Implementation of Temperature and Humidity Monitoring System Using LoRaWAN for Pharmaceutical Industry

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Abstract. The drug production process certainly requires a room with certain conditions where the temperature and humidity must be following the provisions of the Good Manufacturing Practices standard. In the current condition, there are still many production processes that use manual methods to check the room temperature and humidity. If temperature and humidity change beyond the standard, the drug manufacturing process should be stopped. This makes the manufacturing process less effective and efficient. Meanwhile, internet of things (IoT) technology enables automated monitoring using low power wide area network (LPWAN) connectivity that can overcome these problems. Its feature is that the energy used is relatively small so the monitoring system can be efficient. LoRaWAN is one of the LPWAN technologies which also provides a wide range of coverage, low power, and low cost in the implementation. This research offers a monitoring solution for temperature and humidity in the pharmaceutical factory so that the drug manufacturing room can be monitored in real-time. The results are very good in terms of sensor accuracy and signal strength to make a reliable solution.

Keywords: LoRa · LoRaWAN · pharmaceutical industry · monitoring · internet of things · IoT · temperature and humidity sensor First Section

1 Introduction

The drug production process certainly requires supervision to maintain the quality of the drugs produced. the production must be carried out by following established procedures and complying with the regulation of the good manufacturing practices (GMP) standard [1]. The need for temperature and humidity data in every room of the pharmaceutical industry is very important to maintain the quality of the drugs produced.

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Following GMP specifications, the drug production room is divided into several classes, namely classes A, B, C, D, and E. Each class has a temperature and humidity standard according to the activities and types of drugs. The temperature and humidity of the room in the production room must be well-managed. When the temperature and humidity of the production room do not match the predetermined set point, the production must be stopped and reported to the technician and then waiting for a repair response from the technician. This makes the production process stop and reduces the effectiveness and efficiency of the drug manufacturing process.

To overcome this problem, an Internet of Things (IoT)-based monitoring system is needed to monitor the temperature and humidity in the drug production room so that the condition of the room complies with the predetermined set point. The IoT system will include certain connectivity technologies to send data from the sensor to the internet cloud. The decent connectivity type to be used in IoT is from the low power and wide area (LPWAN) technology. One of the popular LPWAN types in IoT is LoRa/LoRaWAN. The advantages of this technology are low battery consumption, a small data rate so it does not require large bandwidth, and a wide coverage area of about 5 km in urban areas and about 15 km in rural areas. LoRaWAN also uses the ISM Band for (Industrial, Scientific, and Medical) frequency spectrum, which is an unlicensed frequency, making this technology cost-effective for the implementation process [2, 3, 4]. This research aims to study the implementation of the temperature and humidity monitoring system in a pharmaceutical factory using LoRaWAN. This paper consists of the introduction in Sect. 1, literature review in Sect. 2, methodology in Sect. 3, result and analysis covered in Sect. 4, and finally, the conclusion in Sect. 5.

2 Literature Review

2.1 Related Studies

Several previous studies discuss temperature and humidity monitoring systems. One related to pharmaceutical production is [5] which developed a temperature and humidity monitoring system using an ESP32 microcontroller, DHT11 sensor, and wi-fi connection. The authors used a Peltier fan to control the temperature and humidity in the room. Another research studied a hydroponic plant cultivation monitoring system [6]. This study uses an Arduino microcontroller as a controller which is connected to the DHT11 sensor which is a sensor for measuring temperature and humidity. The results of testing four DHT11 sensor units outside the room obtained an average temperature value of 28.94 °C and humidity of 59.6% using the Xbee network. The average value of indoor temperature and humidity test results was 29.14 °C and 58.86% with the Xbee's range reaching 70 m.

Other research discusses the evaluation of temperature and humidity in the processing room and distribution room for nutrition production. This study used a retrospective design. Data were collected 4 times a day: in the morning (around 10.00), afternoon (around 14.00) afternoon (around 17.00), and evening (around 19.00). The temperatures in the processing and distribution room are higher than the hospital standard, which is between 25–27 °C. However, when compared to the Indonesian government's standard, the temperature is still relatively safe. Meanwhile, the air humidity in the processing room is still within the standard, but in the distribution room, the humidity is higher than the hospital and the Ministry of Health's standard, which is 40–70% [7].

