ENHANCING VACCINE REFRIGERATOR TEMPERATURE REPORTING SYSTEM USING IOT TECHNOLOGY

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Abstract

Temperature, light, and humidity are significant factors for the quality control of cold storage pharmaceutical products. Especially, temperature is a major factor in the quality reduction of products. The increase of temperature interacts with the quality of pharmaceutical products. Also, the pharmacist always monitors the temperature of the refrigerator via a data logger. However, a conventional data logger requires payment for an SMS notification. Moreover, a commercial refrigerator is equipped with a single temperature sensor. Consequently, the temperature monitoring system can only report the top temperature of the refrigerator. However, the arrangement of pharmaceutical products inside the refrigerator obstructs the direction of cold temperature air flow. Thus, the pharmacist cannot know the bottom temperature inside the refrigerator. If the temperature increases at the bottom of the refrigerator, then the quality of the pharmaceutical products is reduced. As a result, a conventional temperature monitoring system cannot observe the real-time temperature. The arrival of the internet of things (IoT) and smart devices has inspired the development of a conventional pharmaceutical data logger inside refrigerators. Thus, this work presents the enhancement of the reporting system of a cold storage pharmaceutical refrigerator using IoT devices. The results indicate that the pharmacist can monitor the real-time behavior of a vaccine refrigerator. Moreover, the proposed system reduces the cost of a conventional data logger. The proposed system notifies the pharmacist when the temperature exceeds or is lower than the critical point. The proposed system confirms that the pharmacist can make a fast response. Moreover, the proposed system eliminates the limitation of a conventional pharmaceutical temperature monitoring system.

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Introduction

Temperature is one of the parameters which affects the quality of pharmaceutical products. The work of Kumar and Jha (2017) and Taylor (2001) have presented that a refrigerator's maintained temperature is between 2°C-8°C. The typical storage conditions are separated into 4 types. First, the freezer maintained temperature between -25°C to -10°C. Second, cold conditions with the refrigerator's maintained temperature around 2°C-8°C. Third, cool conditions with the refrigerator's maintained temperature between 8°C and 15°C. Fourth, the control room kept temperature around 20°C-25°C. A 10-step procedure to deal with temperature excursions has been presented. The work of Kartoglu and Milstien (2014) and Chojnacky *et al*. (2012) have indicated that the proper cold storage of pharmaceutical products should be kept at temperatures around 2°C-8°C. The thermostat was configured at 5°C. Handling and Storage Solutions introduced a stand-alone refrigerator for the safety of cold storage pharmaceutical products. The refrigerator for the cold storage of pharmaceutical products has enough space and no interference of the flow of the air current. However, the temperature sensor inside the refrigerator is mainly a requirement for pharmacists and people who take care of the quality of pharmaceutical products in cold storage. Also, the temperatures inside the refrigerator have to be collected by the pharmacist and written on a chart. The maximum and minimum temperatures are investigated and written into the chart every day. Then, there was the advent of the digital data logger (DDL). A DDL records the temperature and determines the maximum-minimum temperatures. However, a conventional DDL cannot notify the pharmacist when the temperature increases. Chojnacky *et al*. (2013) showed that drug potency and patient safety are influenced by the control of the vaccine temperature history. Moreover, vaccine providers do not use real-time temperature monitoring systems in their vaccine refrigerators. In addition, an accurate vaccine reporting system is significant in a cold chain pharmaceutical products' monitoring system. The work presented by Thasala Hospital (2018) demonstrated that the conventional method for the refrigerator temperature recording system is written in the vaccine refrigerator recording documents. Pharmacists collect vaccine temperatures and fill in the form. Maximum and minimum temperatures compared with time were investigated. The increase of vaccine temperatures noticed by the pharmacist allowed control of the refrigerator. The conventional method required more working time, but the work by Black *et al*. (2006) introduced the automatic recording system. However, although the pharmacist can read the data when the automated system has finished the procedure of recording the temperature, the pharmacist does not know the real-time refrigerator temperature. The work by Islam *et al*. (2015) presented the application of the internet of things (IoT) in healthcare services. The IoT is technology which has inspired more applications in the healthcare system such as a real-time ECG monitoring system and telemedicine. The IoT technology is equipped with embedded technology and developers have installed more sensors in the healthcare system to transmit data via WiFi technology. The people in the healthcare system can use the data to improve human healthcare. Zanella *et al.* (2014) showed that wireless communication for IoT devices is separated into 2 schemes: indoor and outdoor uses. The IoT in an indoor case uses WiFi technology which provides an internet connection for data transmission. For the outdoor scheme, 3G and 4G LTE have been chosen for data exchange between IoT devices and the data center. Under the IoT, more sensors can be installed and, thus, the IoT technology has been chosen to create a reporting system for vaccine temperatures.

