Deployment of RFID, GPS and IoT Technology for Medical Specimen Logistic System

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วิทยานิพนธ์นี้มีวัตถุประสงค์เพื่อใช้ระบบโลจิสติกส์สำหรับจัดส่งสิ่งส่งตรวจทางการแพทย์โดยใช้เทคโนโลยี RFID ร่วมกับเทคโนโลยี IoT ที่ทันสมัยในโรงพยาบาลจุฬาลงกรณ์ สิ่งส่งตรวจทางการแพทย์คือตัวอย่างที่เก็บจากร่างกายมนุษย์ เช่น ปัสสาวะ น้ำลาย เสมหะ อุจจาระ น้ำอสุจิ ของเหลวในร่างกายและเนื้อเยื่ออื่นๆ สิ่งส่งตรวจทางการแพทย์มักจะถูกรวบรวมจากผู้ป่วยและเก็บไว้ในหลอดทดลอง จากนั้นหลอดทดลองจะถูกส่งไปยังห้องปฏิบัติการที่เกี่ยวข้องเพื่อทำการตรวจ โดยปกติบาร์โค้ดจะถูกติดบนหลอดทดลองเพื่อวัตถุประสงค์ในการบันทึกข้อมูลผู้ป่วย อย่างไรก็ตาม งานวิจัยนี้ใช้เทคโนโลยี RFID กับหลอดทดลองสำหรับการบันทึกข้อมูลผู้ป่วย ซึ่งเหนือกว่าความสามารถของบาร์โค้ด แท็ก RFID ที่ติดไว้ที่หลอดทดลองมีหน่วยความจำสำหรับเก็บข้อมูลผู้ป่วยซึ่งสามารถเขียนได้โดยใช้เครื่องอ่าน RFID และในขณะที่ส่งหลอดทดลองจากแผนกหนึ่งไปยังอีกแผนกหนึ่ง จะใช้กล่องเก็บความเย็นสำหรับการขนส่งเพื่อรักษาคุณภาพของสิ่งส่งตรวจทางการแพทย์ในหลอดทดลอง และเพื่อรักษาอุณหภูมิและความชื้นของหลอดทดลองระหว่างการขนส่ง นอกจากนี้งานวิจัยได้สร้างระบบ IoT เพื่อตรวจวัดค่าอุณหภูมิ ความชื้น และการติดตามตำแหน่ง GPS บนแพลตฟอร์มคลาวด์ โดยสรุปแล้วการผสมผสานแบบใหม่ของเทคโนโลยี RFID และ IoT ในภาคการดูแลสุขภาพในงานวิจัยนี้ทำให้ได้ระบบการจัดการที่ง่ายขึ้นสำหรับการจัดการสิ่งส่งตรวจทางการแพทย์ นำไปสู่ความมั่นใจในเรื่องเวลา ในการบันทึกข้อมูลผู้ป่วยและเวลาในการขนส่งสิ่งส่งตรวจทางการแพทย์

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Mya Myet Thwe Chit : Deployment of RFID, GPS and IoT Technology for Medical Specimen Logistic System . Advisor: Professor Watit Benjapolakul, D. Eng. Co-advisor: Asst. Prof. PANUWAT JANPUGDEE, Ph.D.

This paper aims to implement a specimen logistic system using RFID technology combined with modern IoT technology in Chulalongkorn hospital. The specimen is a sample collected from the human body. Samples can be urine, saliva, sputum, feces, semen, and other bodily fluids and tissues. Samples are usually collected from the patient and stored in a test tube. Then test tubes are delivered to the corresponding laboratory for examination. Normally, barcodes are tagged over the test tubes for the purpose of recording patient information. In this work, RFID is deployed on the test tube instead for patient data logging. This solution overcomes the limitations imposed by using the barcode labels. RFID tag, which is attached on the test tube, has a memory to store patient information which can be written by using an RFID reader. While test tubes being in transit from one department to another, they are kept in a specimen transport cooler box to maintain their quality in proper temperature and humidity. In addition, IoT sensor and GPS system are employed inside the cooler box to provide the temperature and humidity values, as well as the location tracking, which can be accessed via the cloud platform. In summary, the proposed new combination of RFID, GPS, and IoT technologies for medical specimen logistic system can make better and simpler system for specimen transportation and management.

Field of Study:	Electrical Engineering	Student's Signature ....
Academic Year:	2021	Advisor's Signature ....
		Co-advisor's Signature ....

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Mya Myet Thwe Chit

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

6LoWPAN	IPv6 over Low-Power Wireless Personal Area Network
AIDC	Automatic identification and data capture
ASCII	American Standard Code for Information Interchange
BLE	Bluetooth Low Energy
CoAP	Constrained Application Protocol
dBm	decibel-milliwatts
EPC	Electronic Product Code
GPS	Global Positioning System
GUI	Graphical User Interface
H2M	Human to Machine
IoT	Internet of Things
IPv6	Internet Protocol version 6
LPWAN	Low-power wide area network
M2M	Machine to Machine
NB-IoT	Narrowband-Internet of Things
NFC	Near-field communication
RFID	Radio Frequency Identification
RP-SMA	Reverse polarity - SubMiniature version A
RP-TNC	Reverse polarity - Threaded neill–concelman
RSRQ	Reference Signal Received Quality
RSSI	Received signal strength indicator.
URA	Universal Reader Assistant
WSN	Wireless Sensor Network

Chapter 1 Introduction

1.1 Motivation and problem statement

Technology makes people to live longer and peacefully. Invention and innovation of technology drove to become today information age. AI, cloud computing, and IoT technology dominate people's daily life and it involves in almost every single day. In there, healthcare sector is one of the biggest technology-driven sectors whereby replacing the intelligence machines, reduces human errors in jobs.

Nowadays, there are many tech-aid services, devices, and management systems that are used in hospitals to be a Smart Hospitals. Start from the digital thermometer till surgical robot, all electronic equipment contribute hospital to improve patient service, affordable quality healthcare and skillful staff and professional. These new technologies have the potential to track medical assets, pharmaceutical materials, IT equipment, medical supply stock and to identify patients and track[1].

In the past time, hospital had used barcode system in medical record, specimen, and medication because data is one of the precious things. However, barcode systems have tons of weakness in such data-precious place. Traditional methods consist of human intervention in identifying and managing patient data, which may lead to getting errors to fault outcomes[1]. RFID technology, AIDC technology (a wireless automatic identification and data capture) [2], and a disruptive and open innovation[3]are assumed as the next generation of innovation that will improve the healthcare digital transformation. Among those next generation of innovation technology, RFID technology gradually replaces current widely adopted barcode systems. The power of long range and contactless allows automation to minimize manpower requirement.

Recently, the world is facing covid-19 disease infection and thousands of people are being infected every day. Blood testing is one of the testing to detect the covid-19 virus and hence the specimen collection department and laboratories might deal with tons of suspected patients. In fact, Healthcare need for extreme accuracy in drug distribution, handling, and processing. RFID technology could help the medical staff in performing their duties and reduce medical error. RFID isn't as cheap as traditional labelling technologies, but it does offer added value [4].

Traditionally, a barcode system is used in test tubes for patient data saving. Barcodes need to read data in line of sight once at a time and data transformation rate is much slower compared with RFID system. The biggest drawback of barcode applications is that barcode fall short because they are printed labels that could be easily damaged or washed out, being in a health institute where it demands everything being sterilized and sanitized; barcodes fail immensely. Unlike barcode system, RFID technology have numerous advantages. RFID tag on the other hand is versatile. They are made with plastic in general and because of that they are waterproof and heatproof in limited amount. Also, they can easily be attached to equipment and instruments that require sterilization. Thus, the RFID solutions help make everyday processes more accurate and increase operational efficiencies.

This paper aims to implement Specimen logistic systems using RFID technology combined with modern IoT Technology. Specimen is a sample collected from the human body. Samples can be urine, saliva, sputum, feces, semen and other bodily fluids and tissues. Samples are collected and stored in a test tube. Then many test tubes are delivered to the corresponding laboratory for examination. Normally, test tubes use barcode for storing patient information. We implement RFID technology in test tube for data storing. This solution exceeds the limitations that are bound to the barcode labels. RFID tag which will be intended to attach on the surface of the test tube has a memory to store patient information which can be written by using RFID reader. And while delivering test tubes from one department to another, blood transport cooler box is used to maintain test tubes quality and to hold test tubes temperatures and humidity during transportation. We also implement IoT system to the cooler box to get access the temperature value, humidity value and GPS location tracking seamlessly from cloud platform.

By replacing RFID technology in Chulalongkorn hospital instead of using barcode, we expect hospital can more focus on their patients, ensuring patients are satisfied and receiving the best care. This RFID research implementation in healthcare sector can reduce operation times, mislabeling problems, the cost of reading tags for a large bunch of test tubes, and human error in data. And this brings more profit to companies and polish up customer service remarkably. Additionally, we also introduce IoT technology applied in this research during transporting the test tubes from one department to another. IoT management consists of temperature and humidity monitoring, GPS location monitoring, and destination indication system which can fully access on cloud in time. Indeed, this new combination of RFID and cutting-edge IoT technology in healthcare sector can make to be a better simple management system for specimen management. It could lead to ensure not only in patient data logging time and also in test tubes transportation time.

We intend this paper to be worthwhile research mentioning just a first step of the RFID specimen system which would further apply to extend into new technology-driven healthcare research. We believe that this research paper can contribute to the society for RFID implementation in the healthcare sector. Also, the performance testing result of Sparkfun devices' data can be useful for those who intend to use it for their real implementation project.

1.2 Research Objectives

This thesis is mainly designed to implement Specimen logistic system using RFID technology combined with modern IoT Technology in order to improve productivity, operations efficiency in a Chulalongkorn hospital and eliminate human-error in the hospital. In addition, we will explore the URA tool which provides a quick interface for RFID readers.

1.3 Scope of thesis

In general, the scope of this research paper is as following:

- Design the RFID prototype using Sparkfun RFID reader, external antenna, Gen2 tag, and Middleware (Universal Reader Assistant).
- Explore the optimal performance of reading range.
- Provide an insight of URA (Universal Reader Assistant) tool.

- Design IoT prototype using Arduino, NB-IoT, GPS, temperature, and humidity sensor.
- Indicates the test tubes for location correction.

1.4 Outline of the thesis

This paper is divided into six sections. The first section, Chapter-1 gives a brief introduction of research work. The second section, Chapter-2 presented the related background, and theories in detail such as RFID technology and IoT technology accordingly. After that, literature review is examined the third section Chapter-3 and Proposed method and research design of this thesis including component lists, format for each RFID EPC, user memory. And some potential factors affecting the RFID Implementation is taken place in the fourth section Chapter-4. Chapter-5 will conduct about the research preparation, implementation process and result. Then performance evaluation of test result and comparison between the sensor value at receiver side and transmitter side are followed. Chapter-6 presented the troubleshooting of hardware installation and software installation. Finally, the conclusions of the study and future work are drawn in the Chapter-7.

Chapter 2 Background

2.1 Radio Frequency Identification (RFID) Technology

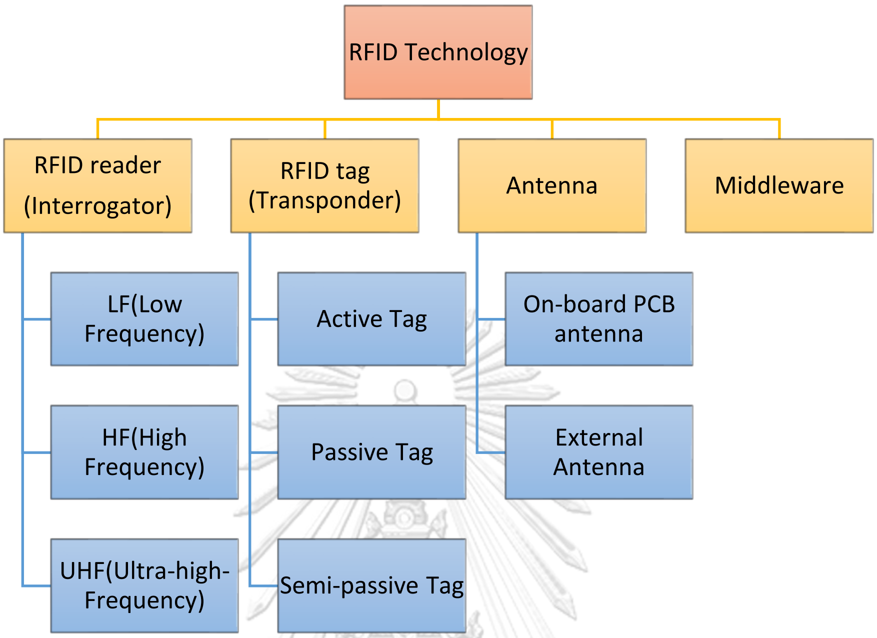

Fig. 1. Hierarchy of RFID Technology

The history of RFID technology started in the 19th century. At that time Michael Faraday's discover electronic inductance and James Clerk Maxwell's formulation of equation becoming electromagnetism. Then Heinrich Rudolf Hertz's experiments carried out Faraday and Maxwell's theories. Their discovery became the foundation of modern radio communication. One of the first Radio Frequency identification applications was in "Identify Friend or Foe" (IFF) systems, British Royal Air Force implemented that system during World War II. Today, advanced IFF systems can be found in aircraft and munitions. As a commercial, RFID devices started using at the toll collection in the late 1980s and early 1990s. When the price falls, the demand increase for the RFID, and people started using it in low-value items, consumer goods, and products. Later, in 1994, RFID devices were used mandatory and almost every railcar in the US. Walmart company first went live with "RFID" in their retailer stores in 2005 to improve inventory management and to track items more efficiently. These days, the RFID technology is using in almost everywhere, controlling physical access, payment systems, access tracking and so on [2].

Before the RF identification was not accessible, the barcode system was one of the well-known systems in around 1970s and deployed it worldwide. Then two-dimensional barcode was invented, and it has more storage space than the former one-dimensional bar code system. Although they are reliable, fast, and easy to use, there are many weaknesses in outdoor usage such as easily damage, non-waterproof, and may be obscured by packaging. Unlike the barcode system, RFID has numerous advantages. They can be used at non-line-of-sight, long-distance detection range, waterproof packaging, and modern RFID system consist simultaneous multiple tag reading abilities and tag security system. Also, there are various types of RFID systems used in different sizes, applications, and settings that have different power supply, operating frequencies, and functionalities. However, RFID technology has still barrier and challenges not only at other sectors but also in healthcare industry such as preliminary investment cost, problem with metal and liquid, security, and technical training especially for developing country[3]. Key components of RFID system are as shown in Fig. 2.

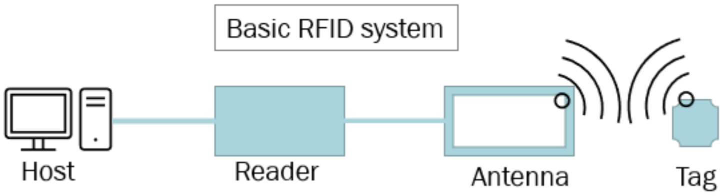

Fig. 2. Basic RFID system

2.1.1 RFID reader

An RFID reader is one of the main components of RFID technology. Reader transmits Radio Electromagnetic wave to medium and when the transponder enters read range, RFID tag's internal antenna draw energy from reader and sent it to IC which generate a signal back to the system. The reader detected a backscatter and interpreted it to the readable information. Reader can be used RF waves to write new information to the tag. Usually, the reader connects with the computer via a cable to display the detected tag information using a software application. An RFID reader can differ in frequency, power supply, and functionality. Some have a built-in onboard PCB antenna to detect the tag in short-range while some support external antenna for greater range too. Below is a list of the common range of frequency and their properties.

Table 1: RFID Reader's frequency ranges

Frequency Range	Passive Read Distance	Example application
Low Frequency (LF) (120 – 150 kHz)	Read Only (<1 foot)	Use in livestock identification, auto key and lock, library books
High Frequency (HF) (13.56 MHz)	Read/Write (>1 meter)	Use in access control and mobile payment, airline baggage
Ultra-high Frequency (UHF) (433 MHz, 860 - 960 MHz)	Read/Write (> 3-5 meters)(Passive)	Especially used for access tracking

2.1.1.1 Sparkfun Simultaneous RFID Reader (SRTR)

For this research, SRTR is chosen to be a core component for RFID. SRTR (M6e nano Model), a product of Sparkfun Electronics, an Arduino-compatible device, is used in this research implementation due to its numerous features such as simultaneous multiple tag reading, writing ability to a tag, support external antenna, and software application. The following table shows detailed information. The detail features of SRTR device are shown in Table 2.

Table 2: Sparkfun Simultaneous RFID Reader (SRTR) specifications

Manufacturer	SparkFun Electronics
Module	M6E-NANO
Dimensions	22 mm L x 26 mm W x 3.0 mm H
Compatible Tag type	EPCglobal Gen 2 tags (ISO 18000-6C)
Max Read Rate	Up to 150 tags/sec to read 96-bit EPC
Max Tag Read Distance	Over 4.5 meters (15 feet) with 6 dBi antenna (33 dBm EIRP)
Max Writing Rate	80msec typical for standard write of 96-bit EPC
RF Power Output	Separate read and write levels, command-adjustable from 0 dBm to +27 dBm in 0.01 dBm steps
Detection range with external antenna	Up to 16 feet (4.9m)
Detection range with onboard antenna	1 to 2 feet
Compatible baud rate with microcontroller	115200 bps
Operating DC Voltage	3.3V to 5V
Power Consumption	0.84 W in ready mode
Idle Power Saving Options	Standby: 0.84 W Sleep: 0.015 W Shutdown: 0.00025 W
For use with	RFID Tags
Frequency	859 MHz to 873 MHz, 915 MHz to 930 MHz
Interface Type	UART
Operating Temperature	-20°C to +60°C
Unit Weight	46 g

2.1.2 RFID tag

Card Type	Paper-thin sticker Type	Glass capsule Type	Button Type	Ultra-small square Type	Transparent Type
					

Fig. 3. RFID tag in different sizes and types

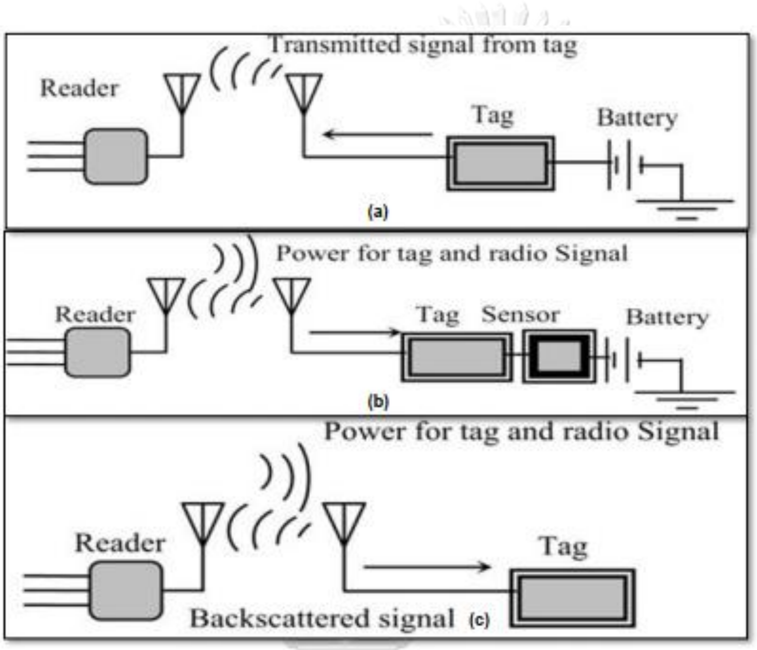

Fig. 4. RFID tag tracking system (a) Active Tag (b) Semi-Passive Tag (c) Passive Tag [4]

Tag plays a vital role in this RFID system. RFID tags are stuck with something to identify that in an RFID system. A single RFID tag consists of an embedded Antenna (receive and transmit signal) and IC with a unique TID (Transponder ID) (for storing data). Tag also has various kinds of types such as active tag, passive tag, and semi-passive tag in common. Generally, those are card type, capsule type, button type, paper-thin sticker type, and non-sticker type as shown in Fig. 3.

