Case Report

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Laboratory Environment Monitoring: Implementation Experience and Field Study in a Tertiary General Hospital

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Objectives: To successfully introduce an Internet of Things (IoT) system in the hospital environment, this study aimed to identify issues that should be considered while implementing an IoT based on a user demand survey and practical experiences in implementing IoT environment monitoring systems. **Methods:** In a field test, two types of IoT monitoring systems (on-premises and cloud) were used in Department of Laboratory Medicine and tested for approximately 10 months from June 16, 2016 to April 30, 2017. Information was collected regarding the issues that arose during the implementation process. **Results:** A total of five issues were identified: sensing and measuring, transmission method, power supply, sensor module shape, and accessibility. **Conclusions:** It is expected that, with sufficient consideration of the various issues derived from this study, IoT monitoring systems can be applied to other areas, such as device interconnection, remote patient monitoring, and equipment/environmental monitoring.

Keywords: Internet of Things, Laboratory, Temperature, Environmental Monitoring

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I. Introduction

The Internet of Things (IoT), which is continuously growing owing to advances in communication technology, ubiquitous identification, sensing technology, and connectivity, is being used to implement various services in diverse industries [1-5]. The healthcare industry is a potential area for the application of IoT. The adoption of IoT interconnection in healthcare could enable a wide variety of functions in many medical applications, such as diagnostics through the internet, patient and environmental monitoring, remote surgeries, and remote health monitoring [3,6-12].

The Department of Laboratory Medicine in a hospital stores and analyses a large number of various reagents and specimens, such as blood, urine, and genetic samples. These reagents and specimens, which are required for diagnosis or laboratory testing, should be stored in a controlled environment to preserve their quality [13]. As the storage conditions are directly related to the clinical results, precise control is required to support accurate clinical decisions. To address such needs, IoT technology can be used to integrate the process of maintaining the required temperature and humidity, periodically track temperature and humidity to prevent accidents, and record data.

The purpose of this paper is to discuss the implementation and adoption of hospital IoT monitoring systems in a laboratory.

II. Case Description

1. Survey of User Needs

The study was conducted at a tertiary university hospital located in South Korea. A survey and focus group interview were conducted to determine the need for IoT monitoring systems in five supportive care departments requiring environmental monitoring. The current quality-control methods and specific needs of each department were understood (Table 1).

Based on the results presented in Table 1, the Department of Laboratory Medicine was selected as the field study site. The equipment to be monitored consisted of refrigerators and freezers where important specimens, reagents, and blood were stored (Table 2).

2. Implementation of IoT Monitoring Systems

The IoT monitoring systems were installed on site and tested for approximately 10 months from June 16, 2016 to April 30, 2017. Two types of environmental monitoring systems were constructed: on-premises and cloud IoT systems. These were commercially available and were customized for the hospital's user requirements and environment. Figure 1 presents the architecture of each system.

For the on-premises monitoring system, all of the system components (e.g., the server, database, and web service) were installed in the hospital. The system was connected to the hospital's internal network, and the collected sensor data were transmitted to the monitoring server through a wired network. The temperature and humidity module used in the on-premises monitoring system in this study was developed in-house based on a Beagleboard (Texas Instruments, Dallas, TX, USA) using a temperature sensor. It was a rod-shaped sensor that was easy to place anywhere in the refrigerator. The ZigBee communication protocol was selected because the refrigerators and freezers were spread throughout the department instead of being arranged in one place.

The cloud IoT monitoring system used a dedicated long-term evolution network. The temperature and humidity modules were developed in-house using SMARTMIEW cloud (Mbuzzer Co., Seoul, Korea). The Bluetooth low-energy (BLE) 4.1 communication protocol was used to transmit the sensor data from each sensor to the gateway.

Data collected from each sensor in both systems were transmitted every minute to the gateway. When the temperature fell outside of the preset tolerance limit, an alert was sent through a dedicated web page or smartphone application.

The IoT monitoring system consists of four core functions: sensor management, temperature and humidity monitoring, alerting and reporting, and indoor mapping.

III. Discussion

The study focused on the various issues that could arise in the implementation process. From the pilot test, a total of five issues were identified.

1. Sensing and Measuring

There are two issues related to measurement. First, temperature variations depend on several factors. While the refrigerator temperature was measured over the test period, temperature variations were caused by the internal location of the measurement or the fullness of the refrigerator [14]. Second, there is a problem with the standard temperature measurement method. According to guidelines [15], the temperature of a liquid should be measured by immersing a mercury thermometer in a glycerol solution in blood refrigerators. However, IoT temperature sensors are produced in a form that cannot be immersed in a liquid.

2. Transmission Method

The protocol used in the on-premises system switched to sleep mode when the data were not being unidirectionally transmitted and woke up once a minute to send the sensor data to the gateway. The protocol used in the cloud IoT system also unidirectionally transmitted data once a minute. However, it waited for the data to be received from the sensor for one minute and then transmitted the data to the gateway, thereafter going into sleep mode. This difference in protocol led to a high data-loss rate in the on-premises system. It woke up once a minute and transmitted data, but if it failed to transmit the data because of some environmental factors while awake, the final values on the display were null.