Literature reviews have shown that vaccine potency and patient safety are influenced by an accurate refrigerator temperature recording system, and that real-time notification by the refrigerator temperature reporting system is of greater significance. Thus, the proposed system introduces a real-time refrigerator temperature reporting system using the IoT technology which transmits temperature data via wireless communication.

Materials and Methods

Nowadays, the development of telecommunication technology is rapidly evolving. Wireless communication technology has become one of the most important things for human life, especially in conjunction with the IoT technology. Islam *et al*. (2015) presented a survey of the IoT applications that have been introduced and affect people's lives such as in logistics, transportation, medicine, and healthcare. Medicine and healthcare services are noted for applications such as the proposed ECG, EKG, and EEG monitoring systems. Traditional medical services are appropriate for people who live in urban areas close to a hospital, but the rapid development of the IoT and embedded technology reduces the inconvenience for people who live in rural areas and increases the quality of life for those people. Doctors in a hospital can monitor ECG, EKG, and EEG signals in the hospital while a patient in a rural area stays at home. Thus, the IoT in healthcare services reduces the use of time and money and increases the quality of people's lives. As regards the quality of drug and pharmaceutical products, a monitoring system for their potency is most important for the pharmacist. Kumar and Jha (2017) and Chojnacky *et al*. (2012) presented the preservation of drugs separated in cold storage from pharmaceutical products/ vaccines and drugs stored inside the inventory with temperature/humidity control. However, this article focuses on enhancing the notification system of the vaccine refrigerator temperature.

A traditional data logger has been used for temperature data collection. The pharmacist exports and analyzes the temperature data every day. This process requires more processing time, so that data export and data analysis consumes more time and is an inconvenience for the pharmacist. Moreover, the pharmacist does not know the real-time temperature from the vaccine refrigerator. The vaccine potency and quality may have been reduced due to an increase in the temperature, so that patient safety is decreased. This article focuses on the improvement of the vaccine temperature notification system using the IoT technology. Our results show that a pharmacist can rapidly resolve a vaccine refrigerator temperature problem.

The focus is on a conventional data logger, and this device which is shown in Figure 1 is the Ebro EBI 20 (Xylem, Inc., Rye Brook, NY, USA) which has been chosen for the temperature calibration procedure. The EBI 20 is placed at the center of the

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วันที่	ระดับอุณหภูมิ (องศาเซลเซียส)						หมายเหตุ	วันที่	ระดับอุณหภูมิ(องศาเซลเซียส)						หมายเหตุ
	09.00		ผู้บันทึก	15.00น		ผู้บันทึก			9.00		ผู้บันทึก	15.00		ผู้บันทึก	
	2-8	F.		2-8	F.				2-8	F.		2-8	F.		
1								16							
2								17							
3								18							
4								19							
5								20							

Figure 1. Conventional data logger and temperature document

refrigerator and there is a form to fill in the vaccine temperatures, as shown in Figure 1. The proposed system uses an ESP8266 embedded microchip device (Espressif Systems, Shanghai, China) which is installed with 2 DS18B20 waterproof temperature sensors. The 2 sensors are separated into the top and bottom of the vaccine refrigerator. A pharmacist exports the recorded temperature via the ThingSpeak IoT cloud platform. A real-time notification system is introduced by the LINE notification application. The proposed system improved the quality of cold pharmaceutical products and introduced the convenience of the reporting system for cold storage pharmaceuticals.