For the RFID tracking system with different tags, see Fig. 4. Active tags have their internal power supply that supports further distance and transmission components; semi-active tags also have their power source that is used only for powering the internal circuitry but not for transmission. Passive tags have no battery to power themselves as they use the electromagnetic signal from the reader as the power source. That is why they are lightweight, lower cost, and thinner than active tags.

However, the cost of UHF RFID tag has been significantly decreased over the last decade due to higher manufacturing yields, and massive deployments of RFID tags in many industries; according to the historical data of tag cost from 2001 to 2019, the cost has rapidly decreased from 34.5 THB to 1.2 THB, the tag cost has been reduced every year at an exponential rate [4].

2.1.2.1 UHF RFID Passive Tag

The passive UHF RFID tag is chosen to be used in this research work due to the outstanding advantages of tag size (smallest), tag cost(cheapest), and data transfer rate (fastest), which are widely adopted in many supply chain applications, especially in tracking system[4]. Sparkfun RFID reader (SRTR)'s M6e nano module works with this UHF Gen2 tag which has larger memory space and faster data rate and being global standard and has other features. There are generally TID, EPC, and user memory so-called memory of a tag. Each tag has 20 bytes for TID that is unique and cannot edit. EPC (Electronic Product Code) is generally 12 bytes, user-editable, and meant to be written to as a UPC type replacement. User memory is a kind of description of EPC name where we can store 64 bytes of data. Additionally, there is a reserved memory where Access Passwords (to restrict people from re-configuring tags) and Kill Passwords (to disable a tag permanently) occupy 4 bytes each in Fig. 5. The passive tag has two types, adhesive, and non-adhesive. We use a non-adhesive tag in this experiment. The detail features of RFID tag are shown in Table 3.

Table 3: UHF Gen2 Passive RFID Tag Specification

Manufacturer	SparkFun Electronics
Product Type	RFID transponders
Type	EPCglobal Gen2 and ISO/IEC 18000-6c
EPC storage	96 Bits
User Memory	512 User Bits
TID Memory storage	64 Bits Unique TID (unalterable serial number)
Reserved Memory	32 Bits Access and 32 Bits Kill Passwords
Dimensions	7 cm L x 1 cm W
Unit Weight	3.698 g

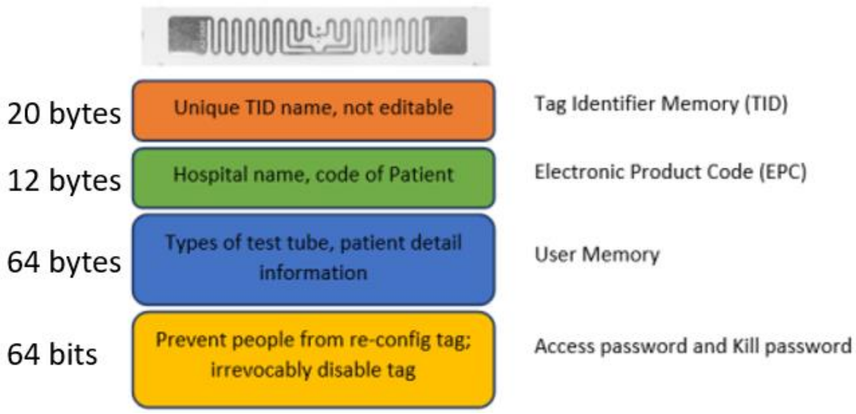

Fig. 5. UHF Gen2 Passive RFID tag structure

2.1.3 UHF RFID External Antenna

SRTR's onboard PCB antenna has a limited detection range. The signal cannot reach over 1 or 2 feet, and the microprocessor getting overheats while working above 5 dBm or over 10 minutes. External High gain antenna capable almost 16 feet with a strong enough power supply, and the RFID reader can use adjustable read/write power (0dBm-27dBm). Due to its linear vertical polarization type, the tag orientation also affects readability of the antenna. As shown in Fig. 6, some tag antenna position cannot receive the RF wave transmitted from the antenna. However, some tag orientation is compatible with antenna's position. The detail features of external antenna are shown in Table 4.

Table 4: UHF RFID external antenna specification

Manufacturer	SparkFun Electronics
Product Type	Aerial / Indoor UHF RFID Antennas
Impedance	50 Ω
Polarization	Linear Vertical
Antenna Connector	TNC Female RP
Maximum Power	100 W
Dimensions	223 mm L x 200 mm W x 60 mm H
Frequency Range	860 to 960 MHz
Gain	6 dBi
Unit Weight	1 kg

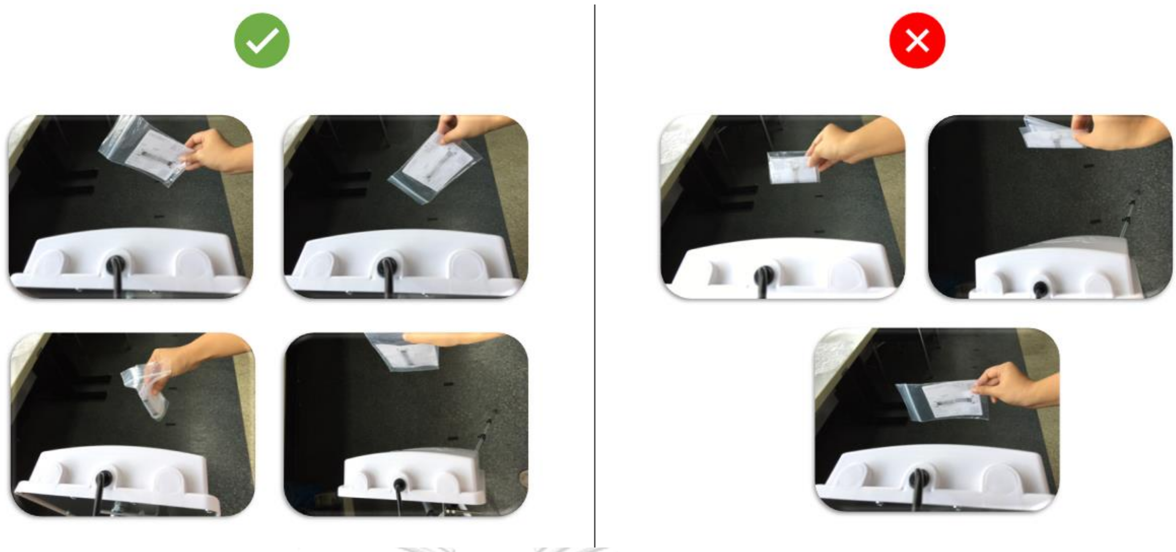

Fig. 6. Antenna with tag orientations

2.1.4 Universal Reader Assistant (URA) tool

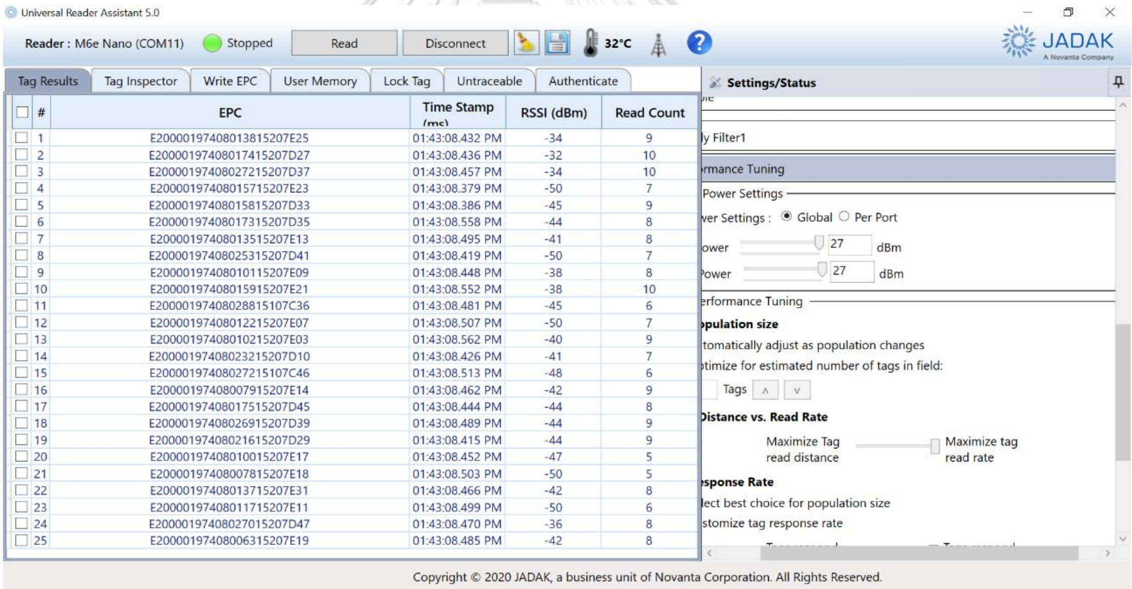

Fig. 7. URA interface

URA tools is developed by ThingMagic. ThingMagic, a division of Jadak Tech, is one of the RFID manufacturers. URA interface is as shown in Fig. 7. Sparkfun RFID reader uses ThingMagic' s M6e Nano module that is flexible for both novices and experts. SRTR can be used with either hardware UART or software UART. Software UART is used with Arduino sketch or Mercury API which is ThingMagic' s extensive software libraries in C, Java, and .Net to get full access features of the reader. Hardware UART is used with USB cable which is connected with a computer to access the features of the reader. The URA, a software tool that is built with Mercury API, has

10

many functions to access the SRTR such as read/write options, performance tuning, and data extension features. If we use URA, the reader connects to a computer USB port via serial connection. However, a standard USB port can provide up to 5V 500mA that is suitable only for 5dBm because a higher value can cause reader to brown out.

2.1.5 Serial Basic Breakout

Sparkfun Serial basic break out is used as a bridge between USB cable from computer and RFID reader. There is a jumper on the rear of the board that controls the output voltage on the VCC pin. the board outputs 3.3V by default. Changing the jumper to 5V will cause the board to output 5V on the VCC pin with 5V signals. The detail features of serial break out are shown in Table 5.

Table 5: Sparkfun Serial basic breakout specification

Manufacturer	SparkFun Electronics
Product Type	USB to Serial Breakout Boards
Support Baud Rate	2400 bps to 115200 bps
Support Voltage	3.3 or 5 V
Operating Temperature	-40 to 85 °C
Unit Weight	7.544 g

2.2 Internet of Things (IoT)

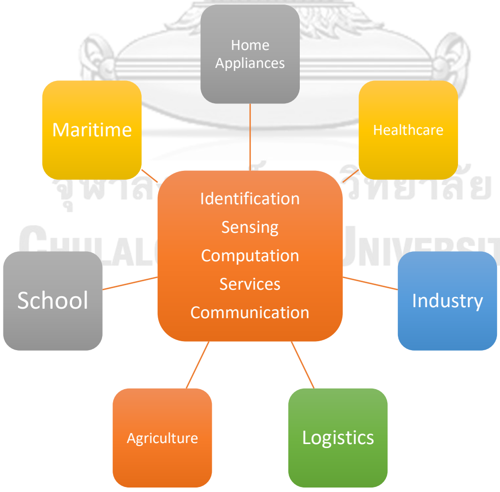

Fig. 8. IoT Technology Topology

With a growth of the technology, human to machine (H2M), Machine to Machine (M2M) communication between devices make things connecting with the system and people. The Internet of Things (IoT) can be described as a network of thing or devices, embedded with sensors, actuators, and other technologies, which have interconnected each other and working together with wire or wirelessly connected with internet. IoT means a group of sensors, actuators, RFID, embedded systems, and wireless sensor network. Nowadays, IoT contribute to consumer applications, industrial, logistics, commercial, healthcare, and smart environment. Among those, IoMT (Internet of Medical Things) play a vital role as medical devices are equipped with specialized sensors for data collection and analysis for research. Also, remote health monitoring and emergency notification systems trigger the IoT more useful. Internet of Things works in many different communication and protocols to connect with smart things such as Internet Protocol Version 6 (IPv6), over Low power Wireless Personal Area Networks (6LOWPAN), ZigBee, Bluetooth Low Energy (BLE), Z-Wave and Near Field Communication (NFC)[5].

In this research work, we introduced an IoT network integrated with test tubes transport cooler box. To achieve the IoT network requirement such as small size, light weight, low cost , low power consumption, multi-functionality and extensibility, this device is comprised into four physically separated modules:

- Power module
- processing module
- communication module and
- sensor/actuator module.

2.2.1 Power Module

It will be developed by using solar panel if necessary. Right now, we use external power bank DC 5V to supply the entire system.

2.2.2 Arduino Mega2560 (Processing Module)

Arduino development board is used in here as a processing module. An Arduino device, open-source development board, has maker friendly IDE, less expensive devices have been the brain of thousands of projects, from a simple one to complex huge one. It has been easy-to-use for fast prototyping in IoT applications. It available in different shapes and sizes and maker can use it as per their needs. Types of Arduinos are Arduino Uno, Arduino Mega, Arduino Nano and so on. Different devices have its own pros and cons as we use Arduino Mega 2560 device for healthcare environment due to its low-cost, portable, high flash memory, more serial pins for serial con: devices and variety of resources to learn [6]. The detail features of Arduino Mega2560 are shown in Table 6.

Table 6: Arduino Mega 2560 specification

Manufacturer	Arduino
Product Type	Development Boards & Kits-AVR
Microcontroller	ATmega2560
Operating Voltage Supply	5V
Digital I/O Pins, Analog I/O Pins	54, 16
Clock Speed	16 MHz
EEPROM	4 KB
Flash Memory	256 KB of which 8KB used by bootloader
Serial Pins (4 serial ports)	Serial pin : 0(RX), 1(TX) Serial1 pin : 19(RX), 18(TX) Serial2 pins : 17(RX), 16(TX) Serial3 pins : 15(RX), 14(TX)
Temperature Range	-40°C to 85°C (Industrial)
Unit Weight	52 g

2.2.3 AIS NB-IoT (Narrowband-Internet of Things) (Communication Module)

Regarding the communication module, NB-IoT is designed for low-power wide area network which cover about 70% of cellular IoT communication in 2020. The advantages of using LPWAN is that it can transmit the data through a radio frequency with a small amount of power usage and large area coverage. There are 3 public telecom operators in Thailand. They are AIS, TRUE and CAT. AIS produce AIS NB-IoT for low-power wide area, developed by the 3GPP (3rd Generation Partnership), use license radio for the frequency band. According to the author performance analysis [7], AIS NB-IoT support a good quality of pings number failed and RSRQ (Reference Signal Received Quality). AIS NB-IoT is chosen because it is available in market currently and is still releasing updated features timely.

AIS NB-IoT shield, Arduino-compatible device, works with 9600 baud rate, support AIS cloud platform: Magellan as well. It uses embedded eSIM for cellular network. Magellan is easy to control and monitor all sensor value from one place. At Magellan platform, we can check sensor data history that sent from NB-IoT shield. Additionally, we can visualize the sensor data showing on dashboard also control the Boolean by using trigger. The detail features of AIS NB-IoT are shown in Table 7.

Table 7: AIS NB-IoT module specification

Manufacturer	AIS operator
Network Technology	LTE Cat NB1 (NB-IoT)
Communication Module	Quectel BC95
Frequency	Band 8 (900MHz)
Protocol	UDP/CoAP
Data Transmission	Downlink: 24 kbps/ Uplink: 15.625 kbps
Serial Communication (UART)	Software Serial

2.2.4 Sht1x Temperature Sensor (Sensor/actuator Module)

Sht1x family has sht10, sht11 and sht15 sensors. We use sht10 sensor as a sensing module which use sht10 chipset. It is tiny and low power consumption device, an Arduino-compatible and easily to deploy. It precisely calculates the temperature and humidity values and interfacing to Arduino device via I2C communication. The detail features of temperature/humidity sensor are shown in Table 8.

Table 8: Sht1x temperature and humidity module specification

Measurement Range	0 to 100% RH (Relative Humidity) -20 to 100 °C (normal range)
Temperature Accuracy	+/- 0.5°C @ max 25°C
Humidity Accuracy	+/- 4.5% RH at 25°C
Supply voltage	2.4 to 5.5 V
Power Consumption	Measuring 3mW (typical) Sleep 2 UW (typical)
Pins	Data, VCC, GND, SCK, VCC, GND
Size	7.5 mm x 4.9 mm x 2.6 mm

2.2.5 GPS EM-506 Module (Sensor/actuator Module)

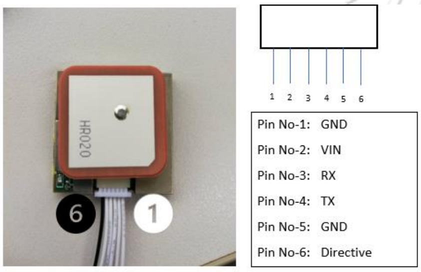

Fig. 9. GPS EM-506 pin numbers

The history of GPS(global positioning system) was started from American scientist where he studied how Russian's Sputnik worked and he found out Doppler effect in radio frequency that sent from the satellite. Because of his effort, we now can identify the location of GPS receptors by receiving the signals from at least 3 satellites. After year by year, the modern technology makes GPS receptors smaller, cheaper, and more accurate [8].

GPS-EM506RE is a coin-sized module, high accuracy, and low power consumption device. We use this device as a GPS sensing module in this research. It works with Arduino at 4800 baud rates. If the device gets signal lock initially, device works even indoor. When you it starts it up, it takes sometimes longer, but it could depend on the cloud cover. GPS accuracy rely on a number of variables, most notably SNR (noisy reception), satellite position, weather, and obstructions such as buildings and mountains. These factors can be an error in your perceived location. The detail features of GPS are shown in Table 9.

Table 9: GPS EM-506 module specification

Manufacturer	SparkFun Electronics
Product Type	EM-506 GPS Module
Channel Support	48-Channel Receiver
Tracking Sensitivity	-163 dBm
Interface	UART
Protocol	OSP
Pins	GND, VIN, RXD, TXD, GND, Directive
Supply voltage	4.5 DCV to 6.5 DCV
Horizontal Position Accuracy	< 2.5 meter
Operation Temperature	-40 to 85 °C
Dimension	30 mm L x 30 mm W x 10.7 mm H
Unit Weight	16 g including cable

2.2.6 Buzzer (Sensor/actuator Module)

Buzzer is set up in order to know the temperature status. If the temperature is getting higher than the limited range, buzzer works as an actuator, and it will sound continuously until temperature get back to normal.

Chapter 3 Literature review

According to my research prototype, it can be divided into the RFID part and the IoT part. For the proposal research paper, a comprehensive search using a combination of a word, “RFID”, “IoT”, “healthcare”, “NB-IoT”, and “RFID technology” were obtained from IEEE Xplore, Science Direct, Google scholar, published books from good reputation publishers, and some official electronic dealer. Total 56 appropriate papers are selected from the database and 16 papers were chosen to make references. Specifically, four different types of paper can be organized as

1. Reviews/survey studies
2. Experiments/models
3. Analytical approach
4. Case studies

The authors from[9] proposed to implement the RFID technology for hospital medicine tracking using RFID technology for asset management, MySQL database for storing user information, and create the GUI (Graphical User Interface), used Visual Basic. Net programming. The author from [10] implements an application of RFID technology for drug management with GPRS system. Family members can take their medicine from a drug box with an RFID tag if they miss taking out the medicine, the system notifies them via the GPRS system. When they took out medicine from the drug box, the webcam takes pictures of the user and loaded their info into a database. For that implementation, the author deployed using HF RFID device, sensor, controller, database server, and webcam. As an application of user interface, they used Visual Basic.Net programming. Another combination of RFID and IoT implementation is carried out by the author [11]. He works on the garbage tracking system using RFID and IoT. Each garbage deployed IoT device and report the waste level to the main control room timely. When garbage is almost full, the IoT system automatically notifies to truck for waste collection. Garbage car has also implemented with GSM module, GPS module with raspberry pi. When the car driver arrives at the garbage, he used his RFID tag on the garbage RFID reader for processing the collection. The main components are an RFID reader with Arduino for computation, a GSM module to send SMS and an ultrasonic sensor for waste level detection. On the other side, Raspberry Pi is a microcontroller with a GPS module for live location and GSM module support to get internet access for all those devices. At paper [12], RFID technology is also applied for monitoring power consumption by utilizing RFID RC522 HF reader, tag, python language, GUI, and Gobtwino for saving data locally. The author from [13]adopted IoT school bus system using Sparkfun RFID electronic and Arduino with GPRS module (sim 900A) and database (Heroku). His idea is that parents can check his/her RFID attached students are correctly taking a school bus or not. In this project, they use Sparkfun RFID, GPS with Arduino and save data to Heroku (database). For the web-based GUI, they were created with Java Programming. Finally, the author from [8]proposed a research work about the medical devices indoor or outdoor location tracking using AIS-NB-IoT and real-time databases. Author [8]and [9]research works are nearly like my proposed system at some point. Concerning RFID technology, the author from [14]proposed the framework for the data formatting of RFID tags for specimen labeling. Finally, as per paper [15], I can learn the procedure of setting up the devices for testing.