Another research discusses the design of a room temperature and humidity control system with an Android application. This study aimed to design a prototype of a temperature and humidity system in a room using an Arduino Uno microcontroller which is controlled by an Android smartphone via wifi communication. The test results show that the application can inform the state of temperature and humidity in a room. Actions that can be taken on the Room Control Application on Android are auto-mode selection, where when the room temperature is detected under 29 °C, the system will activate the heater for heating the room. If the detected temperature is above 29 °C, then the system will activate the fan to cool the room [8].

2.2 LoRaWAN Overview

LoRa/LoRaWAN is one of the LPWAN technologies that has been popularly adopted in massive IoT use cases these days. Like other LPWAN technologies, it offers low energy use, wide area coverage, and low operational cost [9]. Meanwhile, LoRa has unique benefits: it uses an unlicensed frequency spectrum (while Sigfox does) and it is designed for the open standard network (while Sigfox is a proprietary network). The characteristics of some LPWAN technologies are described in Fig. 1 [10].

From the architectural view, LoRa works as a common IoT system. An end-to-end LoRa system comprises device, network, platform, and application. The device can be sensors that are utilized to measure phenomenons. LoRa gateway will send the data through internet access (network) to reach the network server (platform). Then the data/information can be visualized in an application. Figure 2 displayed the LoRaWAN basic architecture [11].

In LoRaWAN, some important parameters need to be taken care of to implement the system optimally [4]:

- Bandwidth

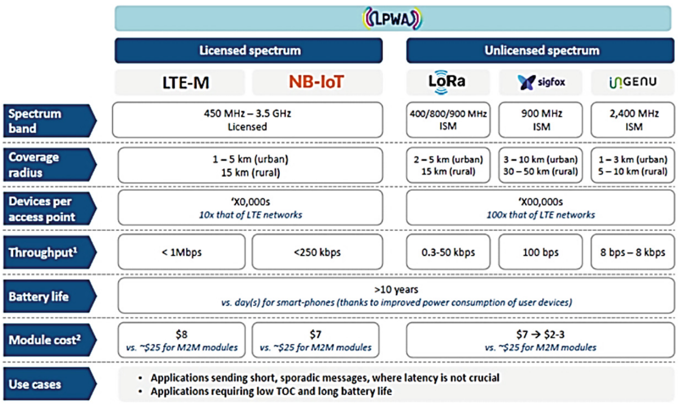

Fig. 1. LPWAN characteristics

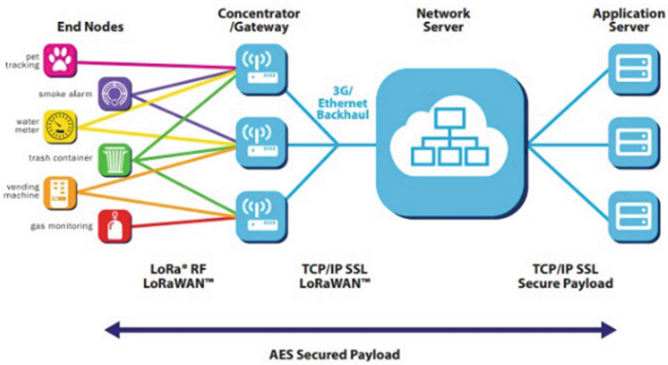

Fig. 2. LoRaWAN architecture

Table 1. RSSI level standard [4]

RSSI (dBm)	Information
−30 s/d −60	Very strong. Transmitter and receiver distance is very close
−60 s/d −90.	Very good. Close coverage
−90 s/d −105	Good. There are some data that are not accepted.
−105 s/d −115	Bad. Can accept but often drop-out
−115 s/d −120	Very bad. Weak signal data is often lost

Bandwidth is the width of the frequency in the transmission band. Higher bandwidths provide higher data rates (resulting in shorter transmission times), but lower sensitivity (due to additional noise integration). A lower bandwidth has high sensitivity, but a lower data rate.