System Model

A system flow chart and system model are presented in Figures 2 and 3, respectively. According to the system flowchart, the temperature sensor is separated into 2 positions with the top and bottom temperature sensors installed. The reliability of the measured value is very significant. A conventional vaccine refrigerator is equipped with a standard temperature sensor and is calibrated every 6 months. Increasing the reliability of the measurement value is a topic of major concern, so the measured temperature values have been calibrated using the comparison calibration method. Measurement values have been collected 50 times from the standard temperature sensor and the proposed system. Finally, the average values have been computed, as shown in Table 2. The correction values have been inserted inside the programing code. The calibration equation is presented in (1) below, in which C is the calibrated value, and M_t is the measured temperature value. The average temperature correction value has been calculated and is presented as 0.85°C, according to Table 1. Thus, the calibrated value has been fed into Equation (1), so that the measurement reliability is increased. Thus, the calibrated temperature value has been checked. An excessive temperature has been transmitted by the LINE notification application.

$$C = M_t + 0.85\ (^{o}C) \tag{1}$$

System Configuration

The configuration of the proposed system is shown in Figure 4. Two DS18B20 temperature sensors have been installed in the top and bottom of the vaccine refrigerator in accordance with the requirements of the pharmacist. Cold air from the ventilating fan flows from the top of the refrigerator and passes to the vaccine and pharmaceutical products. However, the pharmacist does not know the bottom temperature because the OEM vaccine refrigerator is installed with only a temperature sensor at the top of the refrigerator. Two DS18B20 sensors have been installed according to the proposed system.

The proposed system is equipped with an ESP8266 NodeMCU processing unit

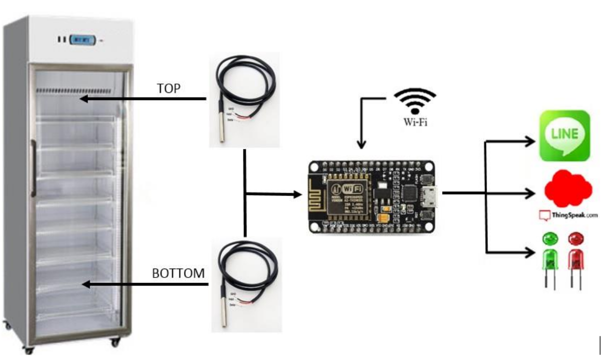


Figure 2. System block diagram

connecting with the DS18B20 sensors. LEDs have been integrated for the offline temperature status monitoring. The system flow chart is presented in Figure 3. When temperatures are located around 2ºC-8ºC the LEDs are illuminated in green. A red color appears when temperatures exceed 8ºC or are lower than 2ºC. Moreover, the processing unit has been connected with the Suranaree University of Technology (SUT) wireless network for the temperature notification system. SUT-@IoT has been launched for the IoT WiFi operation. The processing unit notifies the pharmacist when the vaccine refrigerator temperature exceeds 8ºC via the LINE notification application. Notification messages are shown in Figure 5. The top temperature presents the measured temperature value of the top of the refrigerator, while the bottom temperature introduces the reading