Table 10: Major comparison of existing work and my proposed work

Existing work	My Proposed Research
Barcode Management System - *Line of Sight Scanning* - *Single Scanning* - *Easily Damage and distortion* - *Wrong data and labeling*	RFID - *Non-line of sight scanning* - *Multiple scanning per second* - *Versatile, Waterproof and security* - *Accuracy and efficacy*
A reader module of RC522 13.56 MHz device	Sparkfun RFID device, Jadak's URA

First and foremost, the major difference of this research is deployment of RFID technology in Chulalongkorn hospital by replacing barcode system. As per Table 10, we can easily understand the weakness of barcode management. Comparing it, RFID system can overcome the limitations of user control and external factors such as distortion and damages. As a consequence, RFID management system can improve user experience and security of patient credential information by using access reserved memory. Additionally, unlike other implementation of HF RFID device, this UHF RFID can support longer range detection that is more compatible in hospital environment. I intended to use Sparkfun RFID reader because it can provide external antenna that support long range RF detection(>10 feet) and simultaneously multiple reading ability. This RFID reader is compatible with Gen2 RFID tag that has more user storage, global standard, and security.

For the IoT part, in paper [13], authors proposed a school bus RFID system using Sparkfun RFID reader, antenna, GPRS and Passive tag. Unlike that implementation, I applied different type of RFID tag that is suitable for specimen. Then I have made things work by using URA which is a user-friendly software and can support many features than using with Arduino(such as in kill password, lock password, ASCII reading). Moreover, when RFID tags are detected by reader, not only URA can export tag result (.csv file extension) but also JavaScript in NodeJS program can handle the tag result to upload to MySQL database instantly via HTTP POST method.

Besides that, when URA export csv files of tag result, tag's data are written in hexadecimal, and it is hard to read. For that problem I have developed a GUI application in C# which is composed of basic hex to ASCII converter for user to improve user requirement.

Therefore, this scenario differs from other articles in choosing new type of reader, performance testing with tag and external antenna, URA usage and data storage using NodeJS language. Thus, this prototype can improve more efficiency of reading distance with multi tag and instant data saving and sharing saved-data in multi computers under same network. This prototype enhanced the comfort of the laboratory technician for data logging with RFID technology and alike. Systems improvement are to be considered in the future, such as testing with different types of RFID tags in order to improve convenience aspect of the system.

IoT system in my research is mainly comprised with Arduino with NB-IoT and other sensor components. Authors from [11] and [16] also proposed Arduino with GSM modem connected to GPS Module. Unlike those articles, we used NB-IoT to access network. NB-IoT is better than GSM module especially for IoT devices because it is designed for low power wide area network. Also, this NB-IoT use CoAP protocol for data communication that is typically the most lightweight than HTTP or MQTT in resources requirement. NB-IoT devices send sensor data to cloud platform for storing and monitoring data. Dashboard is used to show sensor data in any animation style and GPS map can be used at there.

In fact, author from [8]proposed implementation of a study using Arduino, NB-IoT, GPS and cloud database. My proposed system is similar with that article. However, I used Arduino Mega development board in order to connect with 2 sensors and 1 actuator. Data from those sensors are needed to upload to cloud platform as payload. Instead of using standard Arduino Uno device, Arduino Mega can handle more payloads to uploading to the cloud platform as its flash memory is by far higher than Uno. Additionally, I initiated sleep mode for that system able to greatly improve battery life and to reduce power consumption of battery. By choosing a match technology from Arduino open-source code, the device can use sleep mode when the task is finish one time, thereby achieves the low power consumption requirements.

Therefore, this implementation can be a new combination of NB-IoT and Arduino Mega with sleep mode which intends the user to be able to monitor sensor data within one place. This system can make user delightful because of longer battery life and easier monitoring sensor data in one platform.

Chapter 4 Proposed method and design

4.1 Proposed RFID + IoT design

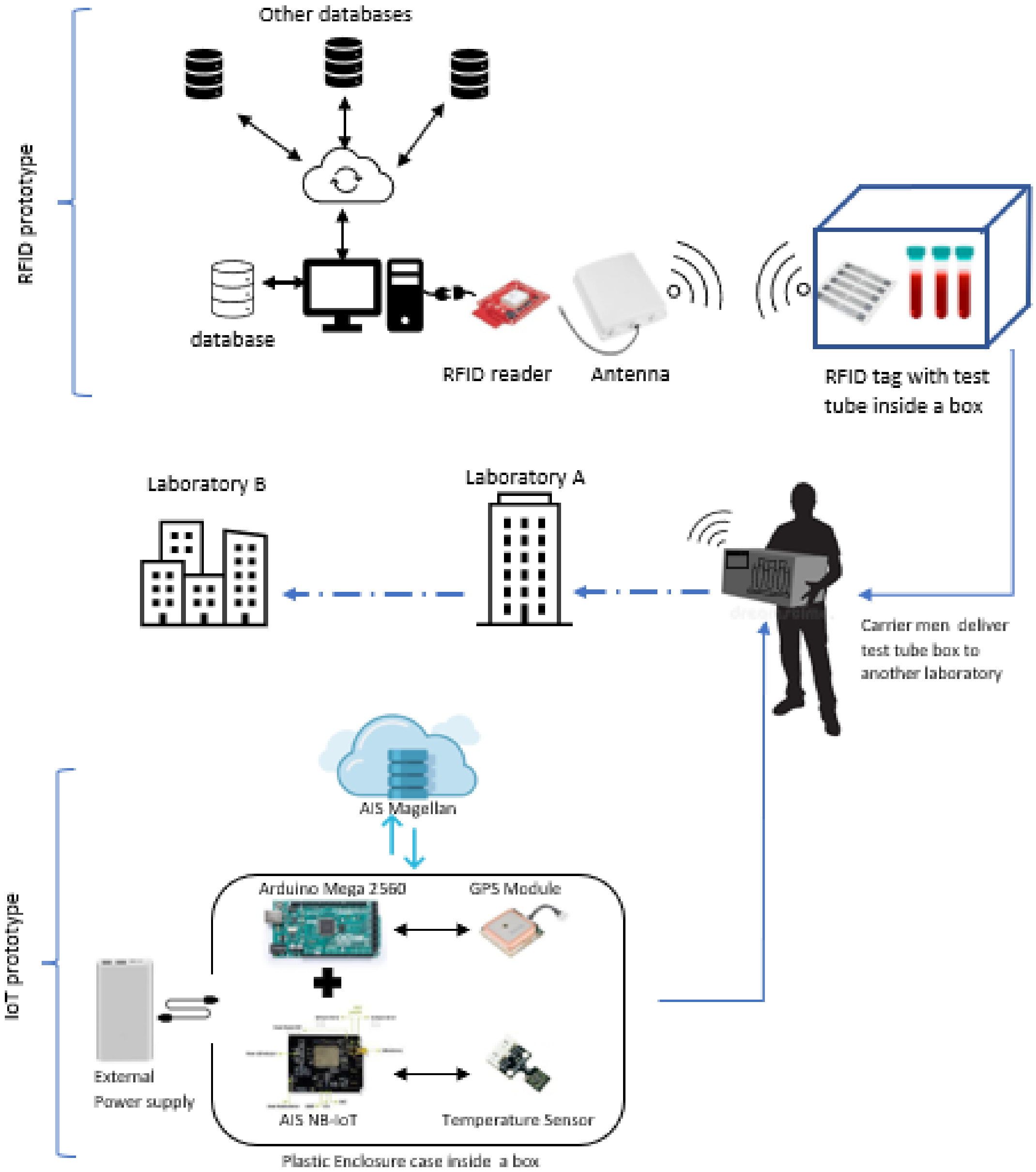

Fig. 10. Proposed RFID+IoT design

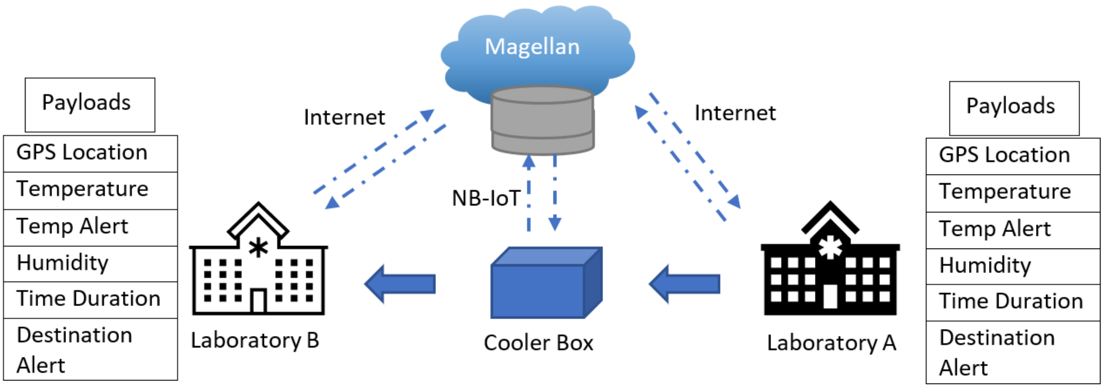

Fig. 11. IoT scenario

In this study, our experimental set up bears a close resemblance to [9] when studying RFID technology applied to experiment, [14] and [15] are referred when testing the performance result of Sparkfun RFID reader with RFID tag, and [8] helps when adopting AIS NB-IoT with sensors. The main objective of this study is to implement the RFID system with URA and the proposed framework [14]is selected because their studies have shown relevance with our research work. Regarding the IoT prototype, the LPWA network is selected. The reason for using AIS NB-IoT is that it has a huge extended coverage area than other GSM /GPRS systems, low power consumption, and support Magellan platform for NB-IoT and plenty of data resources for learning. Besides that, temperature sensors, GPS modules, RFID devices have differed from previous studies products, and it could be a new thing on the list.

If we summarize the above references, all of the devices which they use for the RFID technology is a reader module of RC522 13.56 MHz HF device. These cannot support an external antenna. Unlike it, we use the Sparkfun RFID UHF device which is more capable not only for short distances also for long-distance with full dBm. Besides that, Jadak's URA makes it much easier for users and novices at the beginning to explore full RFID functions and user control. Moreover, Sparkfun and Jadak support plenty of resources for their product. Also, the Sparkfun RFID reader is compatible with Arduino, red board, Raspberry pi for further work extension. That is why we choose this device to implement in a real environment.

On the one hand, our proposed system is not just intending for implantation. Using this RFID device, we measured and test the actual distance of RFID reading range between reader and tag, reader, and plastic box in real Chulalongkorn hospital environment. Therefore, this result will be useful for further modifications.

Regarding the IoT part, unlike the previous papers, we use the NB-IoT device with Mega to reduce the initial implementation cost and developed a program with a sleep mode that can save more energy for long-term use. Generally, AIS NB-IoT is used with Arduino mega which comes with 4 serial pins that allow the user to connect with more serial devices. Uno R3 naturally 1 serial pin that uses for AIS NB-IoT in this proposed system. However, we attach a GPS device that also uses serial communication with Arduino. For this scenario, we developed a program that commands GPS and NB-IoT to work alternatively. It has a couple of advantages such as save energy and low cost. This technique provides not only flexibility but also power consumption reduction as the CPU module can go to sleep mode after processing all its works.

As a consequence, this proposed method can improve the efficiency of specimen workload in the hospital laboratory system. Also, advances in efficiency allow greater productivity in a shorter amount of time, and blood tubes are transported quicker and correctly. As picture can descript more than letter, we will explain our algorithm by flowchart.

Main features on my proposed research

In summary, this proposed system can help as follow:

- By "combining an item with its information", a highly pliable and reliable system
  configuration becomes possible.
- Multiple RFID tags reading system that can scan and read simultaneously test tubes placed inside the plastic box (Sparkfun RFID) without direct contact.
- Reading and writing is possible without line of sight, using Electromagnetic transmission.
- Integration of IoT system to monitoring and tracking many environment conditions such as the temperature, humidity, and GPS sensor
- Save energy and low cost by using the combination between NB-IoT device and Arduino Mega, and by commanding GPS and NB-IoT to work alternatively.

Expected results

- Reduce the loss of blood tubes and data loss over the tubes while using barcode system
- Keep track of the delivery of blood tubes to the particular destination in real-time
- Design to have time efficiency
- Maintain optimal level of equipment by reducing the time for searching loss parts by medical staff
- Enhance the efficiency of tubes processing by scanning multi tags within a box once from greater distances
- Extend the battery life of IoT with the application of sleep mode

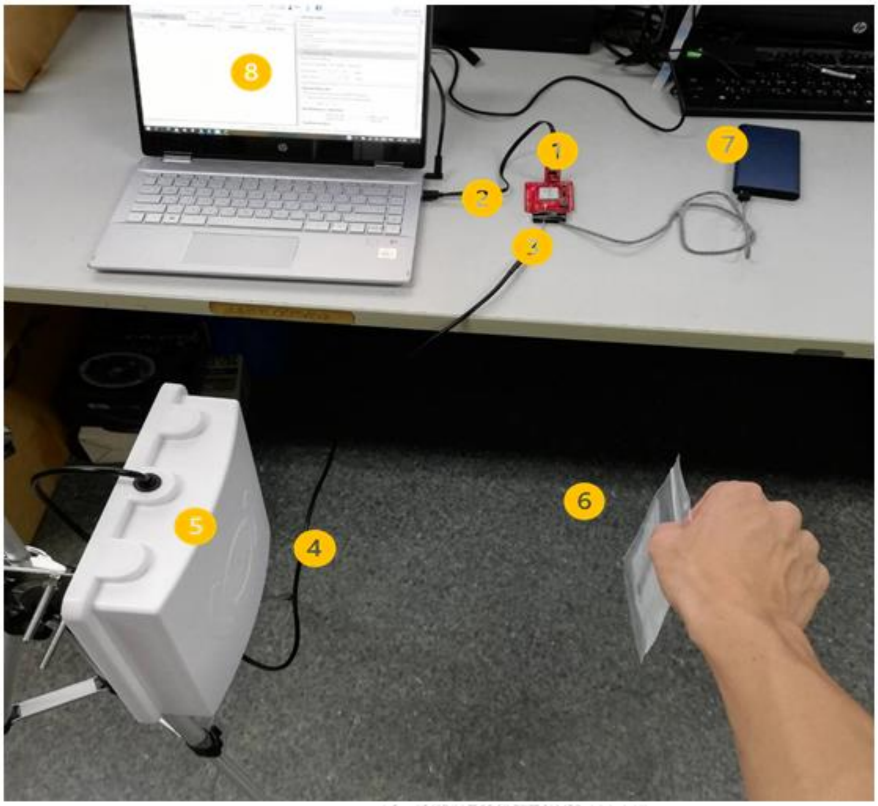

Fig. 12. RFID components

1. USB to reader serial breakout
2. Sparkfun RFID reader
3. Interface Cable RP-SMA to U.FL
4. Interface Cable for RP-TNC to RP-SMA
5. Antenna
6. RFID tag
7. Power bank
8. Host using URA

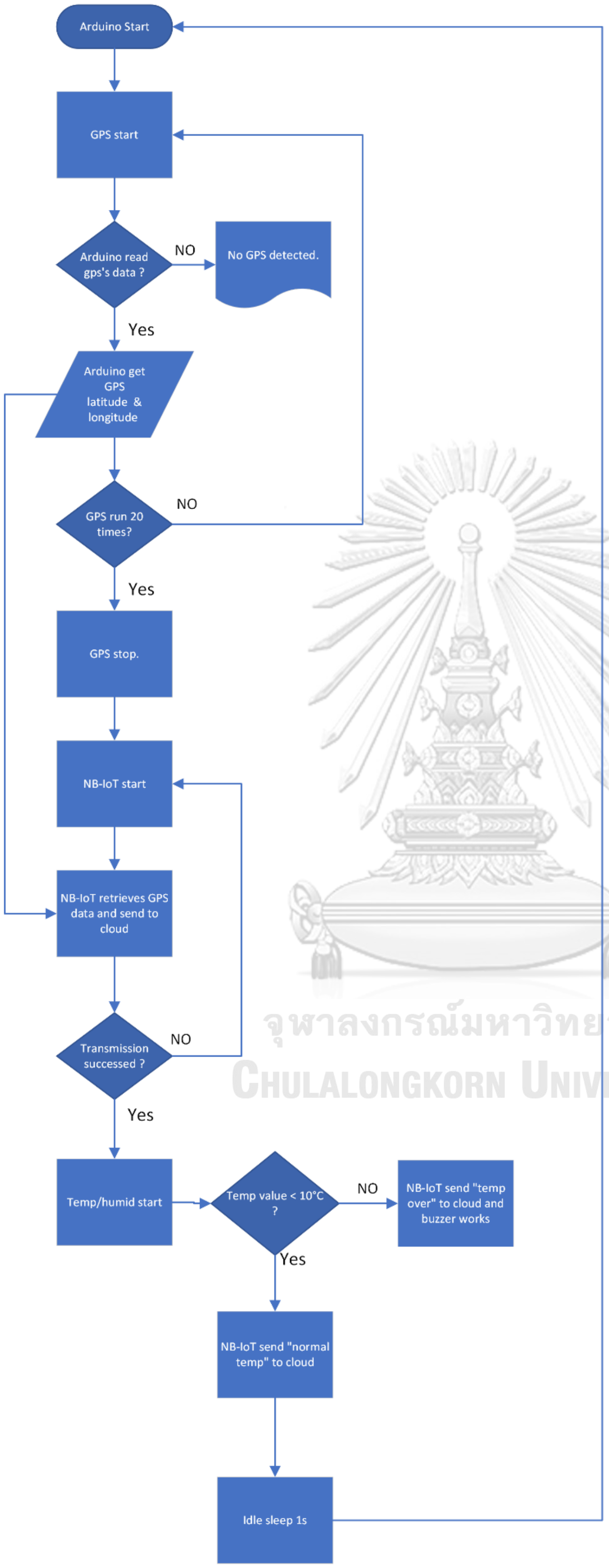

Fig. 13. IoT flowchart

4.2 Research procedure

All of the measurement procedures involve two phases:

1. Laboratory Experiment (at Chulalongkorn Engineering Laboratory)
2. Outdoor Experiment (at Chulalongkorn Hospital)

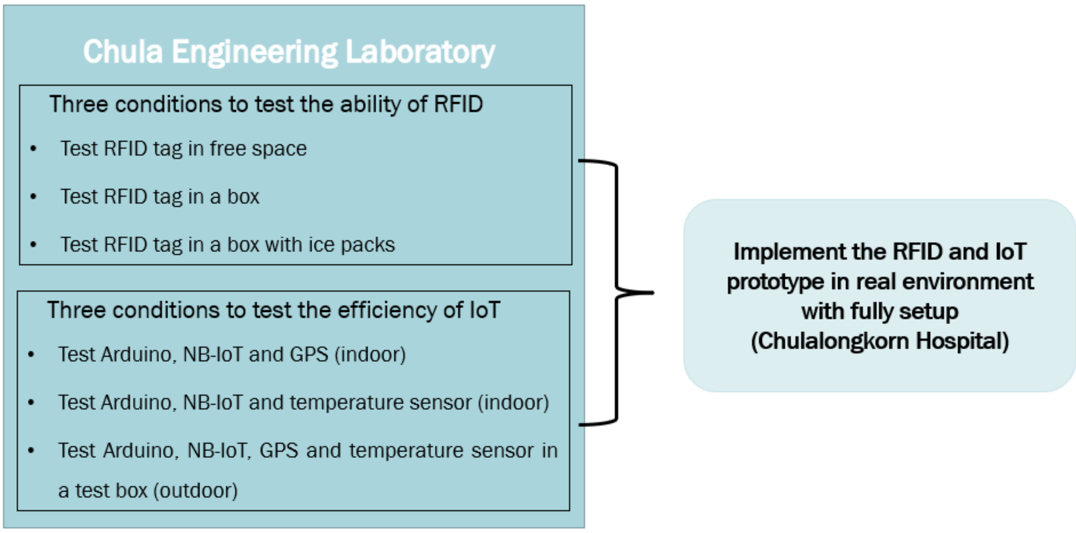

Fig. 14. Research procedure

Chapter 5 Preparation, implementation, and result

5.1 Preparation

5.1.1 Setting up and installation (hardware and software)

This stage covers all the necessary information for hardware, software, and the way to use it .All of the necessary components are listed on Table 11 to 15.