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Table 1. Current status of and demand for quality control by department

Dept.	Elements	Number of equip.	Current status	Limitations for implementation
Laboratory	Room temperature and humidity Refrigerator temperature Freezer temperature CO_2	84	Temperature of equipment that requires temperature measurements, such as refrigerators, freezers, and water baths is checked daily by manual reading of installed mercury thermometers. Room temperature and humidity are managed in specific areas (microbiology laboratory, blood bank, etc.). No separate alarm system.	
Pathology	Room temperature and humidity Refrigerator temperature Freezer temperature Harmful gases	20	Room temperature and humidity are managed by zone (tissue, cell, immunity, molecule, etc.). Harmful indoor gases are measured. Clean bench UV lamp life is monitored. No separate alarm system.	High possibility of communication problems because zones are compartmentalized by walls.
Radiology	Room temperature and humidity Heating cabinet temperature Radiation dose	16	Room temperature and humidity are managed to ensure a comfortable patient examination environment. Air conditioner is in 24-hour operation due to the sensitivity of X-ray detectors.	Temperature and humidity of CT and MRI are automatically maintained. No workload burden for measuring and confirming temperature and humidity. Wireless communication is limited due to the partitioning of the examination environment into rooms for each piece of equipment. No guidelines for temperature and humidity measurement exist. Alarm system exists.
Nuclear medicine	Room temperature and humidity Refrigerator temperature	6	Room temperature and humidity are managed to ensure a comfortable patient examination environment. No separate alarm system.	Limited wireless communication due to shielding. No guidelines for temperature and humidity measurement exist.
Radiation oncology	Room temperature and humidity Radiation dose	6	Room temperature and humidity are managed to ensure a comfortable patient examination environment. No separate alarm system.	Limited wireless communication due to shielding. No guidelines for temperature and humidity measurement exist.

The cloud system also followed a unidirectional protocol, but it had a low data-loss rate because it waited until data were received. The data loss disappeared once the protocol of the on-premises system was changed from unidirectional to bidirectional.

3. Power Supply

We employed batteries to preserve the concept of IoT wireless monitoring. The average lifespan of the batteries was approximately 1.5 years; however, the users' perspective indicated that batteries were not preferred owing to the inconvenience of having to periodically replace them.

4. Sensor Module Shape

A separate module that could collect and process sensor data was needed for the on-premises system. Because it used a wire sensor, the user could position the wire at the desired position, but it was difficult to repair the sensor, and this could cause problems if the number of sensors increased. A chip sensor was used for the cloud system. It was an all-in-one module with a sensing and communicating function. The lack of cables was an advantage, and it could be easily fixed anywhere because of its small size. However, because it was an all-in-one sensor with an integrated processor chip, the refrigerators in which it could be installed were limited.

Table 2. Monitoring equipment

Sensor location	Control element	Tolerance limit
Indoor laboratory	Temperature (°C)	23–27
	Humidity (%)	20–80
Reagent freezer	Temperature (°C)	2–8
Deep freezer	Temperature (°C)	≤−50
General refrigerator	Temperature (°C)	2–8
Walk-in freezer	Temperature (°C)	2–8
Blood freezer	Temperature (°C)	2–8

5. Accessibility

The accessibility of the on-premises monitoring system was low. Even though the system tracked the temperature in real time, users had to connect to the monitoring page of the server through the web portal on a hospital PC to check it. The cloud IoT monitoring system, in contrast, had relatively better accessibility because it used the existing internet network.

The present study implemented a temperature and humidity monitoring system in the department of laboratory medicine at a general university hospital. Considerable demand for and interest in IoT monitoring systems was confirmed. It is expected that if the various issues identified during this study are addressed, IoT monitoring systems can be applied to other areas, such as device interconnection, remote patient monitoring, and equipment/environmental monitoring.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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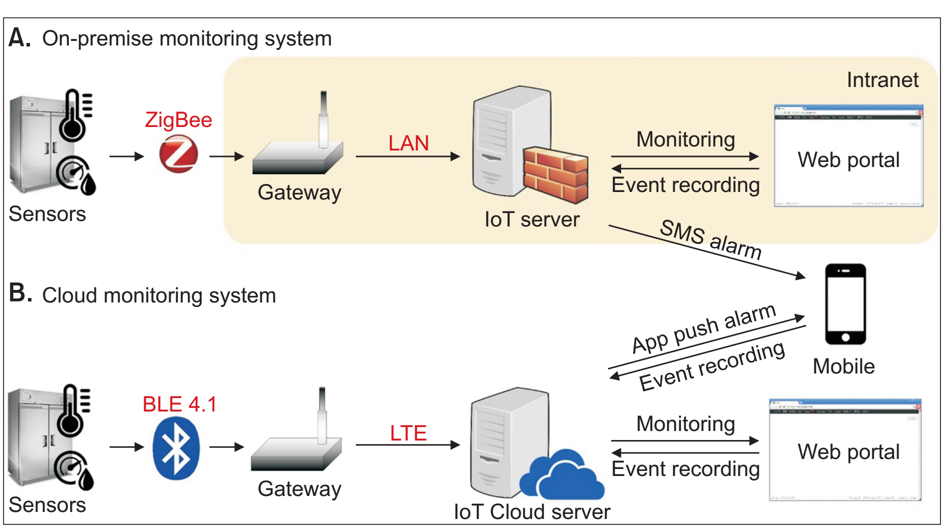

Figure 1. Architecture of both environmental monitoring system types. (A) On-premise monitoring system. (B) Cloud monitoring system.

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