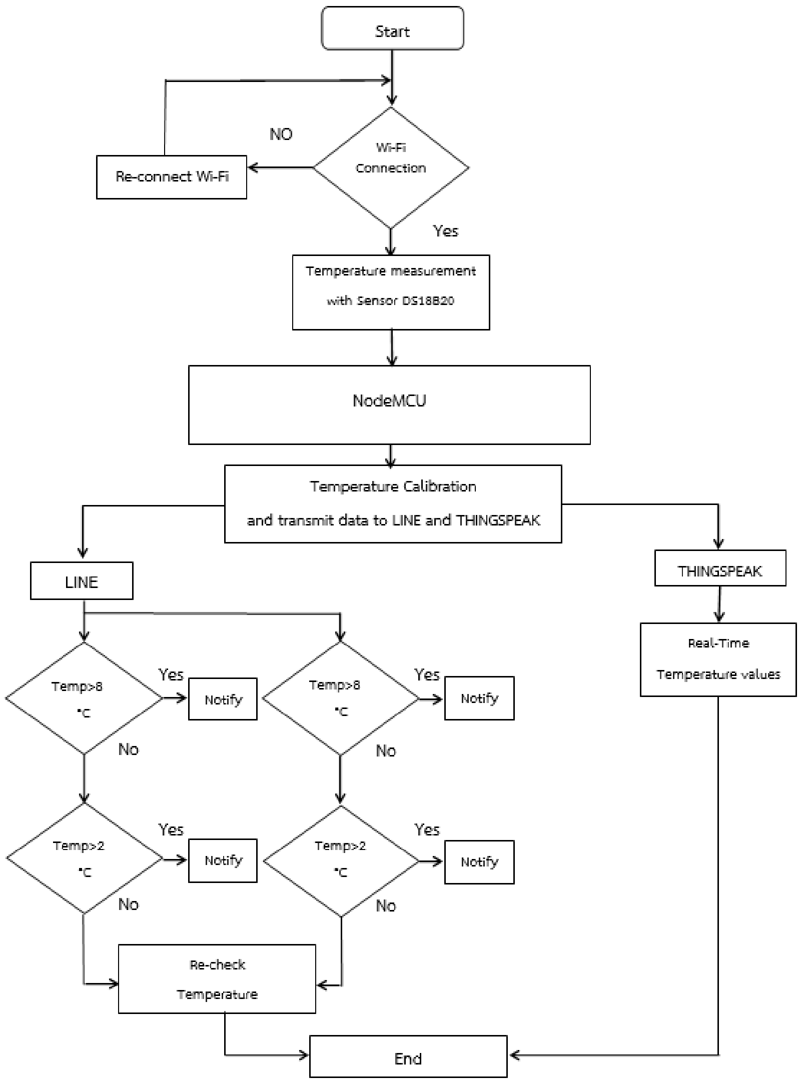


Figure 3. Flow chart

value from the bottom temperature sensor. The pharmacist requires a notification message every 1 second when the temperature increases over 8°C, because the temperature is the most significant factor for cold storage of pharmaceutical products. Also, the vaccine refrigerator has a control when the temperature increases. In addition, the ThinkSpeak IOT cloud platform has been chosen for data collection. The pharmacist has an instant real-time monitor and control of the vaccine refrigerator. Consequently, vaccine potency and patient safety are improved. The 2 sensors have been calibrated via the comparison method with a conventional data logger which is calibrated every 6 months. The measured results are transferred to an R-squared computation corresponding to Equation (2) below, in which x presents the proposed system and y introduces the standard vaccine temperature sensor (EBI-20). The computation of R-squared introduces a reliability of the proposed system. The R-squared of the proposed system is 0.9871 which introduces a high system reliability. Measurement calibrations using the comparison method are presented in Table 2. The result of the R-squared computation shows that the proposed system provides a reliable notification system.

$$\text{R-Squared} = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2 \sum(y-\bar{y})^2}} \quad (2)$$

Experiments and Measurements Setup

The vaccine temperature data collection is introduced in this section. The measurement setup has been collected according to a pharmacist's office hours. The purposes of the experiment are separated into 2 topics. The first is to study the potency of the proposed notification system, and the second is to study the performance of the proposed system. The potency of the proposed system is categorized into 2 issues, so that the reliability and the accuracy of the proposed system have both been investigated. The accuracy of the proposed system has been introduced in a previous section which presented the R-squared computation to guarantee an accurate measured value. The reliability of the proposed system is high due to a lower error percentage, according to Figure 6.

Table 1. Measurement comparison between proposed system and standard temperature sensor