Table 11: Hardware component list

Device	Functionality	Qty
RFID reader	Reading/writing to the RFID tag/tags	3
RFID UHF Passive tag (non-adhesive)	Store patient information that sticks on test tubes	25
RFID UHF external antenna	Enhancing RFID RF wave to detect greater range	3
RFID serial basic breakout	Quickly and easily convert serial signals to USB	3
Interface Cable for RP-TNC to RP-SMA	Connect ultra-high-frequency RFID antennas to a powerful reader board	3
Interface Cable RP-SMA to U.FL	Attach RFID devices to a 2.4GHz antenna	3
Tripod	Attach RFID antenna to a leg of the tripod	3
Blood transport cooler box	Maintains temperature for up to 5 hours Keeps reagents, enzymes and other biological samples cool on the bench top	1
Ice packs	Maintains temperature	10
AC-to-DC adapter	Powering RFID reader	3
Arduino Mega	Attach with NB-IoT	1
Arduino Uno	Attach with RFID reader for checking test tubes' s assigned destination	1
NB-IoT	Connect with Arduino Mega that need small amounts of data, low bandwidth, and long battery life. Support to use "Magellan" cloud platform.	1
GPS	Tracking and tracing cooler box location	1
Temperature and humidity sensor	Measure the temperature of its environment	1
Buzzer	When temperature getting higher than limited value, it works as an actuator	1
External power bank	Powering Arduino mega and Arduino Uno	2
Laptop	Act as an interface for controlling RFID reader	3

We implemented a protocol in the central node by using the VB programming language (Visual Basic). Moreover, we create GUI (Graphical User Interface) and database(User Application Layer)for storing the mobile node information such as ID, EPC, Time and Read_count. A database is a place where we store information, and we organize the information in our database in such a way that our programs and applications can provide useful functions for end-users. For GUI, we also provide the ability to the user to customize their own ASCII text by changing the input Hex code.

Table 12: software component list

Software	Function	Used for
URA	Universal Reader Assistant works as an interface for controlling RFID reader. It is compatible with window operating system.	RFID
C#	GUI is written with C# to convert Hex to ASCII code.	Hex to ASCII conversion
Node.js	JavaScript runs on node.js that can receive, parse, display the data and upload those tag result to MySQL database.	For database MySQL
Magellan	NB-IoT device supports “Magellan” cloud platform that shows sensor value timely from sensors and visualize data with the help of widgets.	Cloud platform
Arduino IDE	Arduino IDE is to write code and upload it to the board.	To interact with Arduino board

Table 13: Sample EPC name for RFID tag

No.	EPC name
1	4368756c615f415f48311263
2	4368756c615f415f94498624
3	4368756c615f415f88296930
4	4368756c615f415f14729546
5	4368756c615f415f24755995
6	4368756c615f415f55571260
7	4368756c615f415f58521969
8	4368756c615f415f30220509
9	4368756c615f415f76374934
10	4368756c615f415f12675823
11	4368756c615f415f90395109
12	4368756c615f415f77450458
13	4368756c615f415f16007623
14	4368756c615f425f11586366
15	4368756c615f425f33313563
16	4368756c615f425f53620075
17	4368756c615f425f26755287
18	4368756c615f425f17318887
19	4368756c615f425f56252580
20	4368756c615f425f51073231
21	4368756c615f425f87733079
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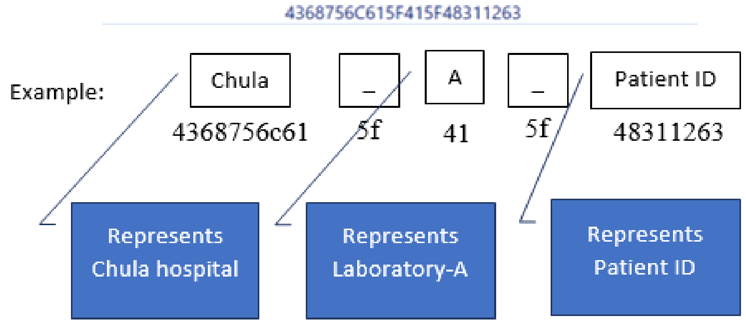


Fig. 15. Example of EPC name

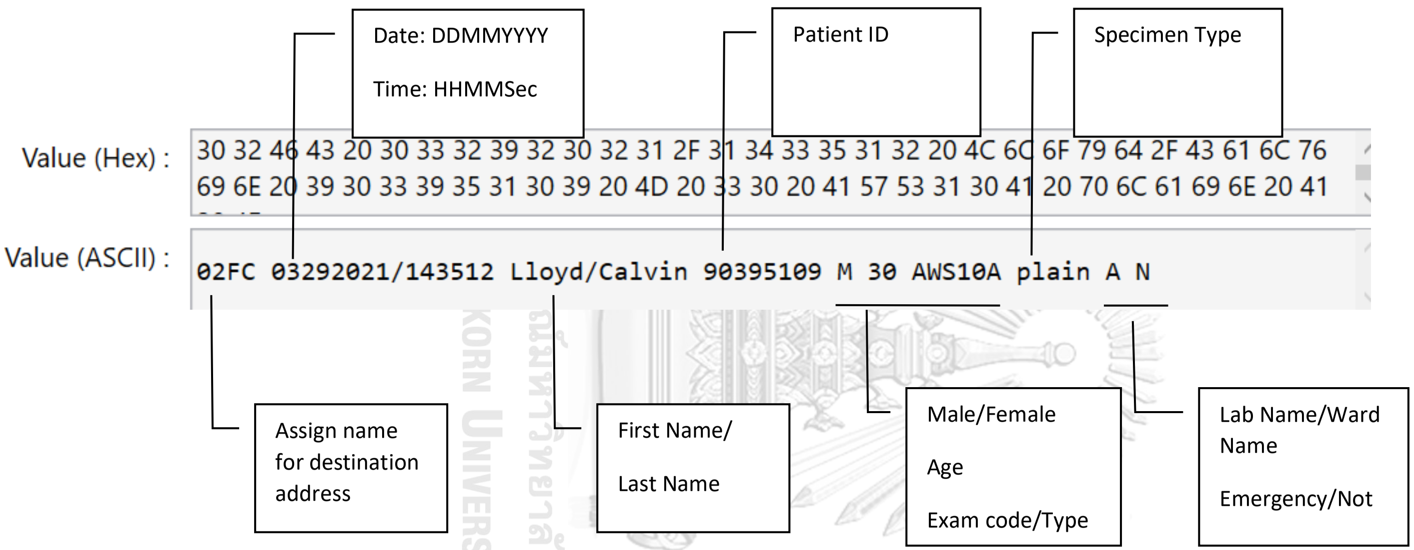


Fig. 16. Example of patient information

Table 14: Sample test tubes transport cooler box's RFID tag data

Box No	Amount of Blood Tubes inside a box	Total test tubes for Station-1	Name of station-1 test tubes	Total test tubes for Station-2	Name of station-2 test tubes	Officer Name	Timestamp
4368756c614368756c61	25	13	12345678910111213	12	141516171819202122232425	Bob	03292021

Table 15: Sample patient data for RFID tag user memory

No.	GPS	Specimen Collection Time	First Name	Last Name	Patient ID	Patient Gender	Patient Age	Exam code or type	Specimen Type	Lab Name or Ward name	Emergency or Not
1	02FC	03292021/143502	John	nick	48311263	M	20	AWS10A	serum	A	Y
2	02FC	03292021/143503	John	Carter	94498624	F	21	AWS10A	Plain	B	N
3	02FC	03292021/143504	Elve	Unte	88296930	M	22	AWS10A	Green	A	Y
4	02FC	03292021/143505	John	Carter	14729546	F	23	AWS10A	Serum	B	N
5	02FC	03292021/143506	John	Carter	24755995	M	24	AWS10A	Plain	A	N
6	02FC	03292021/143507	Lloyd	Calvin	55571260	F	25	AWS10A	Green	B	Y
7	02FC	03292021/143508	Barber	Mave	58521969	M	26	AWS10A	Serum	A	N
8	02FC	03292021/143509	Eve	Starve	30220509	F	27	AWS10A	Plain	B	Y
9	02FC	03292021/143510	Martin	Dave	76374934	M	28	AWS10A	Green	A	N
10	02FC	03292021/143511	Barber	Mave	12675823	F	29	AWS10A	Serum	B	Y
11	02FC	03292021/143512	Lloyd	Calvin	90395109	M	30	AWS10A	Plain	A	N
12	02FC	03292021/143513	Elve	Unte	77450458	F	31	AWS10A	Green	B	N
13	02FC	03292021/143514	Barber	Mave	16007623	M	32	AWS10A	Serum	A	Y
14	125F	03292021/143515	Lloyd	Calvin	11586366	F	33	AWS10A	Plain	B	N
15	125F	03292021/143516	Junnie	Jung	33313563	M	34	AWS10A	Green	A	Y
16	125F	03292021/143517	Hahm	June	53620075	F	35	AWS10A	Serum	B	Y
17	125F	03292021/143518	Eve	Starve	26755287	M	36	AWS10A	Plain	A	N
18	125F	03292021/143519	Mark	Lewis	17318887	F	37	AWS10A	Green	B	Y
19	125F	03292021/143520	Jole	Baen	56252580	M	38	AWS10A	Serum	A	N
20	125F	03292021/143521	Junnie	Jung	51073231	F	39	AWS10A	Plain	B	N
21	125F	03292021/143522	Hahm	June	87733079	M	40	AWS10A	Green	A	Y
22	125F	03292021/143523	Eve	Starve	83240604	F	41	AWS10A	Serum	B	N
23	125F	03292021/143524	Martin	Dave	26237206	M	42	AWS10A	Plain	A	Y
24	125F	03292021/143525	Barber	Mave	27170923	F	43	AWS10A	Green	B	N
25	125F	03292021/143526	Lloyd	Calvin	45057542	M	44	AWS10A	Serum	A	Y

5.1.2 Universal Reader Assistant

URA is a product of ThingMagic, which has many features as descript in the Fig. 17. Among these features, we focus only on: Tag Result, write EPC, user memory and tag inspector section. Initially, we need to set up “Serial” reader type, Baud rate, Region to “TH” mean “Thailand” and Antenna is “01” for reading RFID tag.

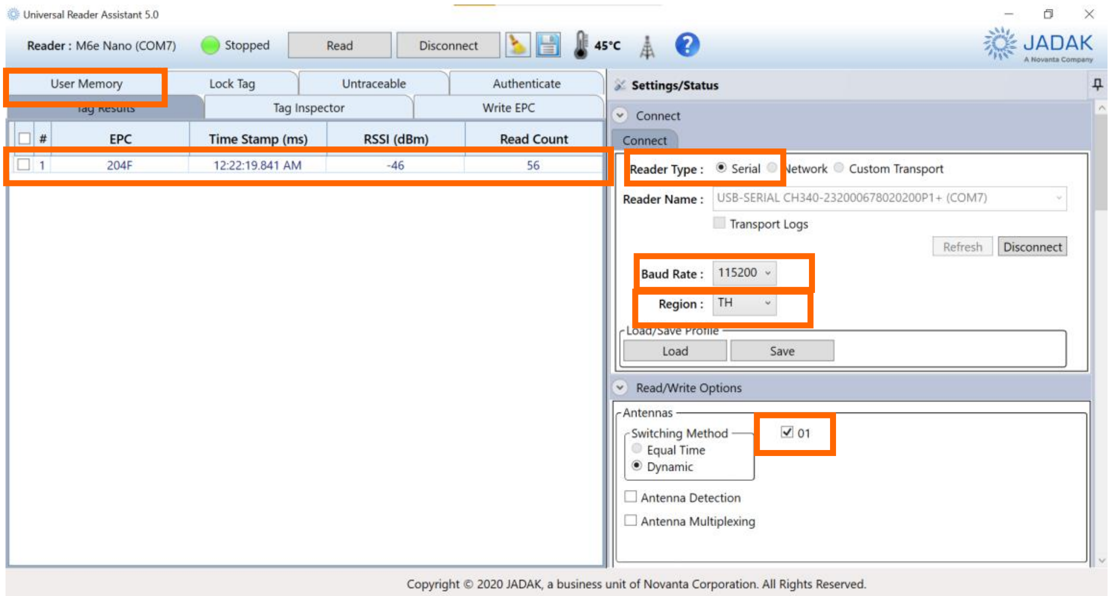


Fig. 17. URA features for RFID

5.2 Indoor implementation and result

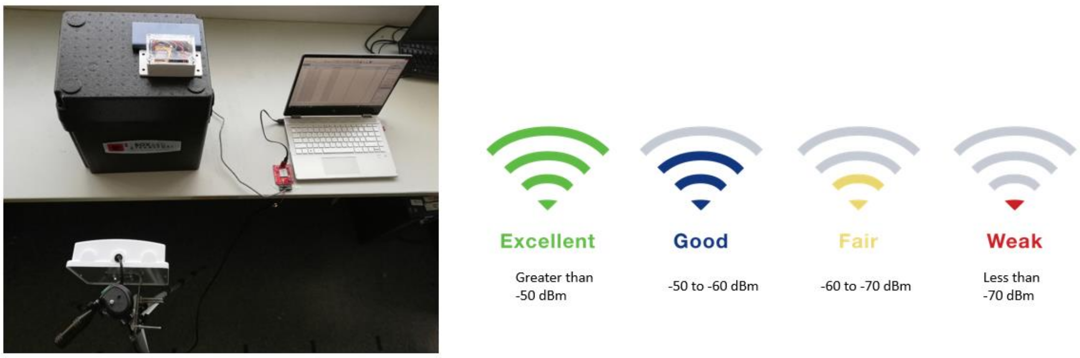


Fig. 18. overview photo of RFID test

5.2.1 RFID result

When the RFID prototype was implemented, we used Sparkfun products that support external antenna attachment and multi tag detection systems. Also, we used Universal Reader Assistant (URA) software which is used as an interface for a reader. In this implementation, we applied Gen2 RFID non-adhesive tag for the test tube.

We have tested the RFID reader ability with 3 conditions. They are as following

A. Onboard PCB antenna
    1. Test RFID tag in free space (free means there is no obstacle between antenna and RFID tag)
B. External antenna
    1. Test RFID tag in free space (reading)
    2. Test RFID tag in free space (writing)
    3. Test RFID multi tag in a box
    4. Test RFID multi tag in a box with ice packs
C. Test with 3 antennas

A. Onboard PCB antenna

Sparkfun RFID reader has not only onboard PCB antenna but also support external antenna attachment. However, The board we are using has a single external antenna connection. According to the manufacturer, onboard PCB antenna can read up to 1 to 2 feet. At real environment, we have tested it and all of the test result detail can be seen in below Fig. 19.

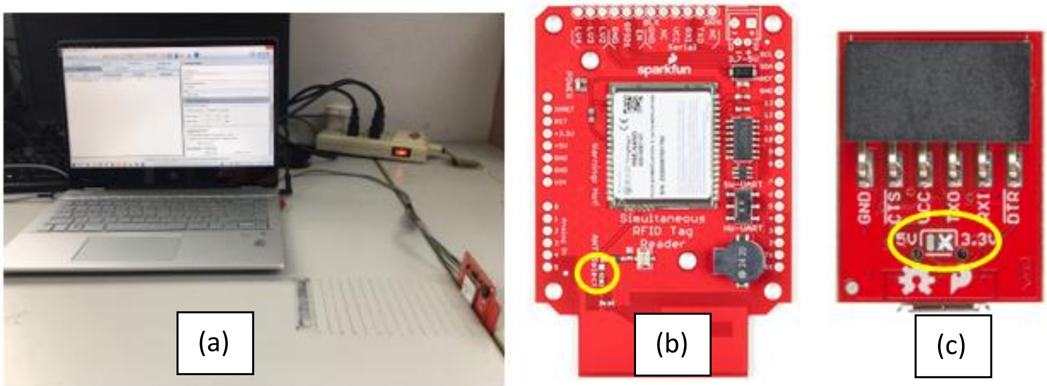
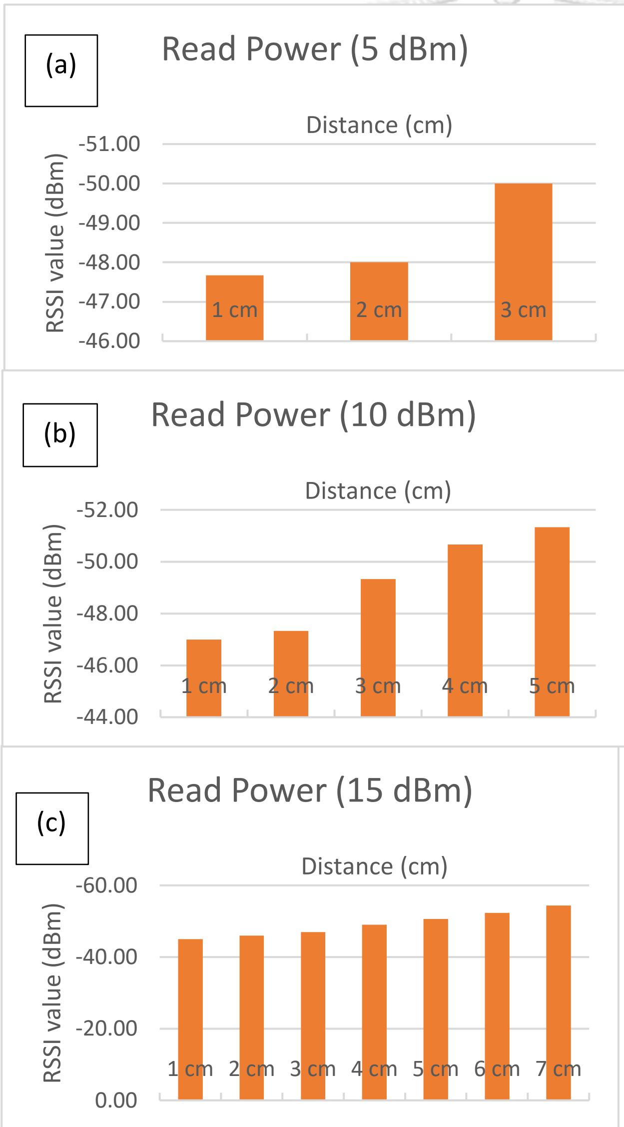


Fig. 19. (a) RFID test with PCB antenna (b) position of PCB antenna on RFID reader (c) breakout's default output power 3.3V

1. Test RFID tag in free space (PCB antenna)

Initially, we made an experiment an RFID reader with an RFID tag using internal PCB antenna. There is no external power supply for RFID reader. And serial breakout was setting to default 3.3 V. At here, external power supply is very important for RFID detection. This RFID reader was using USB power from computer that has a limited power output. Normally, manufacturer recommend using only Read power (5 dBm) if we use USB power supply. However, this experiment can show how long-distance RFID reader can detect to RFID single tag using different read power (dBm). Firstly, we set 5 dBm read power and change RFID tag 1 cm by 1 cm. Every testing was made 3 times repeated and average value is final result. During repeated testing, some fail due to not enough read power supply that we do not consider it. Although The board has adjustable power output from 0dBm to 27dBm, we cannot use 25 dBm and 27 dBm for that time as USB cannot provide enough. All of the result are visualized with chart (Fig. 20) in order to easily understandable.



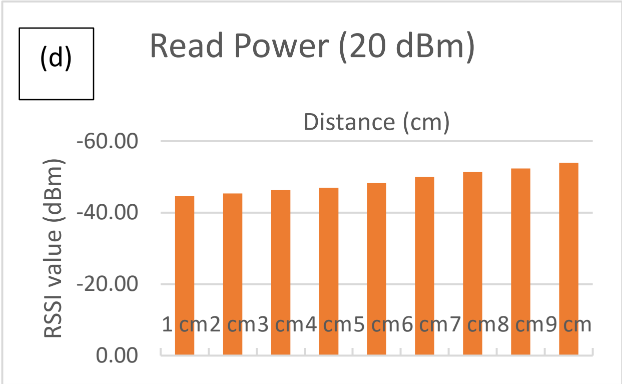


Fig. 20. RFID tag detection result with PCB antenna using 5dBm, 10dBm, 15dBm, and 20dBm

As we can see above chart, when we increase reading power the RFID reader can detect longer range. However, as long as the distance from the reader is far, the RSSI value is decrease. The longest distance we got from the test result is 9 cm using 20 dBm.

