system with real-time patient counted inside the quarantine stations

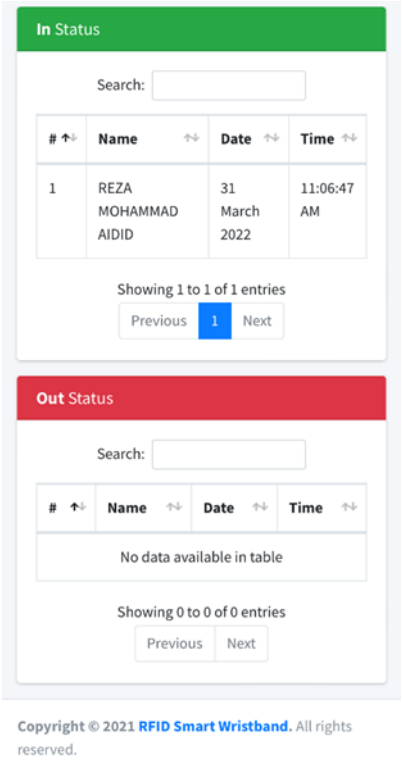


Figure 27 (b). shows the patient's essential information to be used for emergency cases or PIC's references

Figure 27. Monitoring dashboard

Figure 28 shows the transition of the real-time monitoring of the RFID readers. The RFID 1 is turned to yellow when the readers are in reading mode. This monitoring tools was developed for maintenance and troubleshooting purposes.

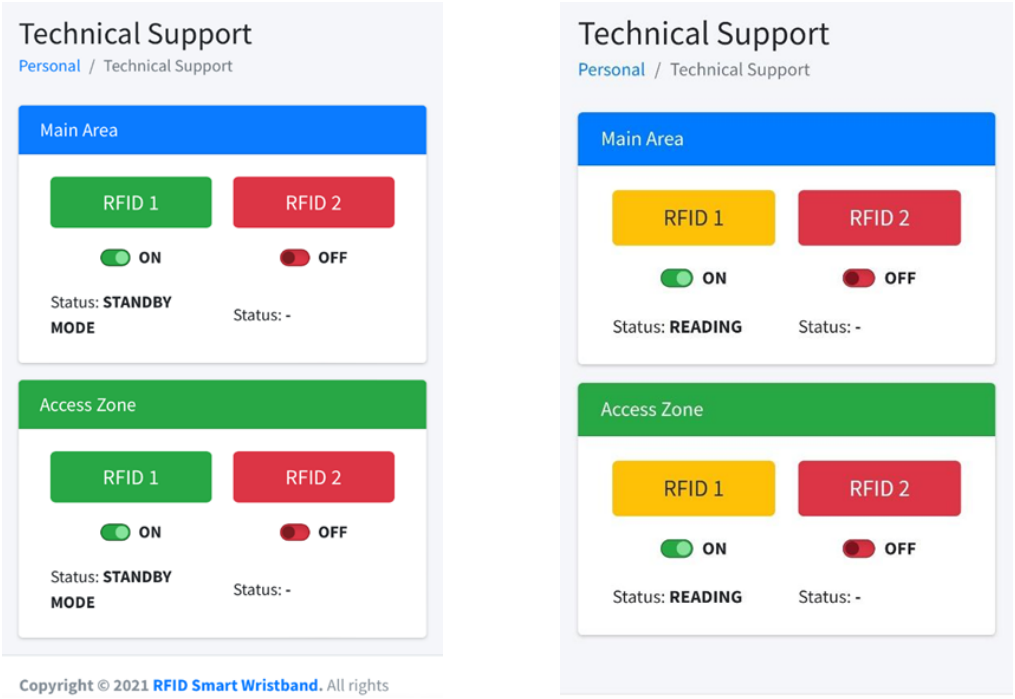


Figure 28. Technical support page changing mode state display

Figure 29 shows some of the activities captured by the IoT monitoring system to proof the real-time monitoring is working well or not. The result shown the successfulness of the real-time system when able to capture the patient escape the quarantine stations and able to capture when the patient returned to the quarantine stations. The IoT monitoring system are also working well using the smartphone.