No.	Proposed system (°C)	Standard temperature sensor EBI-20 (°C)	Corrections (°C)
1	31.06	32.10	1.04
2	31.06	32.10	1.04
3	31.23	32.10	0.88
4	31.23	32.10	0.88
5	31.23	32.10	0.88
6	31.23	32.10	0.88
7	31.23	32.10	0.88
8	31.23	32.10	0.88
9	31.23	32.10	0.88
10	31.23	32.10	0.88
11	31.06	32.00	0.94
12	31.06	32.00	0.94
13	31.06	32.00	0.94
14	31.06	32.00	0.94
15	31.06	32.00	0.94
16	31.13	32.10	0.98
17	31.19	32.10	0.91
18	31.19	32.10	0.91
19	31.19	32.10	0.91
20	31.19	32.10	0.91
21	31.19	32.10	0.91
22	31.19	32.10	0.91
23	31.19	32.10	0.91
24	31.19	32.10	0.91
25	31.19	32.10	0.91
26	31.31	32.10	0.79
27	31.31	32.10	0.79
28	31.25	32.10	0.85
29	31.31	32.10	0.79
30	31.31	32.10	0.79
31	31.31	32.10	0.79
32	31.38	32.10	0.73
33	31.38	32.10	0.73
34	31.38	32.10	0.73
35	31.38	32.10	0.73
36	31.38	32.10	0.73
37	31.38	32.10	0.73
38	31.38	32.10	0.73
39	31.38	32.10	0.73
40	31.38	32.10	0.73
41	31.38	32.10	0.73
42	31.38	32.30	0.92
43	31.38	32.30	0.92
44	31.38	32.30	0.92
45	31.38	32.30	0.92
46	31.23	32.30	1.07
47	31.68	32.40	0.72
48	31.68	32.40	0.72
49	31.65	32.40	0.75
50	31.65	32.40	0.75
Avg.	28.75	29.54	0.85

Measurement error has been increased due to the office hours of a pharmacist during which the doors of the vaccine refrigerator have been opened frequently. Vaccines have been inserted onto the shelves of the refrigerator. However, the measurement error does not

Table 2. Measurement calibration using comparison method

No	Proposed system x	Standard Vaccine Temperature Sensor EBI-20 y	$x - \bar{x}$	$(x - \bar{x})^2$	$y - \bar{y}$	$(y - \bar{y})^2$	$(x - \bar{x})(y - \bar{y})$
1	5.72	5.70	0.12380	0.01533	0.12800	0.01638	0.01585
2	5.72	5.70	0.12380	0.01533	0.12800	0.01638	0.01585
3	5.72	5.70	0.12380	0.01533	0.12800	0.01638	0.01585
4	5.72	5.70	0.12380	0.01533	0.12800	0.01638	0.01585
5	5.72	5.70	0.12380	0.01533	0.12800	0.01638	0.01585
6	5.72	5.70	0.12380	0.01533	0.12800	0.01638	0.01585
7	5.72	5.70	0.12380	0.01533	0.12800	0.01638	0.01585
8	5.72	5.70	0.12380	0.01533	0.12800	0.01638	0.01585
9	5.72	5.70	0.12380	0.01533	0.12380	0.01533	0.01533
10	5.72	5.70	0.12380	0.01533	0.12380	0.01533	0.01533
11	5.72	5.70	0.12380	0.01533	0.12380	0.01533	0.01533
12	5.72	5.70	0.12380	0.01533	0.12800	0.01638	0.01585
13	5.72	5.70	0.12380	0.01533	0.12800	0.01638	0.01585
14	5.72	5.70	0.12380	0.01533	0.12800	0.01638	0.01585
15	5.66	5.60	0.06380	0.00407	0.02800	0.00078	0.00179
16	5.66	5.60	0.06380	0.00407	0.02800	0.00078	0.00179
17	5.66	5.60	0.06380	0.00407	0.02800	0.00078	0.00179
18	5.66	5.60	0.06380	0.00407	0.02800	0.00078	0.00179
19	5.61	5.60	0.01380	0.00019	0.02800	0.00078	0.00039
20	5.61	5.60	0.01380	0.00019	0.02800	0.00078	0.00039
21	5.61	5.60	0.01380	0.00019	0.02800	0.00078	0.00039
22	5.61	5.60	0.01380	0.00019	0.02800	0.00078	0.00039
23	5.61	5.50	0.01380	0.00019	-0.07200	0.00518	-0.00099
24	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
25	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
26	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
27	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
28	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
29	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
30	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
31	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
32	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
33	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
34	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
35	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
36	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
37	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
38	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
39	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
40	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
41	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
42	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
43	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
44	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
45	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
46	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
47	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
48	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
49	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
50	5.52	5.50	-0.07620	0.00581	-0.07200	0.00518	0.00549
Avg.	5.60	5.57		0.00777		0.00755	0.00752