B. External antenna

Initial studies were carried out using onboard antenna for a period of time. RFID reading range result was collected during the first step. Subsequently we have done an experiment using external antenna. Sparkfun RFID reader support single UHF(860-960 MHz) external antenna. This UHF antenna's gain is 6dBi. Gain is simply using radiated energy from some directions to intensify others. The higher the dBi number of the antenna, the less of a broad field pattern. The signal direction will go further directly but in a narrower direction. Thus, UHF antenna need to be pointed in preferred direction to send radio frequency signal so that limited signal can be intensified in desired location.

In addition, another important factor is polarization. This antenna uses linear vertical polarization and the positioning of an RFID tag to antenna is also the key. Manufacturer said with the correct antenna we can read RFID tag up to 16 feet. Therefore, we adjusted the serial breakout voltage from 3.3 V to 5 V and used external power supply for RFID reader. At real environment, testing result is influenced by both user-defined settings and by external environmental factors. We made an experiment at Chulalongkorn engineering laboratory.

At first condition, we set the read power at 5 dBm which is the lowest read power for RFID reader. At the 5 dBm, we move a tag from the external antenna 30 cm by each time. At read power 5 dBm, the detection is done at 30 cm away from external antenna in all degrees. After that, we fix the read power at 10 dBm and measure the distance again in order to get a good stable distance. As a result, 60 cm is the longest distance for that reading power. Every test was done 3 times repeated in each attempt. As a result, the more we use power for RFID detection, the longer distance we get.

However, According to the result, read power 20 dBm is good enough for RFID detection because it's RSSI is not too weak if compared with 25 dBm and 27 dBm. Als, the distance(300 cm) is a wide enough for RFID detection.

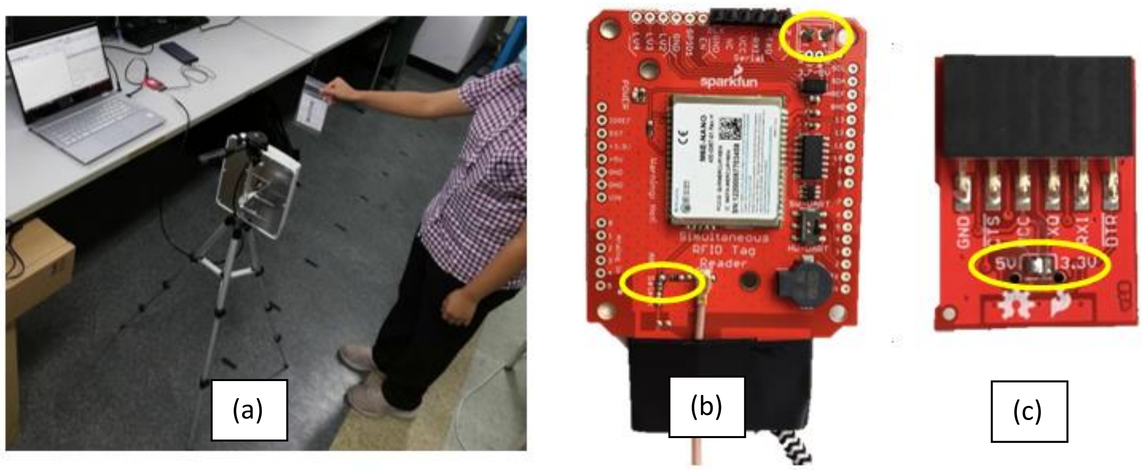


Fig. 21. (a) RFID tag testing with external antenna (b) external antenna position on RFID reader (c) adjust output power from 3.3V to 5V on breakout

1. Test RFID in free space (external antenna)

   First, we have tested single RFID tag reading in free space 30 cm by 30 cm.

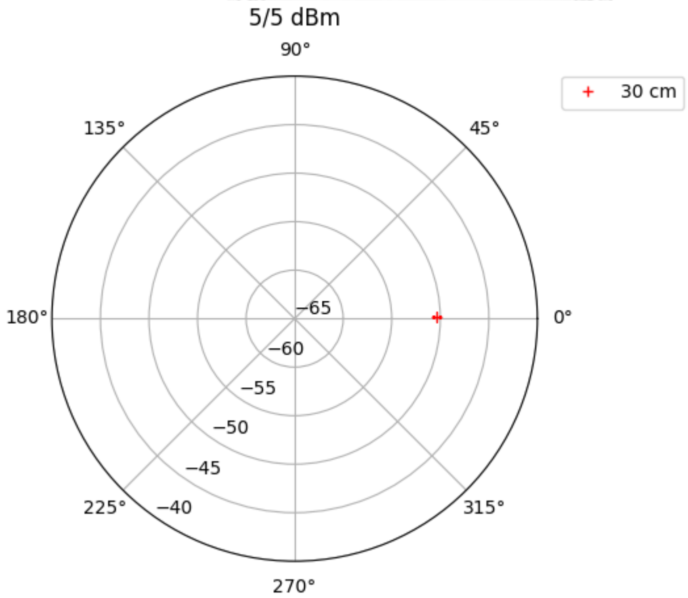


Fig. 22. RFID detection range with 5dBm

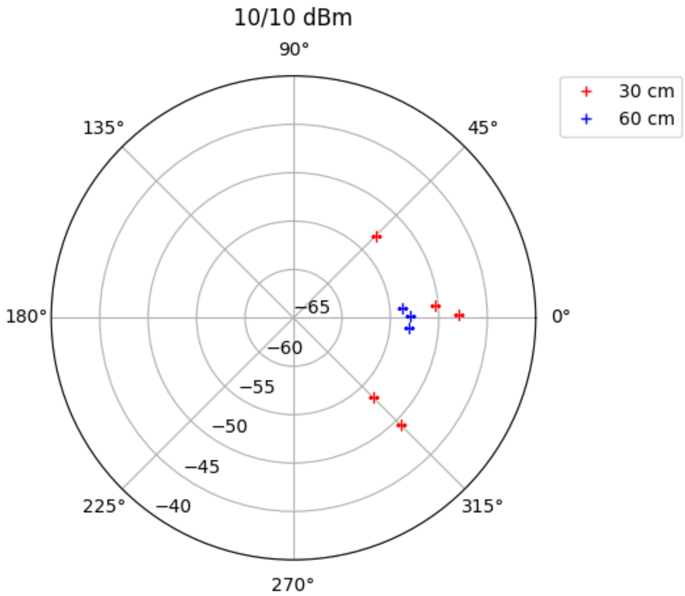


Fig. 23. RFID detection range with 10dBm

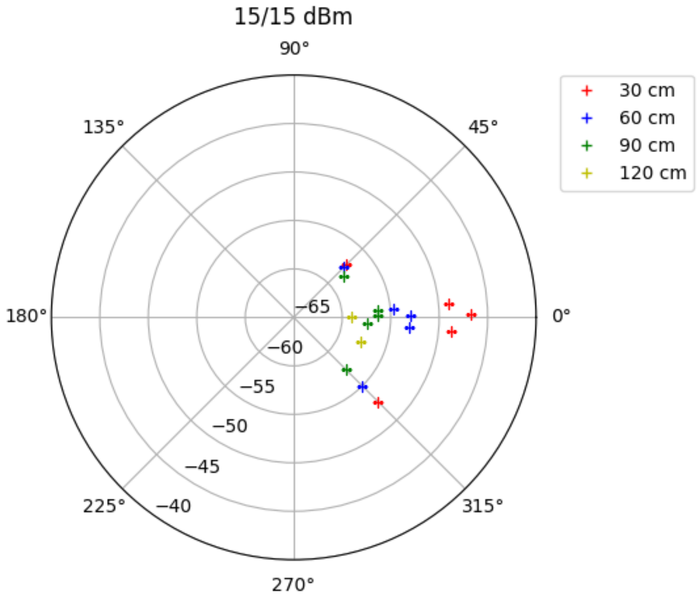


Fig. 24. RFID detection range with 15dBm

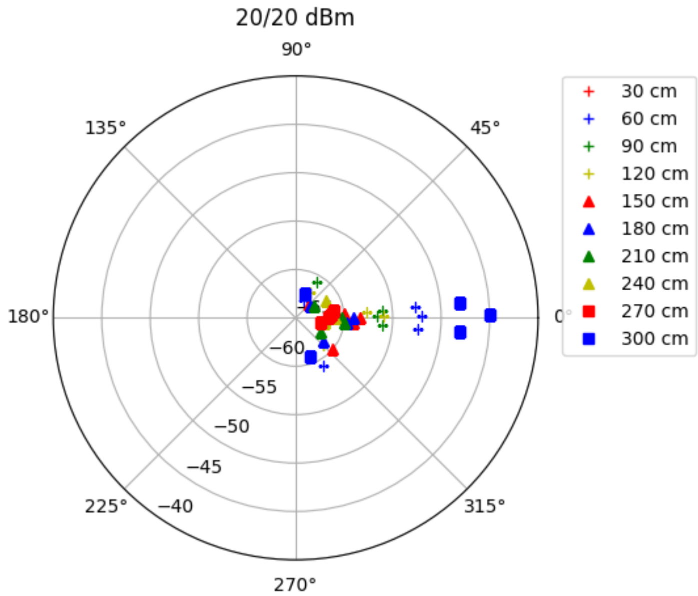


Fig. 25. RFID detection range with 20 dBm

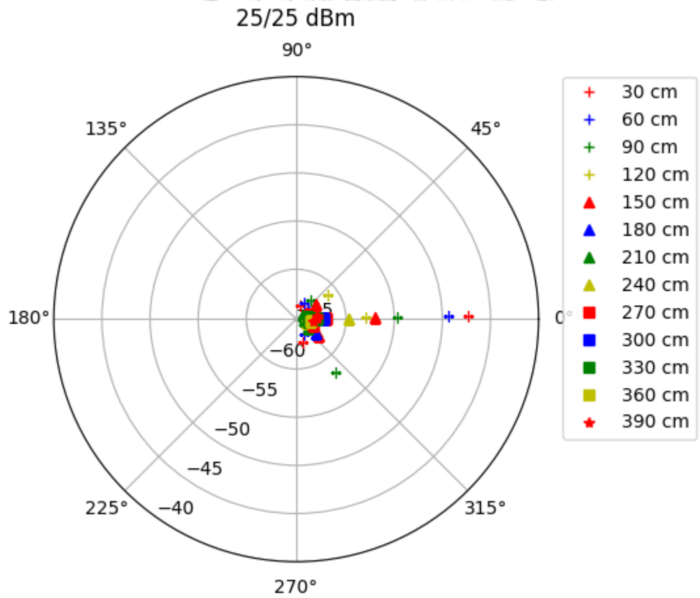


Fig. 26. RFID detection range with 25dBm

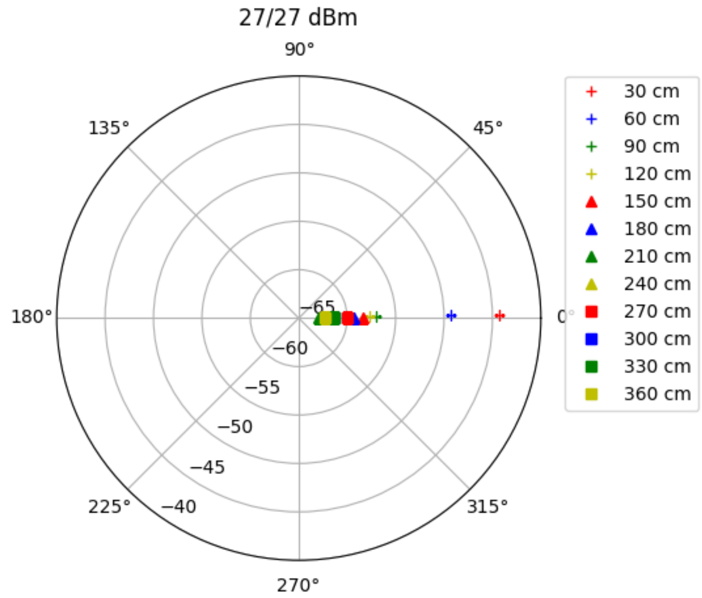


Fig. 27. RFID detection range with 27dBm

2. Test RFID tag in free space(writing)

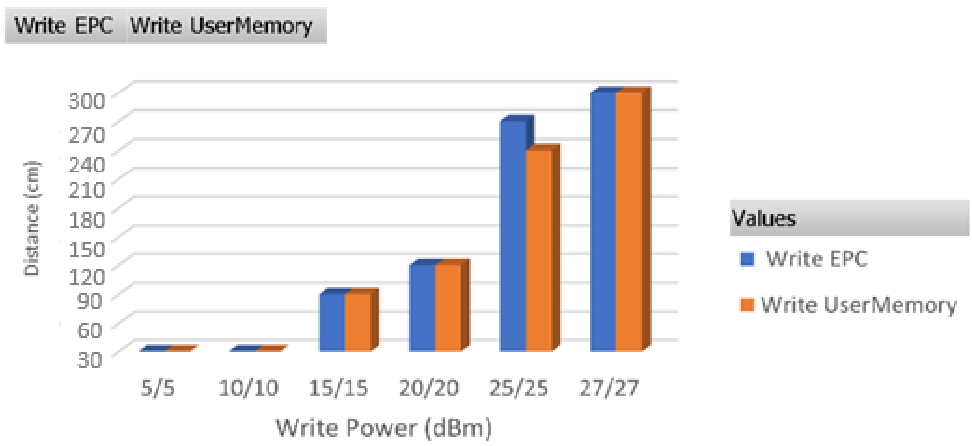


Fig. 28. RFID tag writing range test result

We also have tested not only RFID tag reading ability but also RFID tag writing ability of a tag in free space. According to the column chart, we can easily understand that 25dBm and 27 dBm output power is by far the longest distance over 200 cm away from antenna. We can adjust RFID coverage area to compatible with hospital's environment.

3. Test RFID multi tag in a box

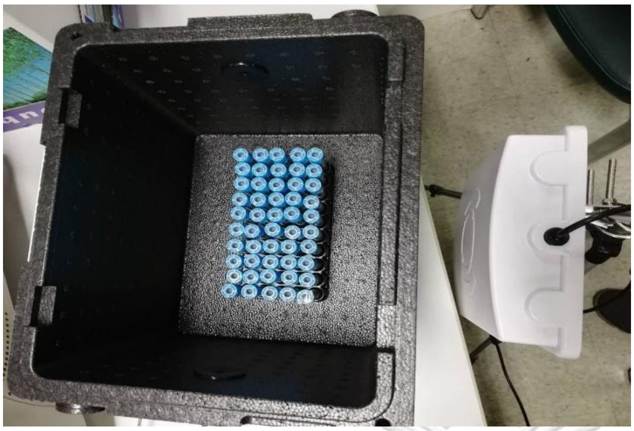


Fig. 29. Multiple tag detection range

After we tested the RFID tag with a single tag, we now can know the optimal distance and dB power for each. Then we tested with multiple tags in a box in order to know the distance and read power to detect the full test tubes in a rack. We use 50 multi tags and change distances. In a result, 22 cm away from the antenna for 50 tags can get full RFID tag detection result with 27 dBm.

4. Test RFID multi tag in a box with ice packs

When we test it with ice packs, we also consider about the position of ice packs because ice pack is a kind of obstacle for RF wave, and it can decrease the RSSI of tag. This experiment shows in Fig. 5 that is the same in a real environment test box delivery situation. We have tested the RFID detection range by changing different positions, items, and power supply. According to Fig. 15, we assume that a maximum 25 blood tubes is suitable for one box and ice packs should be placed only at the back and beside the box.

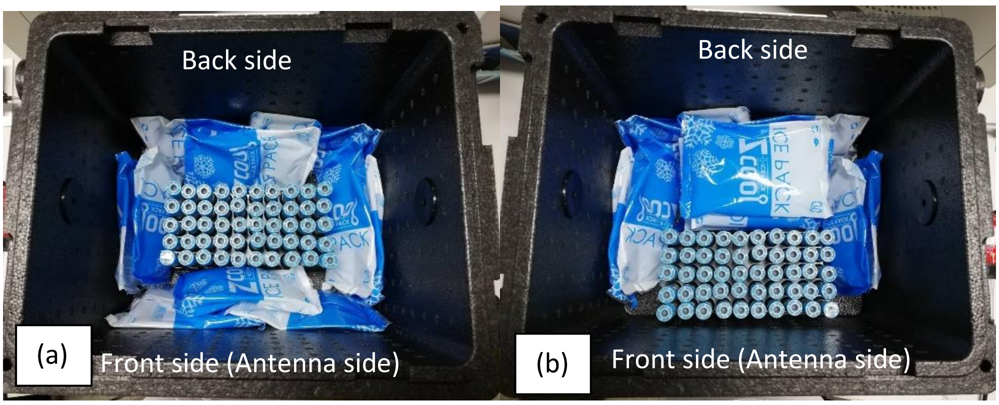


Fig. 30. Multiple 50 RFID tag detection test with 10 ice packs inside a cooler box (a) surrounding positions (b) put-aside position

Figure	Box from Distance antenna (cm)	Number of test tubes	Read Power (dBm)	Average number of detections	Percentage
a	30	50	27	34	68%
b	30	50	27	46.67	93%

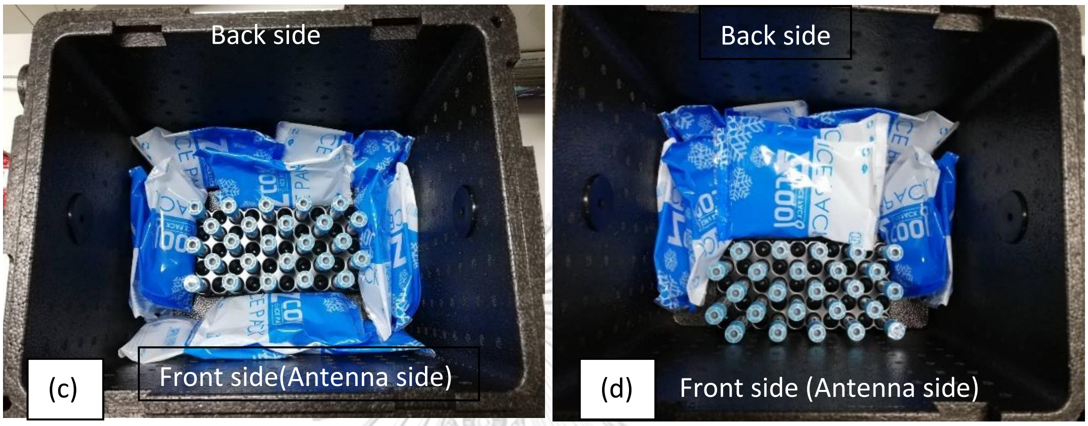


Fig. 31. Multiple 25 RFID tag detection test with 10 ice packs inside a cooler box (c) surrounding positions (d) put-aside position

Figure	Box from Distance antenna (cm)	Number of test tubes	Read Power (dBm)	Average number of detections	Percentage
c	30	25	27	21	84%
d	30	25	27	25	100%

C. Test with 3 antennas

Fig. 32. Test RFID tag result with 3 external antennas

After we have done a test with different approaches, we tested the RFID tag with 3 external antennas to be similar with real environment situation. At the first condition, a man was holding 25 test tubes and he walked along the way to the three antennas. When he reached in front of the antenna, he placed test tubes 30 cm away from antenna then he walked to next antenna. The reading power are 25 dBm and 27 dBm used in there. Each condition was okay to detection all test tubes. However, when we use 27dBm reading power, RFID reader getting hotter in a short time.

Fig. 33. RFID tag result with 3 antennas

5.2.2 IoT Result

According to the visual observation, it confirmed that the sensor worked as expected. Fig. 34 showed the GPS value that received around Chulalongkorn engineering campus. IoT test included individual GPS testing, individual temperature/humidity sensor testing and all together testing. Among those, Fig. 34 showed the test result of GPS testing that powered by external battery.