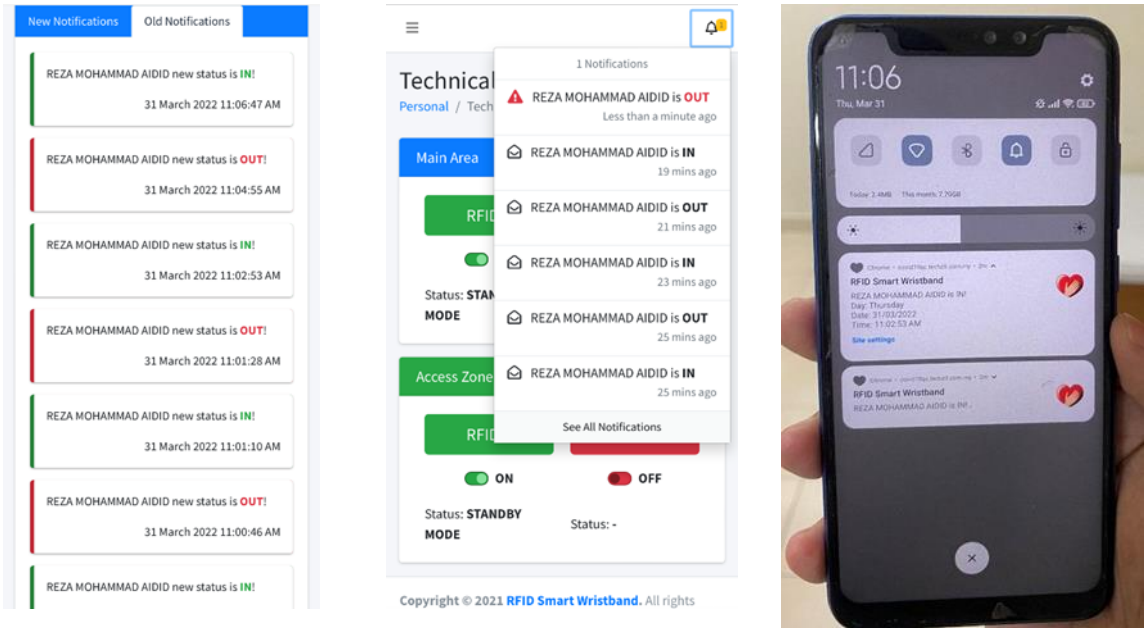


Figure 29. Alerts notification display includes push notification on mobile phone

7. Results analysis

7.1 Phase 1 - Development of wearable metamaterial UHF RFID tag antenna (FSS RFID wristband)

The comparison result between simulated result and measured result of the RFID wristband tag antenna was slightly different. The positive gain was successfully obtained with the minimum requirement due to the limitations of the antenna tag in UHF frequency range. The research works still need to be more details in parameter analysis such as simulating more possible effects, includes wristband cover in simulation material and find more solution in enhancing the antenna tag performances.

7.2 Phase 2 - Development of RFID reader infrastructure

The RRIS was successfully tested with 2 different designs where suitable to be installed at hall or spacious room and dorm or small room. The RRIS hardware and sensors used cannot be fixed because of it is depends on the building structure and quarantine environment. For example, Design A used less motion sensors compared to the Design B due to Design A structured more open space. To have stable and robust internet connectivity also one of the challenges faced by the team to validate every single process and procedure.

7.3 Phase 3 - Development of user-interface management system

The GUI for IoT RFID Monitoring System was well developed with the additional features that made the monitoring system expand the monitoring access to more than 2 quarantine stations. By using web-based platform, the GUI are compatible for multi devices but still have the limitations on push notification where this feature required access from user to enable it. Moreover, there is still room for enhancement in the GUI with regards to system automation control. The existing system that has been developed lacks clear indicators for users to comprehensively monitor system performance. On certain pages, manual page refresh is still required to update new data.

In addition, the technical team should consider employing a broader range of tools and equipment to diagnose and troubleshoot hardware malfunctions effectively.

7.4 Phase 4 - Full run testing, commissioning and validation

The testing was held are successful with the proof of functionalities outcome for every single test as listed in Table 12.

The testing was held are successful with the proof of functionalities outcome for every single installation and testing process as shown in Table 14. Start with the installation of the RFID infrastructure and patient ready to wear the convenient FSS RFID wristband. Both of it are tested with 2 layers of test where covered hardware test and established connection between hardware and the IoT monitoring system. The test was successful held with the mock-up patient and the real SOP implemented at quarantine stations are applied (verified by the HTF's officer and doctor). The alert system has also undergone testing to demonstrate that the PoC can enhance the existing protocol in cases of patient escape or patient collapse. These features are tested during the testing session with the mock-up patient has escaped for several attempts and has been idle for 3 cycles to indicate the patient is collapsed.