- Spreading factor (SF)
  The spreading factor can be defined as the number of bits in 1 symbol. A higher spreading factor improves signal to noise ratio (SNR), sensitivity, and range, but also increases packet airtime. Spreading Factor values in LoRa consist of SF7 to SF12, each number in SF represents the modulated chips per symbol. Spreading spectrum uses code division multiple access (CDMA) technique.
- Duty cycle
  Coding rate refers to the number of bits that contain data or information to be transmitted. The coding rate is formulated to handle packet error rate (PER) due to interference.
- Received signal strength indicator (RSSI)
  RSSI is a parameter that shows the receiving power of all signals in the channel frequency band used. In LoRaWAN, an RSSI in the range of −90 to −100 is practically acceptable (smaller is better). Table 1 shows the RSSI level standard.

3 Methodology

The flowchart of this study is described in Fig. 3. At first, the sensor must be developed before the next process, location determination is done. The next process is system installation and then data collection and drive test. Then we should match the result with quality standards, so the data transmission is smooth. If complies, we proceed to the system implementation while it does not, we should refer again to the location determination process to obtain the optimum positioning of the gateway and sensors.

Meanwhile, Fig. 4 depicts the system's architecture. The sensor is configured using LoRaWAN technology to get benefits such as low battery consumption and long-distance range. This device reads the temperature and humidity then the data is sent to the gateway to be forwarded to the network server. On the network server, the data will be processed and then forwarded to the application server so that the data can be viewed and monitored in real-time by the user.

This system works using temperature and humidity sensors, where the data will be sent to the platform to be displayed in real-time. The device will make the temperature and humidity in the room adjusted automatically if the room conditions are not at the preferred temperature and humidity. For example, if the temperature and humidity in the production room decrease, the sensor will automatically send data so that the temperature and humidity can return to normal according to the already set.

After the system has been implemented, the next procedure is to test the functionality of the temperature and humidity sensor. Here are the steps of this procedure:

1. Make sure the temperature and humidity sensor has been installed in the room according to the equipment ID of each sensor device.

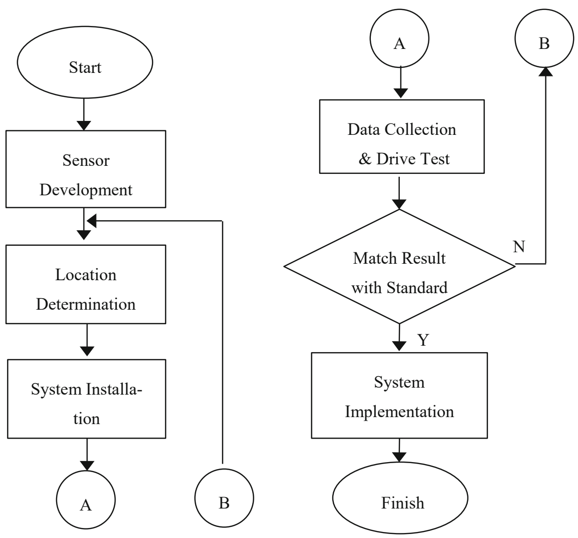

Fig. 3. System design flowchart

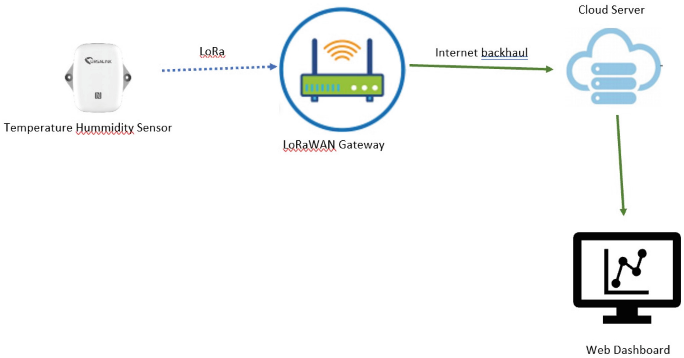

Fig. 4. System architecture

2. Make sure the power supply or battery on the sensor is plugged in and the sensor is on.
3. Prepare the sensor's user interface application on the mobile phone for validation of sensor values with NFC communication.
4. Ensure that the sensor reading data listed on the dashboard corresponds to what is seen in real-time on the sensor using the mobile phone user interface on the site with a transmission duration of 10 min.
5. Ensure that the sensor reading data on the dashboard is in accordance with the testing equipment. In this study, a device used is Kestrel 3000 with a temperature accuracy of ±1 °C and humidity of ±5% [12].

Figure 5 describes the architecture of the system's test using the sensor and Kestrel 3000 as a comparison device.