Fig. 34. Comparison of GPS test at Chula Engineering campus

5.3 Outdoor (Real environment) implementation and result

Firstly, we implemented RFID devices at main building, laboratory-A, and laboratory-B. We wrote sample patient information (Table.15), sample box information (Table.14) and EPC name (Table.13) to each RFID tag. Then test tubes are placed in a box for delivering to another laboratory and integrated with IoT box. A carrier man carried a box from main building to laboratory-A (Fig. 35). The duration from main building to laboratory-A is around 4 minutes (Fig .38). When a carrier man arrived in laboratory-A, medical staff scan a box to know the number of test tubes for lab-A and take out from the box(Fig. 37). After that, a carrier man delivered a box from lab-A to lab-B(Fig. 39). The duration from lab-A to lab-B is around 6 minutes. When he arrived in a lab-B, medical staff scan box's RFID tag to know the number of test tubes for that lab(Fig. 36). And then they took out those test tubes for further examination.

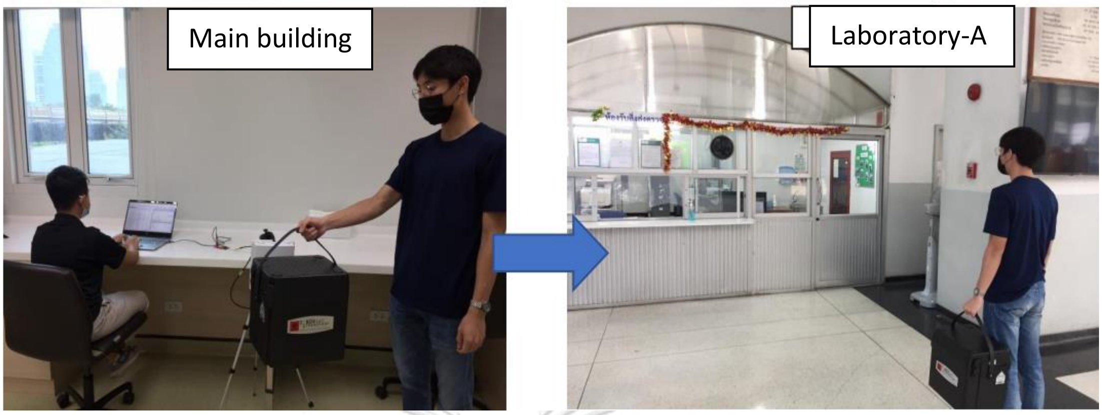


Fig. 35. RFID implementation at main building and delivered to laboratory-A

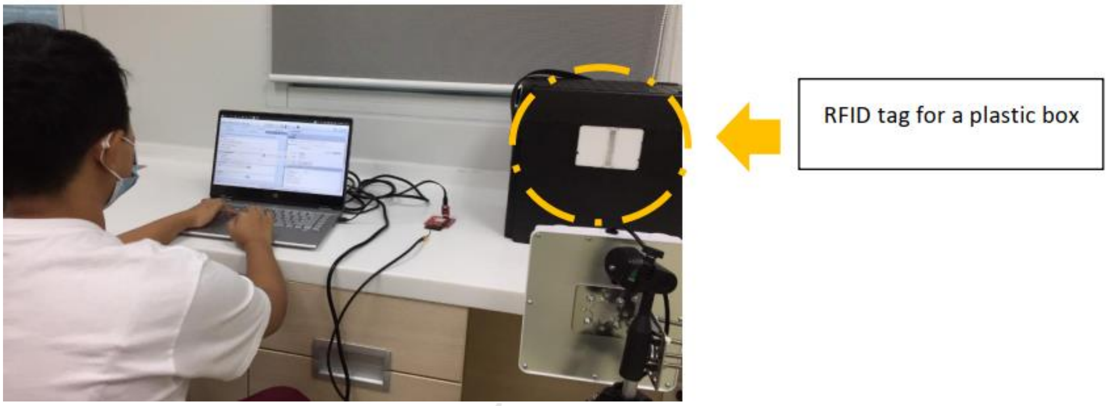


Fig. 36. Writing test tubes information into box's RFID tag

Fig. 37. 13 test tubes for lab-A

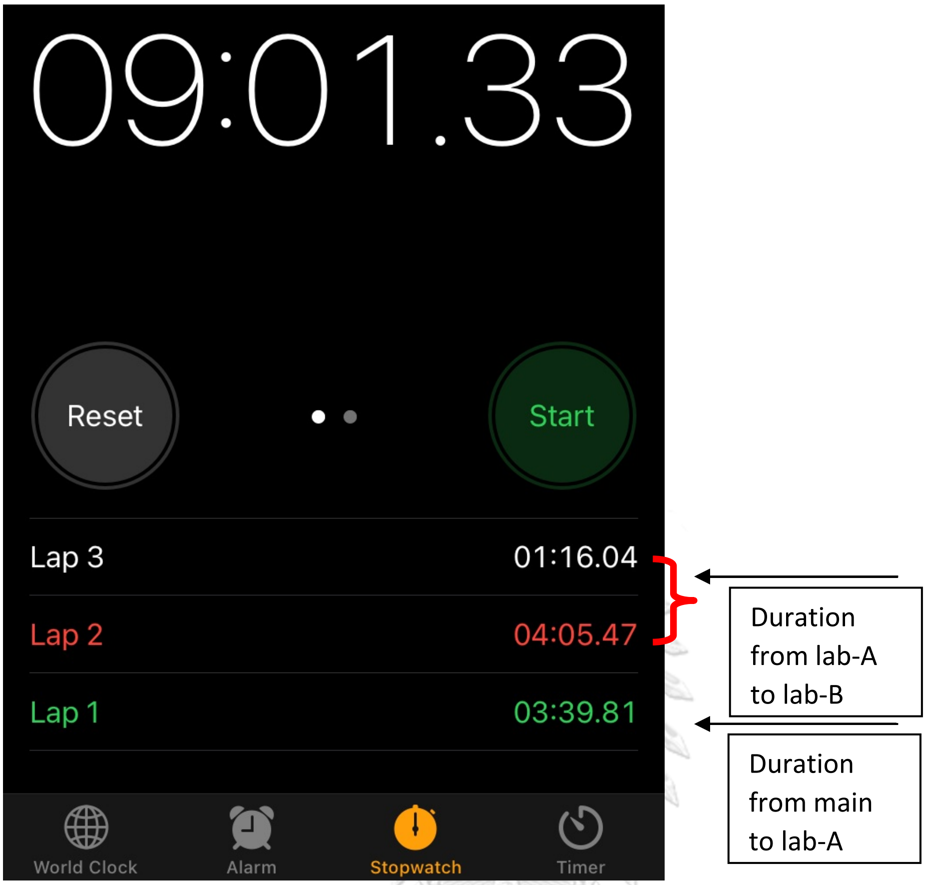


Fig. 38. Walking time duration from main building to another laboratories

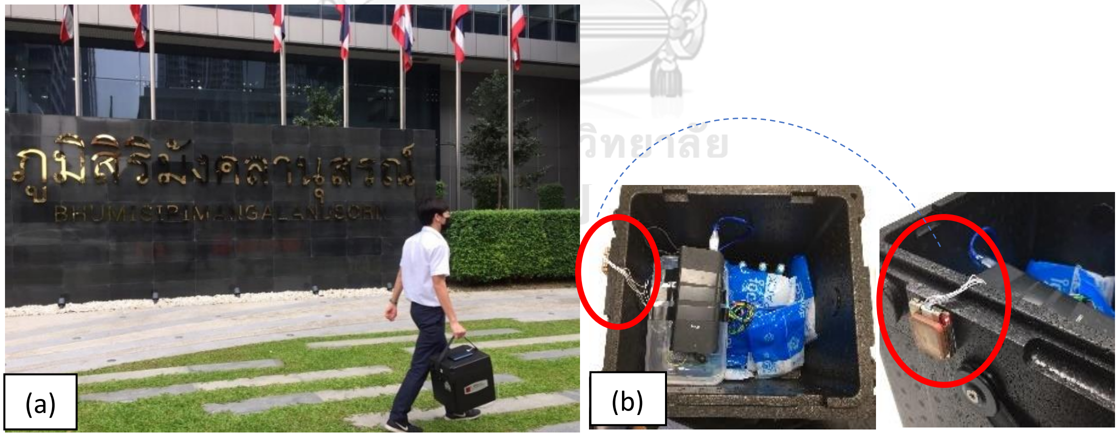


Fig. 39. (a) A carrier man is delivering test tubes (b) IoT prototype integrated in a plastic box

5.3.1 RFID result

At Chulalongkorn hospital, we made an experiment include RFID tag reading/writing process and IoT network testing. The test can be broken down into four major conditions.

1. Test RFID with empty test tubes in a box without icepacks
2. Test RFID with empty test tubes in a box with icepacks
3. Test RFID with liquid test tubes in a box without icepacks
4. Test RFID with liquid test tubes in a box with icepacks

Firstly, we compared the two blood tubes together at the same distance(30cm) from an RFID external antenna. EPC name (2049) is filled with a liquid and another one is not filled anything. The RSSI result is according to the Fig. 40. As per the tag result, we can know that the RSSI of a tag can be declined due to a liquid inside a tube.

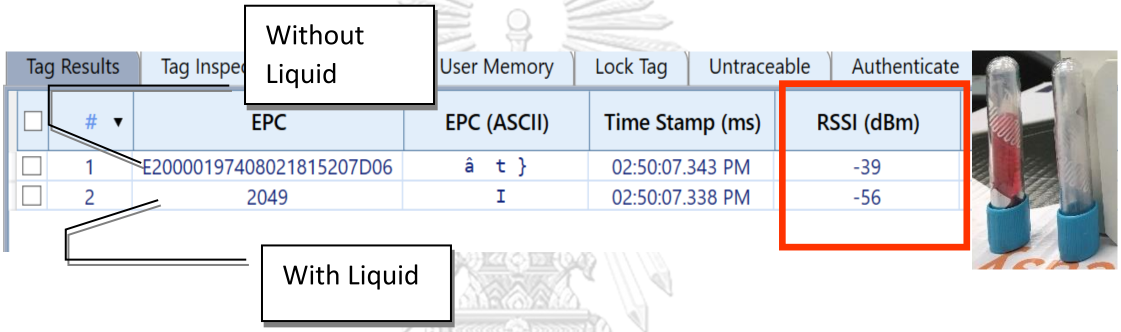


Fig. 40. RFID reading ability to different tags

We have tested RFID reading/writing ability for the 25 test tubes at laboratory-A. The test tubes remain as an empty bottle at this stage. When we tried to read RFID tag from the antenna, all of the blood tubes are detected with read power 25 dBm. The distance from the antenna to box is around 91 cm. Among those, I firstly checked box information in order to know the total number of test boxes for laboratory-A. To check box information, we have to click the box number at the “tag result” tab. According to the tag inspector result, we can know easily that Number(1) to Number(13) test tubes are for laboratory-A in Fig. 41.

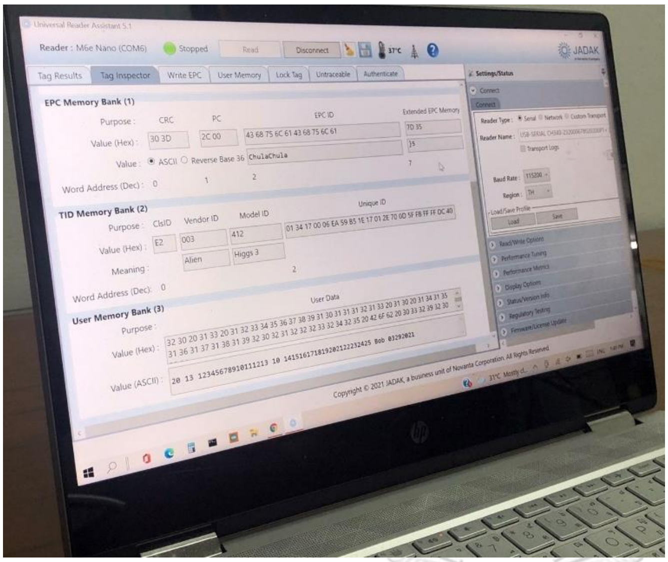


Fig. 41. Box information is checked in Tag Inspector tab

(a)

No.	EPC name
1	4368756c615f415f48311263
2	4368756c615f415f94498624
3	4368756c615f415f88296930
4	4368756c615f415f14729546
5	4368756c615f415f24755995
6	4368756c615f415f55571260
7	4368756c615f415f58521969
8	4368756c615f415f30220509
9	4368756c615f415f76374934
10	4368756c615f415f12675823
11	4368756c615f415f90395109
12	4368756c615f415f77450458
13	4368756c615f415f16007623
14	4368756c615f425f11586366
15	4368756c615f425f33313563
16	4368756c615f425f53620075
17	4368756c615f425f26755287
18	4368756c615f425f17318887
19	4368756c615f425f56252580
20	4368756c615f425f51073231
21	4368756c615f425f87733079
22	4368756c615f425f83240604
23	4368756c615f425f26237206
24	4368756c615f425f27170923
25	4368756c615f425f45057542

(b)

#	EPC
1	4368756C615F415F76374934
2	4368756C615F415F94498624
3	4368756C615F425F83240604
4	4368756C615F415F77450458
5	4368756C615F415F90395109
6	4368756C615F415F24755995
7	4368756C615F415F14729546
8	4368756C615F425F53620075
9	4368756C615F415F16007623
10	4368756C615F425F27170923
11	4368756C615F415F55571260
12	4368756C615F425F51073231
13	4368756C615F415F30220509
14	4368756C614368756C61
15	4368756C615F425F26237206
16	4368756C615F415F48311263
17	4368756C615F415F12675823
18	4368756C615F415F88296930
19	4368756C615F425F33313563
20	4368756C615F425F17318887
21	4368756C615F425F11586366
22	4368756C615F425F56252580
23	4368756C615F425F26755287
24	4368756C615F425F87733079
25	4368756C615F415F58521969
26	4368756C615F425F45057542

Box number

Fig. 42. (a) Tag result of pre-assigned numbers and (b) detected numbers

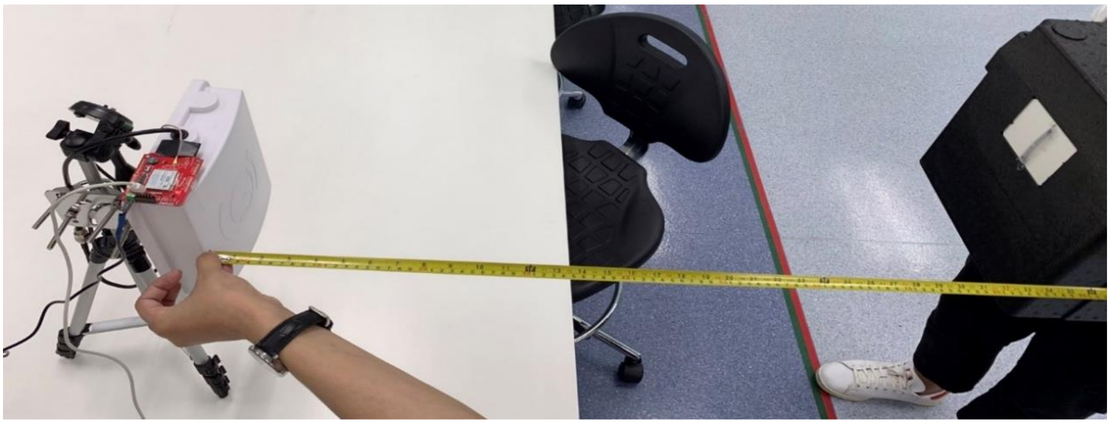


Fig. 43. Distance between box and antenna (without icepacks condition)

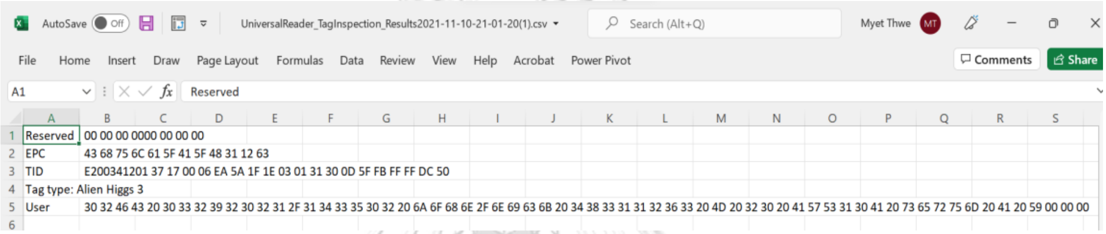
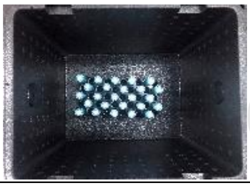


Fig. 44. URA can export (.csv file) of Tag results and Tag Inspector results

Table 16: Test result of RFID at hospital

Picture	Conditions	RFID Read/Write Power	Good Detection Distance(cm)
	25 empty test tubes inside a cooler box, without icepacks	25dBm	91 cm
	25 empty test tubes inside a cooler box, 10 icepacks	25dBm	20 cm
	25 test tubes filled liquid inside a cooler box, without icepacks	25dBm	10 cm
	25 test tubes filled liquid inside a cooler box, 10 icepacks	25dBm	5 cm