exceed the 3% threshold. The measurement error confirms that the proposed system introduces reliability and has accurate measurement results. To study the performance of the notification system, a notification message appears every 1 second when the temperature increases. Inserting vaccines and drugs into the refrigerator are the major factor. Moreover, blackouts are another issue which affects the vaccine refrigerator. In addition, power from a redundant generator was created for 30 min. Focusing on the traditional data logger, the pharmacist cannot know the real-time status of the vaccine refrigerator. The traditional data logger does not transmit notification messages to the pharmacist, so that vaccines and drugs may be lost. However, the proposed system can notify the pharmacist to take control and make a decision rapidly.

Results and Discussions

Important results are introduced in this section. The measurement results are separated into 2 types: quality of services (QS) and quality of experiences (QE). QS is the performance parameter which guarantees the potency of the proposed system. This article also introduces a comparison of the standard temperature sensor versus the proposed system and measurement error for the QS parameters. A comparison of the standard temperature sensor versus the proposed system is presented in Figure 7. The measurement values of the proposed system are close to the standard temperature sensor which guaranteed 0.9871 of the R-squared. Thus, the proposed system provides a high quality of service. Moreover, the measurement error is shown in Figure 6. The measurement error reference +3% has shown that the measurement error of the sensor is less than ±3%. Also, +3% refers to the measurement error threshold. The proposed system indicates that the measurement error is lower than the threshold value. The measured results can confirm that the quality of services is high. Thus, the proposed system introduces a highly reliable notification system.

Other measurement results are presented in Figure 8(a-b) which introduces the vaccine refrigerator temperature values from the top and bottom sensor placements. Variation of the temperature depends on the operation of the air conditioner compressor. The temperature increased when the operation of the compressor was off. As a result, the proposed

Figure 4. Devices and configuration

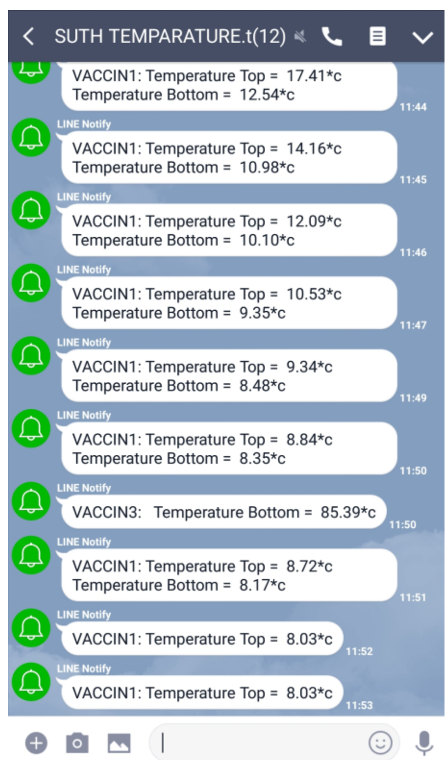


Figure 5. LINE notification

system can notify the pharmacist when the temperature exceeds 8°C. Moreover, the pharmacist can decide when the temperature has increased for a long time. The proposed vaccine refrigerator temperature notification system improves the constraints of the conventional data logger. In addition, the vaccine potency has been cured by the proposed system and patient safety is increased due to the quality control by the proposed system. Focusing on the temperature reduction, the temperature decreased due to the compressor's operation. The proposed system can notify the pharmacist when the temperature decreases to lower than 2°C. The pharmacist can find the real-time temperature via the proposed system. Also, the measurement results indicate a high QS.

This article also focuses on QE which is another important factor. The proposed system introduces user satisfaction in terms of QE. User experiences of the proposed system are categorized in 5 issues which are presented in Figure 9. Satisfaction assessment has been provided by 10 people who work inside the Department of Pharmacy at Suranaree University Hospital. Four men and 6 women have submitted their satisfaction assessments. The satisfaction assessment is divided into 5 scores. Number 1 refers to the lowest score while number 5 refers to the highest satisfaction score. Focusing on the first topic, sensor reliability has been evaluated. The assessors indicated a satisfaction score of 3.40. For the real-time temperature monitoring system, the result was a satisfaction score of 3.50. Fast notification, user friendly, and useful for the pharmacist all had a satisfaction score of 4.00. The average score is 3.78.