8. Conclusion

The monitoring system and localisation of COVID-19 patient was well developed in 12 months. The new RFID wristband invented with the ability to read the user's location in the quarantine stations. With the support of sensors integrated in the RRIS, the quarantine stations can be more secured and easier to manage as well as the IoT RFID monitoring system that was developed in web-based platform are more convenient to handle and more user friendly. Align with National Agenda to win a war against this virus, this PoC is going to help Ministry of Health Malaysia (stakeholders to be engaged) contain the COVID-19 from spreading again by monitoring localisation and health condition of PUI and PUS (the end users). The proposed RFID has the potential to change an organisation's ability to get real time information on the location of assets and even personnel. The use of RFID technology reduces operational costs by reducing the need for human operators in systems that collect information and in revenue collection.

Furthermore, the proposed RFID FSS wristband can be distributed in bulk quantities to authority and hospital as it would be much cheaper than a smart mobile phone. This application not just limited for COVID-19 patient, PUS and PUI but also can be applied in monitoring elderly that need special care, patient with mental health, Alzheimer patient, small and big industries and for private or public sector as well. It is believed that this technology will be an integral part of future smart healthcare components of smart cities in the post COVID-19 era.

Based on study and analysis, this PoC still can be improved such as details analysis on antenna design, study on bad internet connectivity solution for IoT project, enhance the system automation control and provide more details on technical support to diagnose as well as troubleshooting. Heat map monitoring system display also are recommended for future works, this feature can improve the monitoring quality for all roles and technical team. Regarding to the link towards standardisation, here is the summary that can be made and recommended from this PoC as listed in Annex A.

Annex A
(informative)

Recommendation for standardisation of RFID

Main hardware: From customised settings of RFID Reader into specific configurations and specifications. As mentioned in Table 9, here is the main hardware that recommend being standardise.

Table A1. Recommendation for standardisation of RFID specification

Hardware	Specification
(A) RFID Reader Long Range	a) Frequency: 919 MHz – 923 MHz b) Protocol: ISO 18000-6C c) Antenna: 12 dBi d) Reading Distance: 10~15 meter e) Communication: TCP/IP and Wi-Fi f) Status indicator: Buzzer and LED light flashes g) Power Supply: 12V h) Working temperature: -20℃ ~ +70℃ i) Dimension: 445 x 445 x 35mm
(B) RFID Reader Medium Range	a) Frequency: 919 MHz - 923 MHz b) Protocol: ISO 18000-6C c) Antenna: 8dBi d) Reading Distance: 6~10 meter e) Communication TCP/IP and Wi-Fi f) Status indicator: Buzzer and LED light flashes g) Power Supply: 12V h) Working temperature: -20℃ ~ +50℃ i) Dimension: 227 x 227 x 60mm
For (A) and (B)	a) Reading set with the 10 ms of interval b) RSSI reading range: 78 < RSSI ≤ FF c) Transmitting Power: Reading = 26 dBm | Idle = 5 dBm d) Working Mode: Trigger mode
RFID Reader Desktop Version	a) Frequency: 919 MHz - 923 MHz b) Protocol: ISO 18000-6C c) Communication: USB and Wi-Fi d) Built-in antenna: 1 dBi Antenna
UHF RFID Tag Antenna (FSS RFID wristband)	a) Type of RFID Antenna: Passive b) Frequency range: 919 MHz – 923 MHz c) Efficiency: > 80% d) Realized Gain: 1.2 dBi to 1.4 dBi e) Physical Profile: i. Substrate = Kodak Photo paper ii. Substrate Thickness = 0.254 mm iii. Dielectric Constant = 2.85 iv. Conductive = Silver Trace v. Antenna Cover = Flexible and Waterproof Medical Wristband

For infrastructure installation, as Figure 10 (D), the RFID Reader are recommended placed at 2.0 to 2.2 m with the tilt angle 60° to 70°. Considered detection object, which is human, the optimum detection range is 6 to 8 feet and range angle is 160° to 180° (Refer to Figure 17 last row). The full setup is as setup in Figure 14, but the full setup is depending on the infrastructure of the targeted facility.

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Publication of:

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