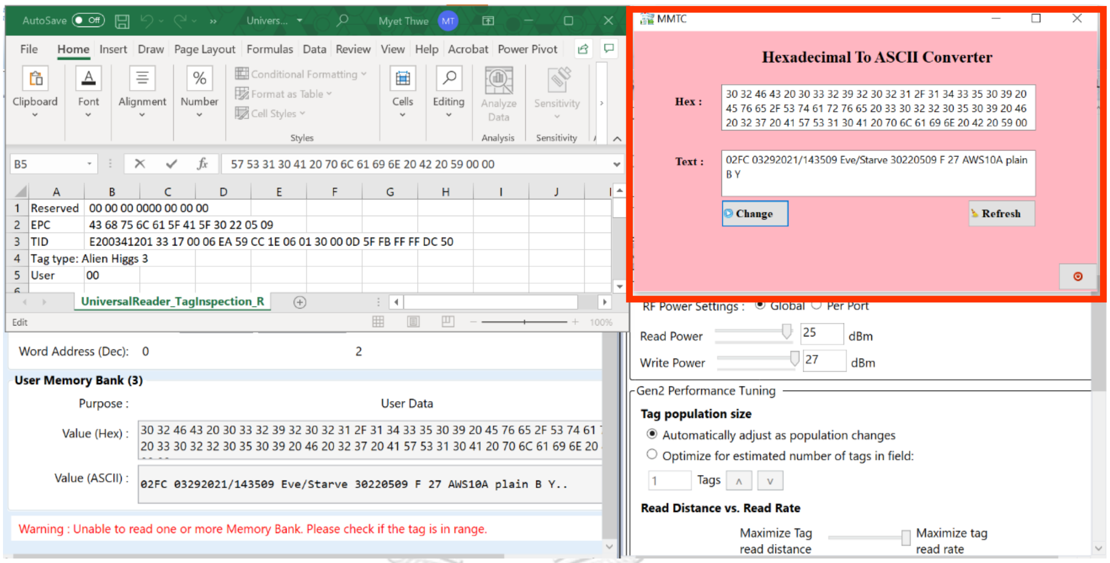


Fig. 45. Hex to ASCII conversion using C# in VB.Net program

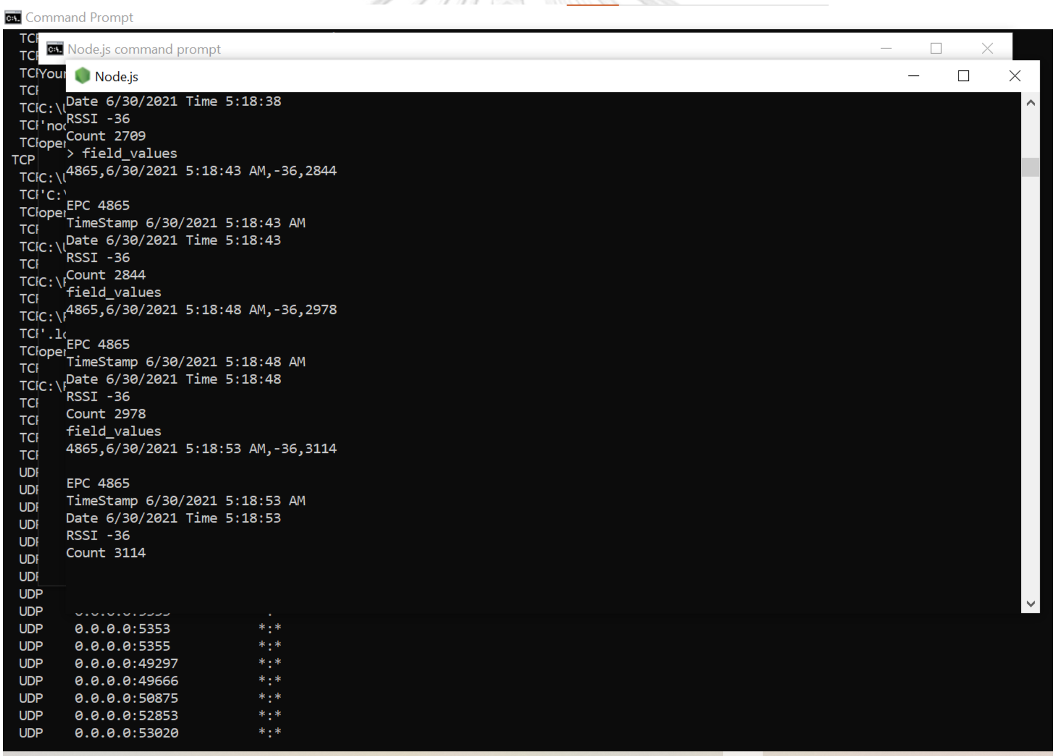


Fig. 46. Tag result sends to MySQL using Node.js via HTTP transport

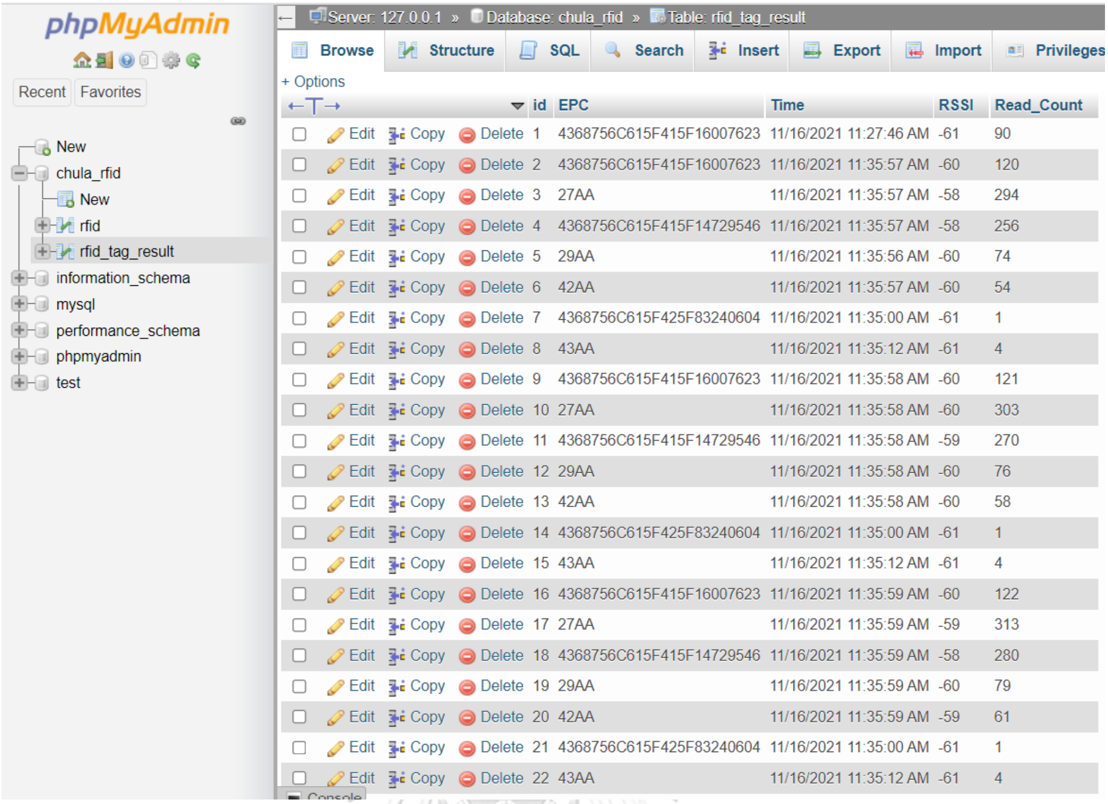


Fig. 47. Tag results send from URA can be checked in MySQL

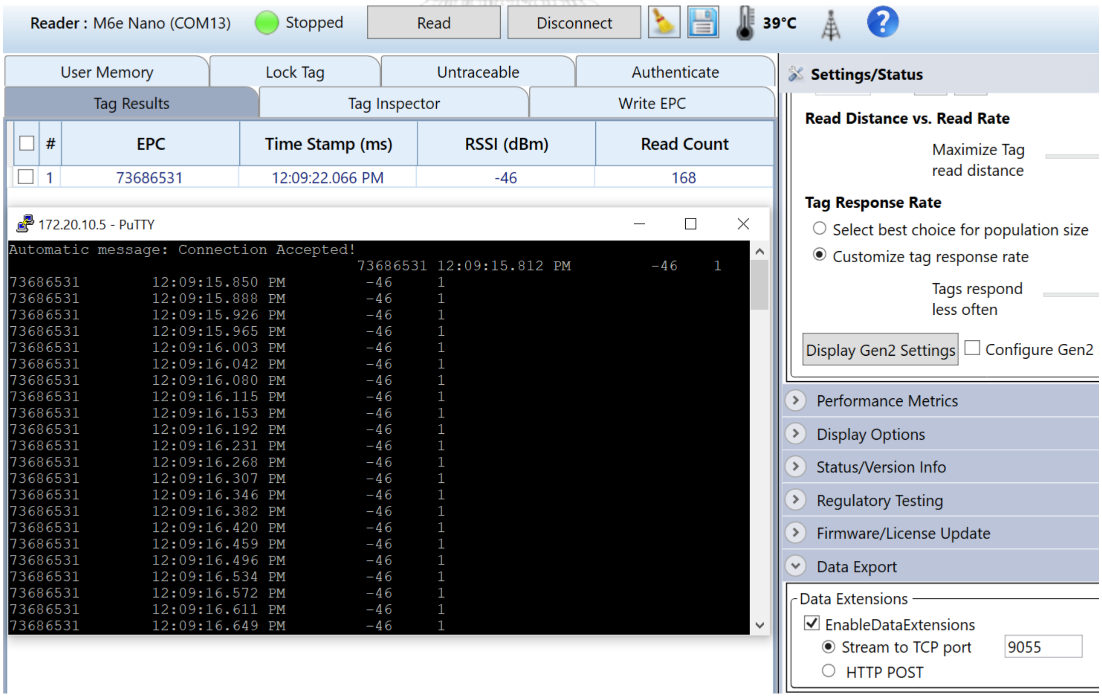


Fig. 48. Tag result sends to TCP port using PuTTY

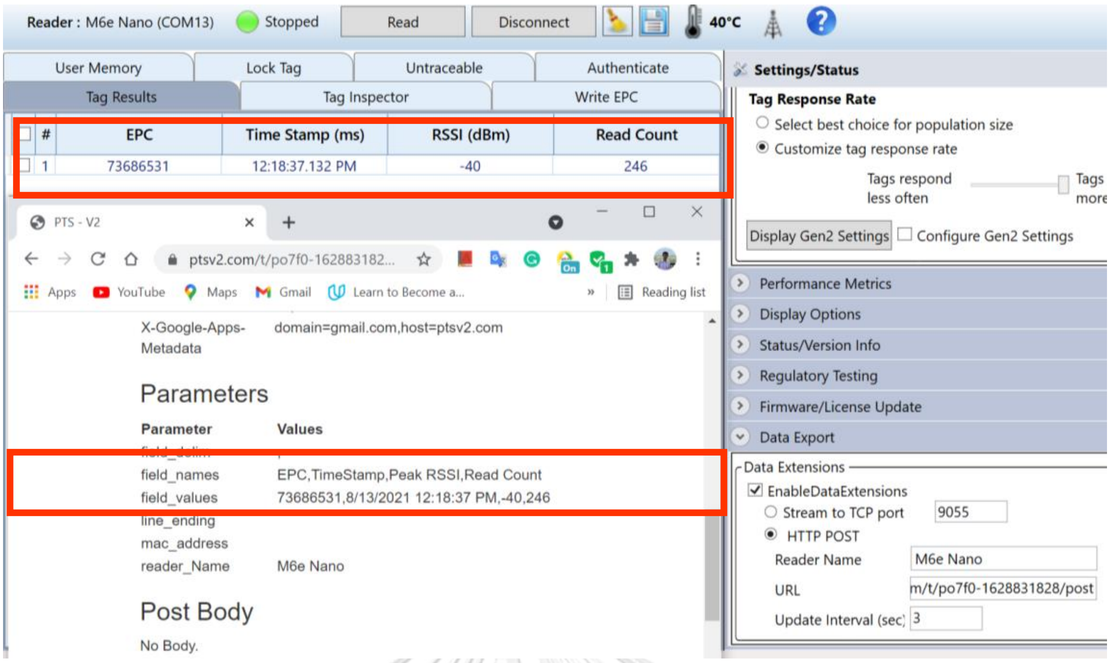


Fig. 49. Tag results send to ptsv2 via HTTP Post (Sample-1)

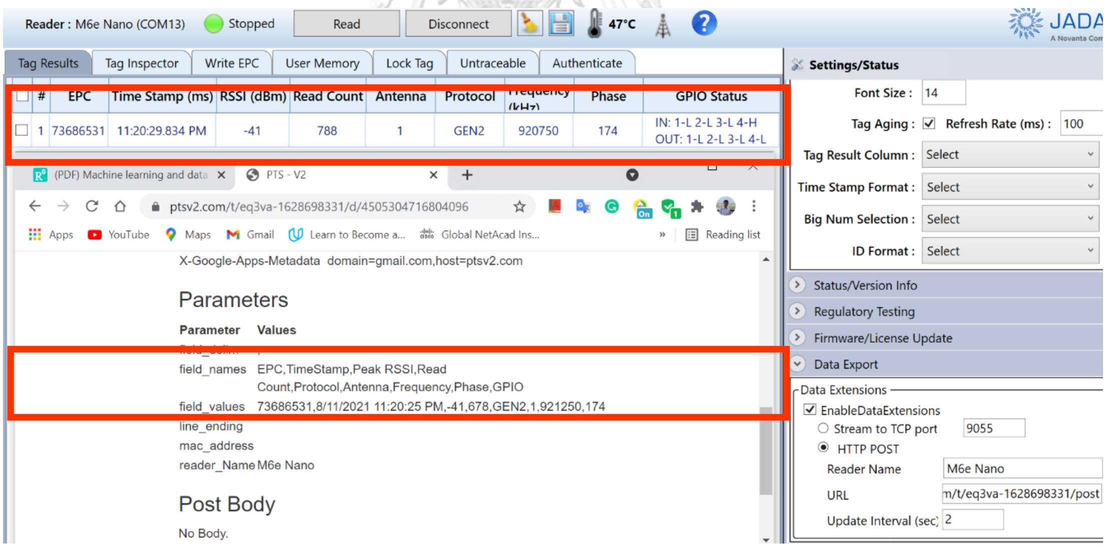


Fig. 50. Tag results send to ptsv2 via HTTP Post (Sample-2)

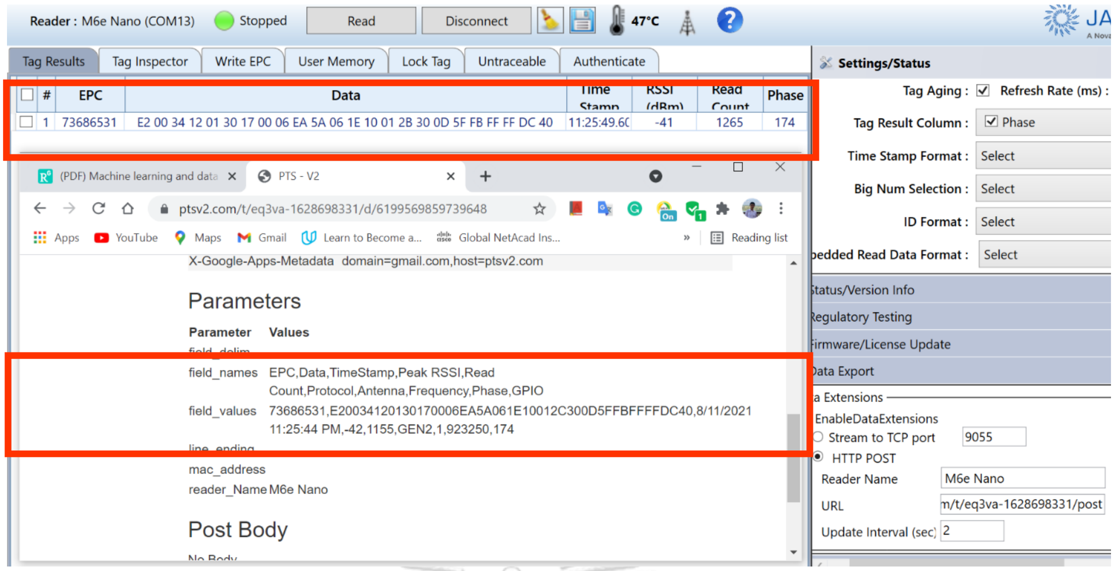


Fig. 51. Tag results send to ptsv2 via HTTP Post (Sample-3)

5.3.2 IoT result

The IoT prototype is integrated in a cooler box to get the temperature value, humidity value and location of the box as shown in Fig. 39(b). GPS receiver antenna is placed outside of the box's edge in order to enhance better satellite signal strength. While delivering from one to another laboratory, an IoT prototype is working, and it is sending sensor values every minute to the Magellan Cloud. There, we can check every logs and history of sensor values. Also, we can check the real-time sensor value in Magellan's dashboard as shown in Fig. 52.

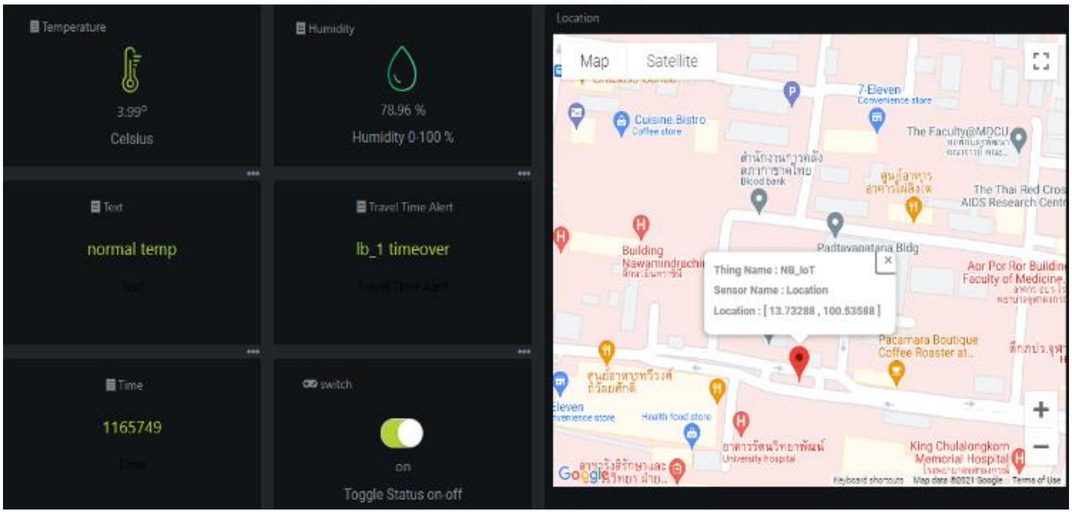


Fig. 52. sensor values show on Magellan

5.3.3 Performance evaluation

In this section, performance evaluation of sensor value will be discussed. The performances of the device have been evaluated by making a comparison of sensor value from the receiver side(Arduino side) and the transmitter side (NB-IoT side) shown in (Fig. 53,Fig. 54). As an experiment, the success ratio of payload transmission was measured. Total 6 modules were deployed in a box inside plastic box outdoor environment. In response to the query, receiver node reports to the transmitter node whether they detected a sensor value. This design choice was made primarily to cut the cost and complexity of each device, since the device do not have any intrinsic need to handle when get error. At that time, NB-IoT tried to retransmit it data to cloud up to 4 times.

Besides that, Electromagnetic interference(EMI) might happen when the signal cables are involved in the EMI process, this can cause a noise in signal transmission. Because of the noise, sensor value at Arduino side(receiver) and sensor values at Magellan side(transmitter) can be different due to latency. We collected temperature and humidity sensor value at both side at the same time in order to know if there is any data lost or not. According to Fig. 53 and Fig. 54, we can clearly see that there are not many differences between the receiver and transmitter side and NB-IoT device can transmit sensor value to the cloud in Chulalongkorn Hospital campus. Fig. 55 is GPS tracking latitude and longitude that we made a visualization for it.