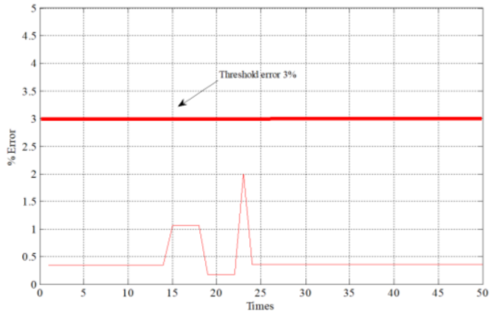


Figure 6. Measurement error

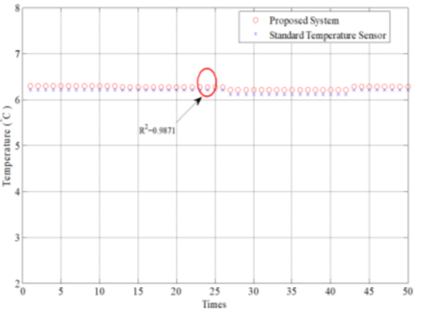
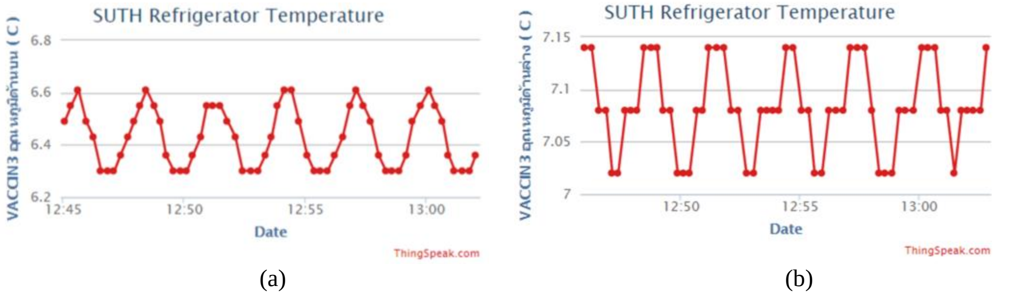


Figure 7. Comparison of standard temperature sensor and proposed system



(a) (b)

Figure 8. a) Temperature results from top of refrigerator, b) Temperature results from bottom of refrigerator

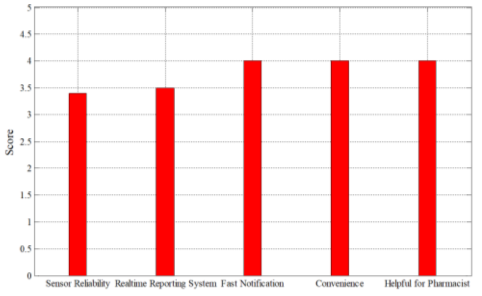


Figure 9. User's experience

Conclusions

The proposed system improved the quality of pharmaceutical products inside the refrigerator. Applying the IoT technology can eliminate the constraints of a general vaccine temperature monitoring system. The arrangement of pharmaceutical products obstructs the direction of the cold air and the pharmaceutical products at the bottom receive an increasing air temperature. Thus, quality of those pharmaceutical products decreases. As a result, the pharmacist cannot know the temperature at the bottom of the refrigerator. Thus, the bottom temperature sensor has been inserted. The proposed system introduced a top and bottom temperature monitoring system via the IoT and LINE application. The proposed system calibrated a cheap sensor to guarantee the potency of the measured values. Installing 2 temperature sensors enhanced the confidence of the pharmacist by 3% of measurement error and 0.9871 of the R-squared. The proposed system can rapidly notify the pharmacist so that the pharmacist can take a fast action with the vaccine refrigerator. As a result, the vaccine potency and drugs potency have been cured according to pharmaceutical standardization, and patient safety has been increased due to receiving high quality pharmaceutical products.

Acknowledgement

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