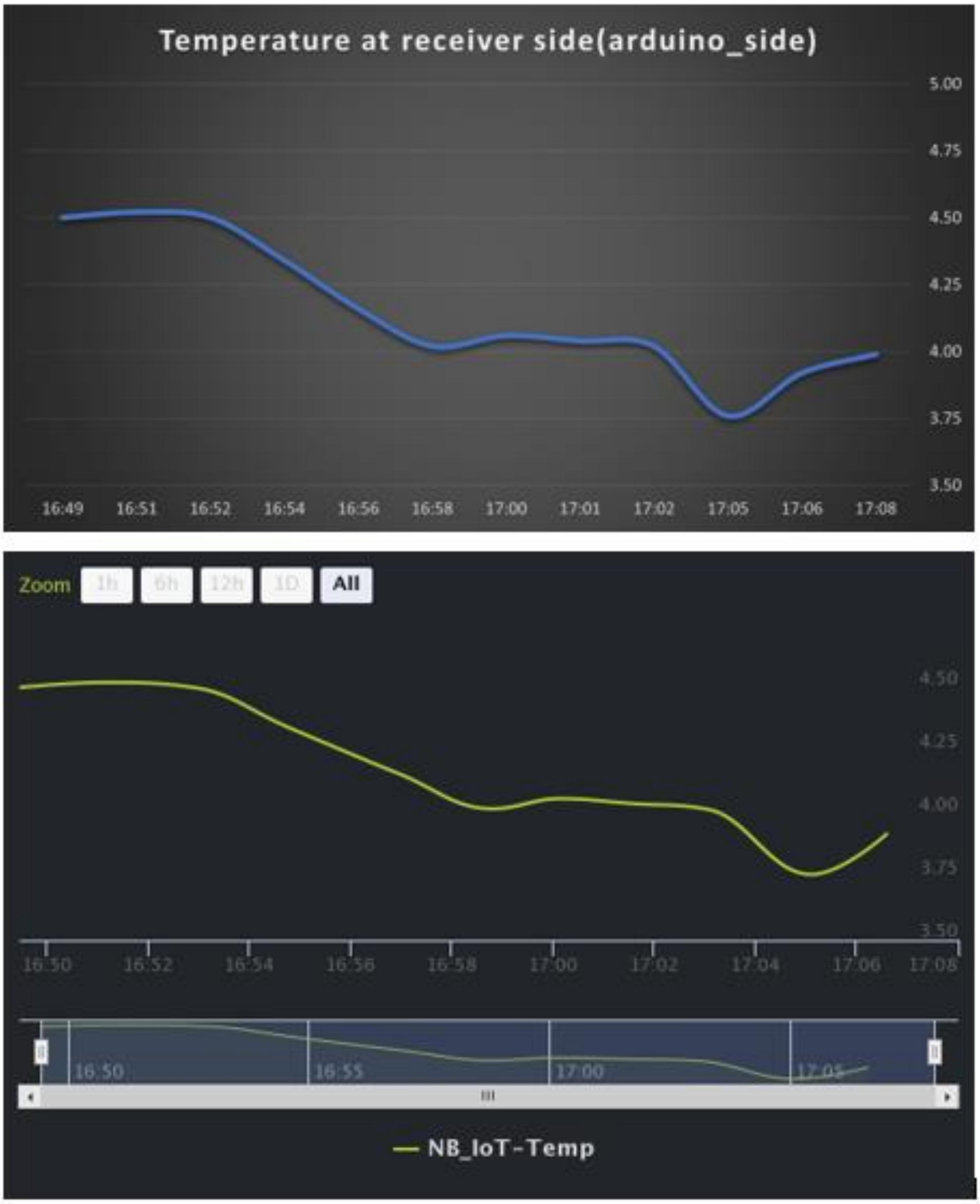


Fig. 53. temperature sensor value comparison on both end side

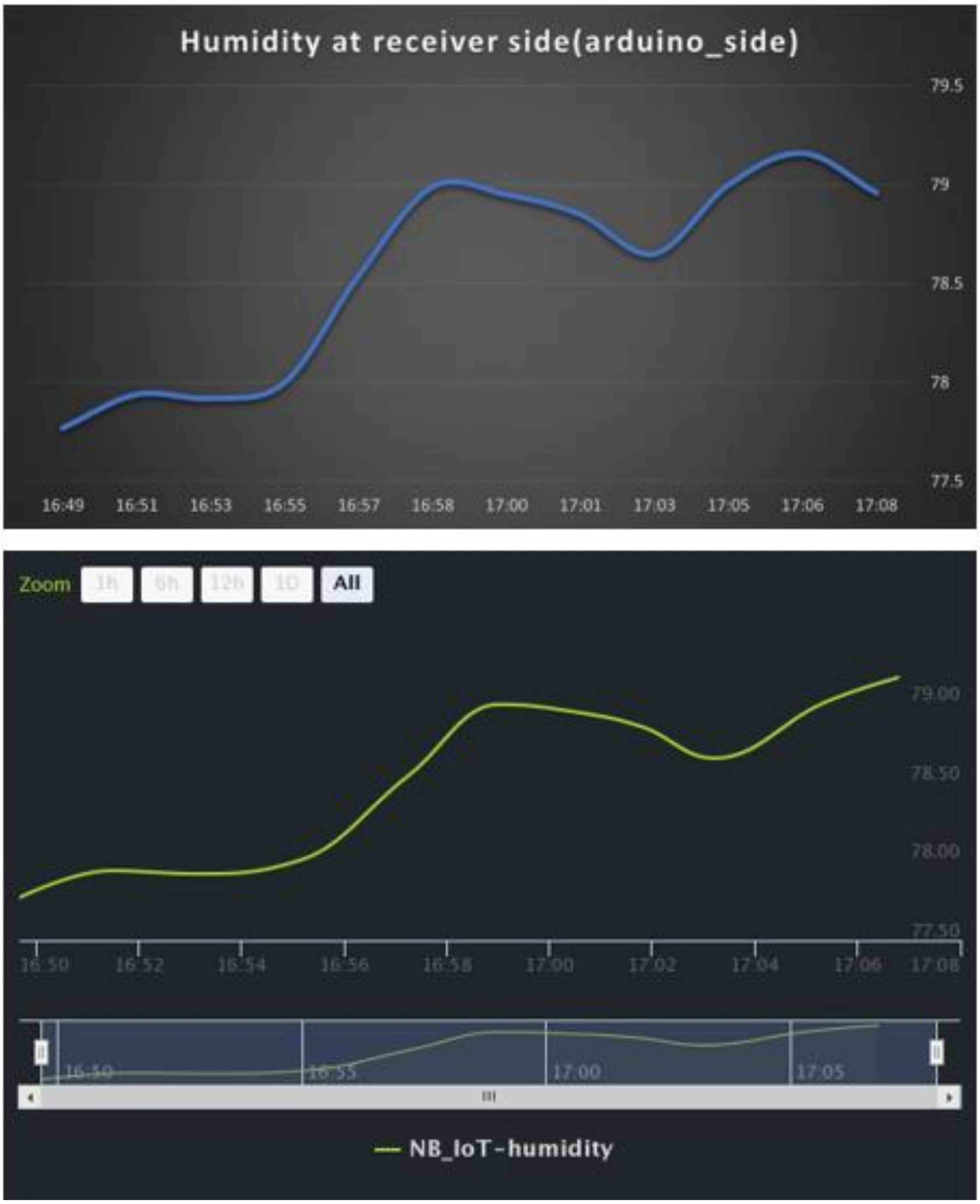


Fig. 54. humidity sensor value comparison on both end side

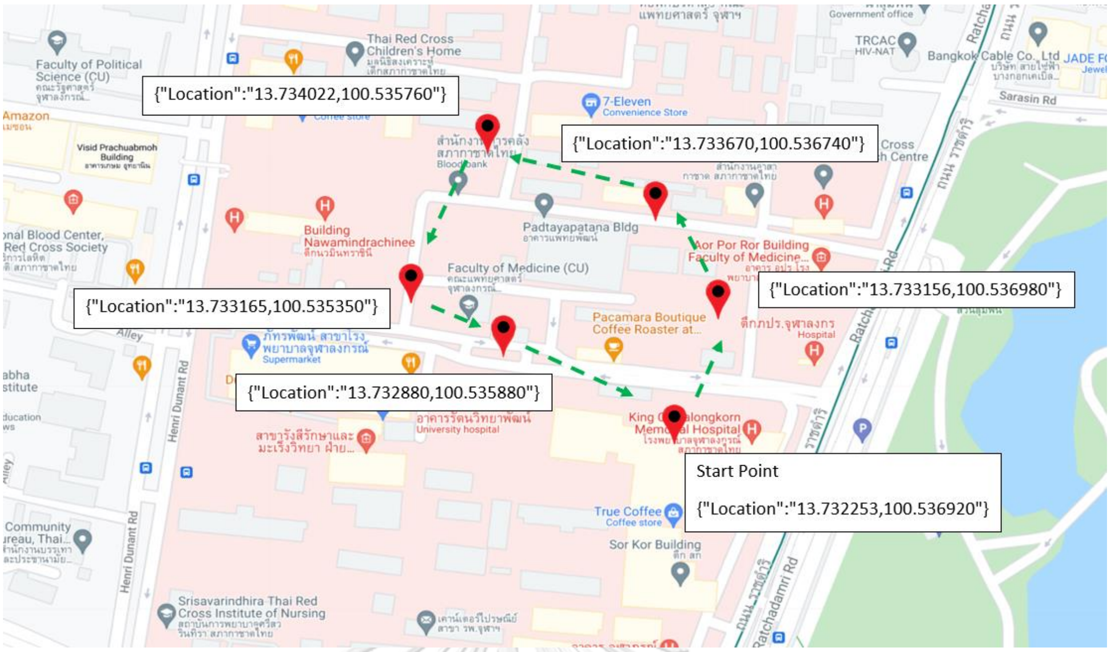


Fig. 55. GPS routing walking around hospital campus

Chapter 6 Troubleshooting

6.1 USB cable problems

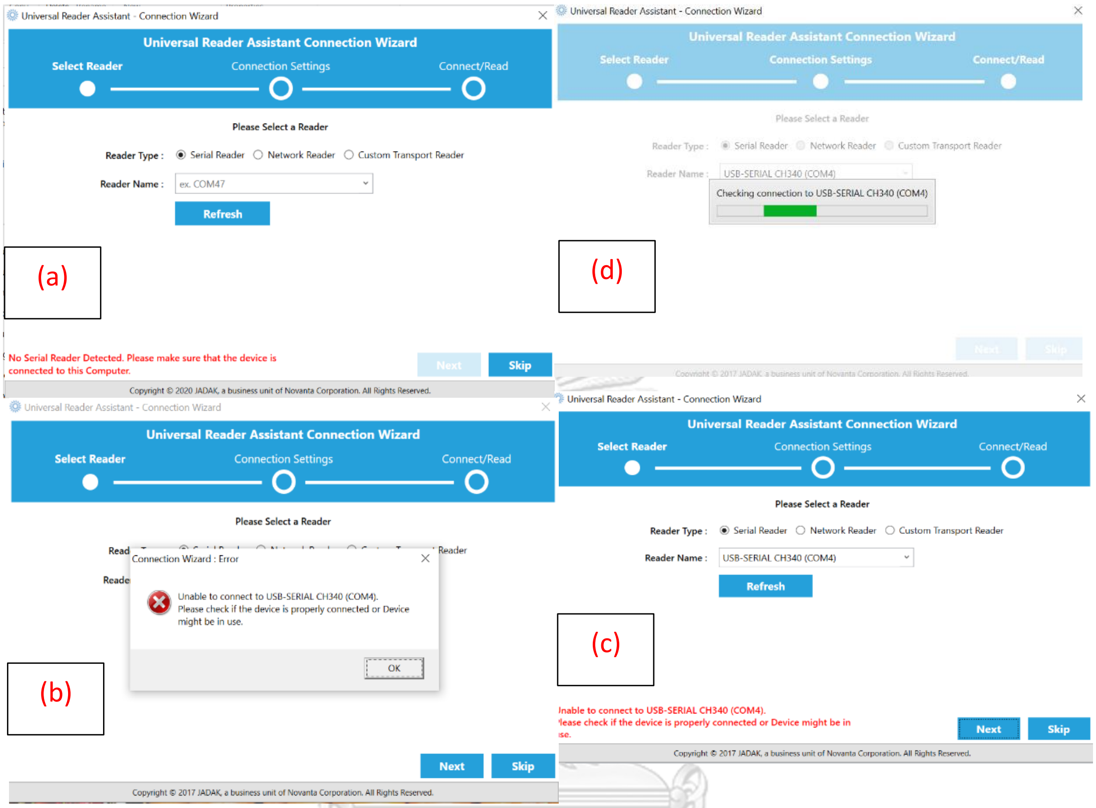


Fig. 56. (a) No serial reader detected.
(b) Unable to connect to USB COM port.
(c) Unable to connect to USB COM port.
(d) Checking connection to USB COM port.

If USB cable problems occur, you must check as following.

1) Cable is damaged or not.
2) Cable is completely connected with RFID reader and computer or not.
3) USB converter and RFID reader is properly connected or not.
4) Computer USB port is damaged or not.
5) Selected Reader Name is correct or not.

6.2 Operation problems

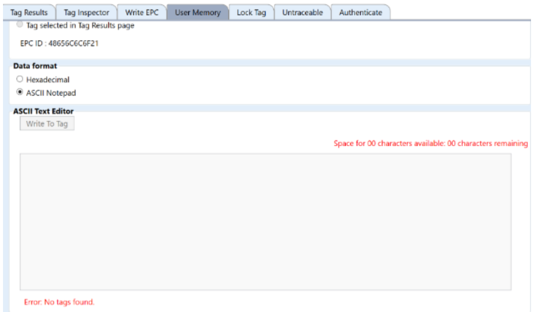


Fig. 58. User Memory (No Tags found)

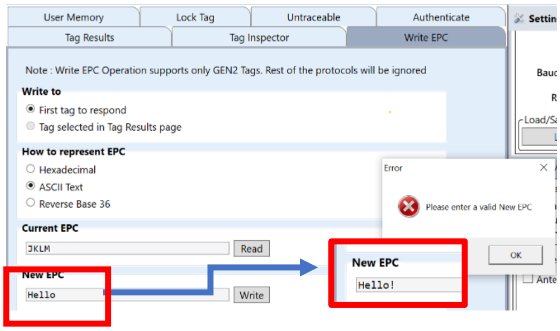


Fig. 57. Invalid EPC name

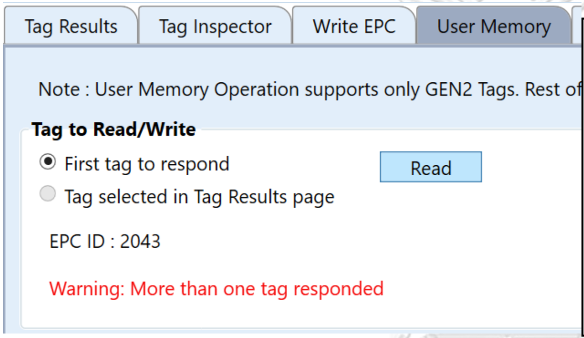


Fig. 59. More than one tag responded error

Fig. 57: Odd number of names is not available. Use even number of new EPC name.

Fig. 58: Not Enough Read power or tag is not reaching within reading range. Try to increase reading power or check tag position.

Fig. 59: Multiple tag is reaching within detection range. Reduce writing power.

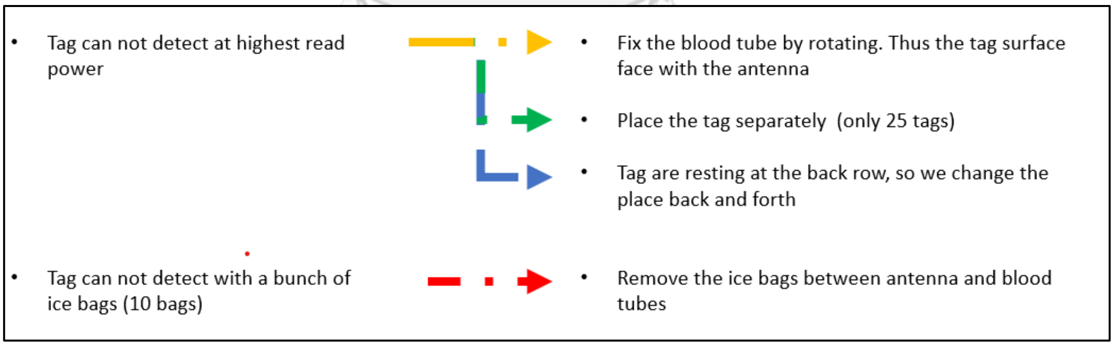


Fig. 60. Common problems

6.3 USB COM Port problem

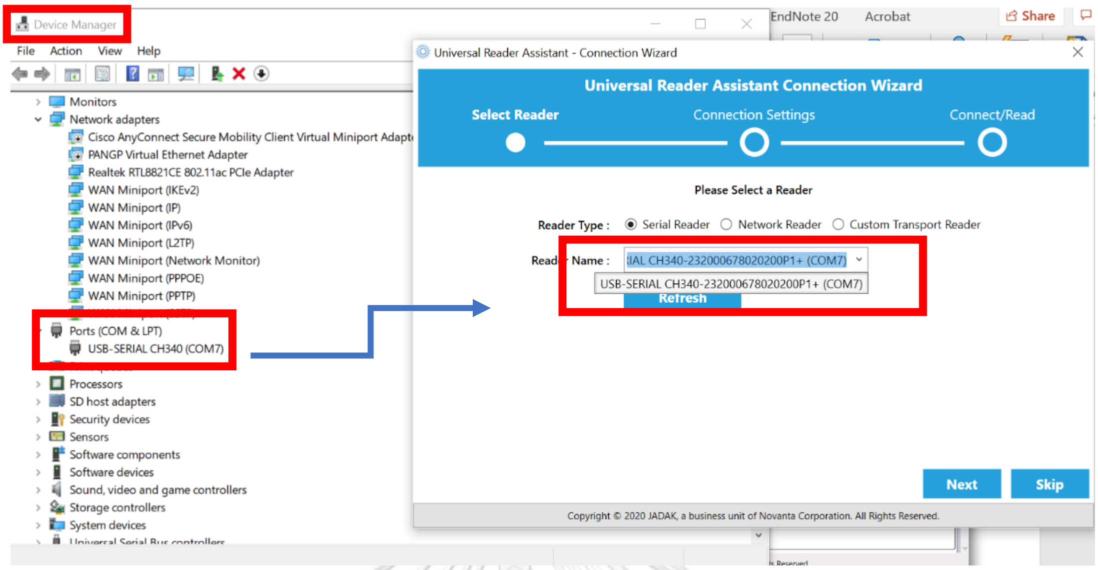


Fig. 61. Common USB COM port problem

If URA cannot detect USB COM port, user can check as following.

1) At computer, go to device manager.
2) Check at Ports(COM & LPT) where user can know the port name which is used for URA connection to RFID reader.
3) If there is not any COM port,
   - i. Check USB cable.
   - ii. Right click on "Ports (COM & LPT)" and click "scan for hardware changes".

6.4 Common problems

1) Reader is not reading tags
   - Verify known good Gen2 tags are near the reader antenna.
   - Try modifying the Performance Tuning Options to force tags to respond more frequently.
   - Check antenna cables on reader.
   - Increase the Read Power setting in Performance Tuning Options.
2) Read "Performance" is slow

Performance, as it relates to tag reading, is very use case dependent. Typically, it comes down to whether you are trying to read lots of tags once or a few tags repeatedly. If the reader settings aren't correct for your use case the performance will appear poor.

- Use the Performance Tuning Options to modify the settings for your use case.
- See the *MercuryAPI Programmer's Guide | Performance Tuning* section for details about Gen2 settings and try using the Advanced Performance Tuning options directly.

6.5 IoT problems

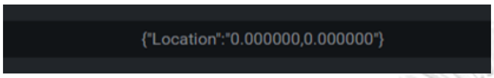


Fig. 62. GPS location is not valid error

Problem	Remedies
At cloud platform, location can be 0.0000,0.0000 because GPS cannot get signal from satellite. GPS may get low signal or lost signal inside of the building.	Place GPS module as near as outdoor when using indoor. Or wait GPS a couple of mins to get signal from satellite.

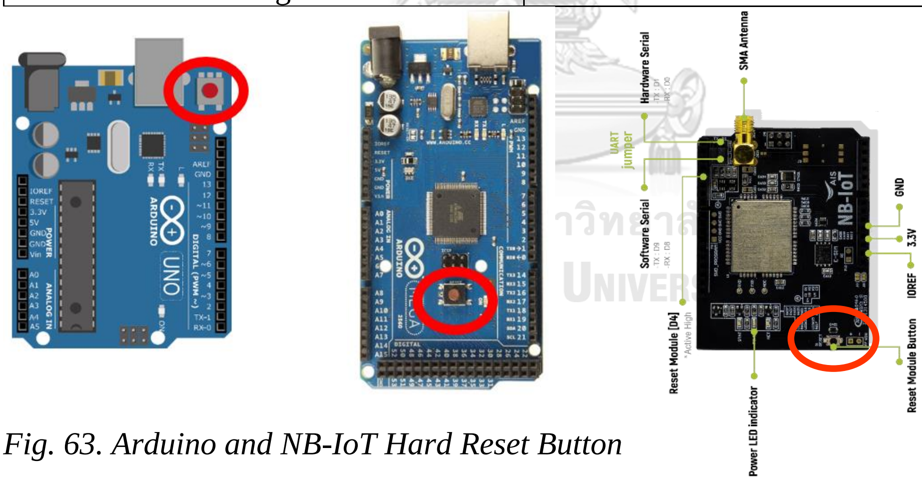


Fig. 63. Arduino and NB-IoT Hard Reset Button

Problem	Remedies
If mysterious or unexpected problem occurs.	The external RESET button is used for restarting the Arduino's bootloader, effectively stopping the execution of the code that was already present on the Arduino and then rerunning it after a few seconds of delay by which point the bootloader is ready.

Chapter 7 Conclusions

In summary, while RFID technology has been adopted in healthcare for many years, more recent upgrades of being a standard protocol, security mechanism, and variety of products with different capabilities are making RFID practical for new applications and implementations. By exploiting RFID characteristics and possibilities, this technology is considered to have the potential for better service to patients, laboratory scientists, and the hospital management team.

Throughout this research, we proposed the methods or technologies to be familiar with to overcome the limitations of implementation. Our experiment for performance testing could be supported for a new researcher for their further work. Moreover, we highlighted a few insights of the URA application, and a format of RFID tag for labeling is explained in this paper. In addition, IoT technology is applied in test tube box delivering routes to make sure the desired temperature value is an overheated or undercooling point and GPS live tracking is enabled.

In future work, this implementation can be carried for further hardware improvements and software improvement. Needs to do further research both on hardware and software are still existed to make computer rugged enough for use in the hospital. Further experiments can be carried out by testing with different sizes of RFID tag and different types of cooler box which might be one of the interferences between RFID antenna and RFID tag. Additionally, RFID radiation can relate with tag's antenna direction. In this research, we did not test the effectiveness of tag rotation while scanning with UHF antenna. Tag rotational test result can also make a new research outcome. Lastly, placing RFID device inside a cooler box could be a new further work. Regarding IoT part, Machine learning could be applied for the calculation of choosing a route from delivering, choosing priorities of blood tube types and the researcher could develop better programming to make IoT work more efficiently.

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