4 Result and Discussion

In this study, the implementation experiment was carried out in a pharmaceutical factory building where in the building there was 20 sensor devices or end devices, each end device installed in a different room. The LoRa gateway is installed in the main area of the building, not more than 100 m from each sensor.

4.1 Data Validation

Data validation is needed to determine the accuracy of the sensor in reading the temperature and humidity in the room. First, from temperature validation, the data comparison is done by comparing dashboard output with the Kestrel device. Table 2 shows that the accuracy level of the sensors is excellent, with the worst value being 91.75%.

Meanwhile, Table 3 shows the results for humidity measurements where results are also very good with minimum accuracy is 95.24%.

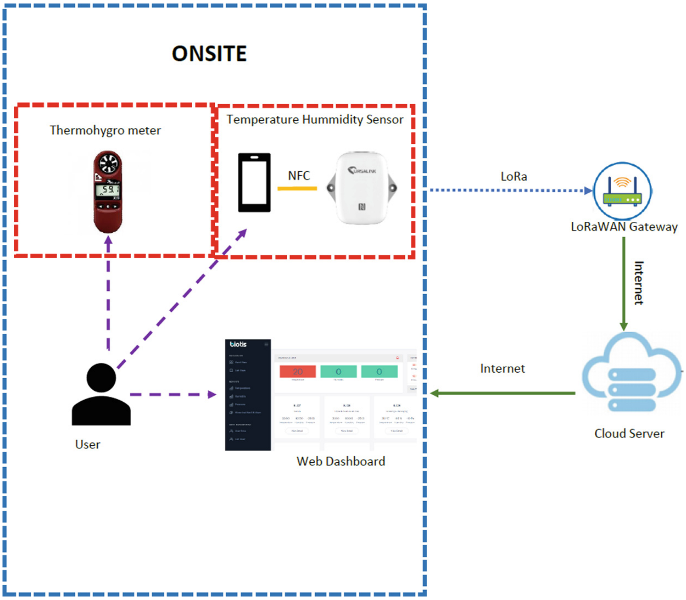

Fig. 5. Temperature and humidity sensor test architecture

Table 2. Temperature validation

Room ID	Room Name	Kestrel	Dasboard	Difference	Accuracy (%)
B-127	Decon	32.8	32.3	0.5	98.48
B-128	Unpack Aluminium Cap	33.1	32.4	0.7	97.89
B-129	Labeling & Packaging	33.2	32.8	0.4	98.80
B-130	Label Temp. Storage	32.4	31.8	0.6	98.15
B-131	Material Temp. Storage	32.9	32.1	0.8	97.57
B-135	Unpacking	32.4	31.9	0.5	98.46
B-136	Vial temp. Strg	32.4	31.6	0.8	97.53
B-701	Buffer	30.4	29.6	0.8	97.37
B-701A	MAL	30.4	29.5	0.9	97.04
B-704	Air Lock	30.7	29.8	0.9	97.07
B-706	Clean Corridor	30.2	29.6	0.6	98.01
B-707	Blending-1	30.7	29.7	1	96.74
B-708	Blending-2	31.5	28.9	2.6	91.75

(continued)

Table 2. (*continued*)

Room ID	Room Name	Kestrel	Dasboard	Difference	Accuracy (%)
B-709 1	Filling	30.5	29.6	0.9	97.05
B-709 2	Filling	30.4	29.5	0.9	97.04
B-710	Air Lock	30.5	29.6	0.9	97.05
B-711	Capping	30.5	29.9	0.6	98.03
B-712	Decon	30.7	29.8	0.9	97.07

Table 3. Humidity validation

Room ID	Room Name	Kestrel	Dasboard	Difference	Accuracy (%)
B-127	Decon	61.0	63.0	2	96.72
B-128	Unpack Aluminium Cap	59.9	59.0	0.9	98.50
B-129	Labeling & Packaging	60.2	60.0	0.2	99.67
B-130	Label Temp. Storage	62.1	64.5	2.4	96.14
B-131	Material Temp. Storage	60.4	62.0	1.6	97.35
B-135	Unpacking	62.8	61.0	1.8	97.13
B-136	Vial temp. Strg	60.9	58.0	2.9	95.24
B-701	Buffer	69.0	71.0	2	97.10
B-701A	MAL	69.3	73.0	3.7	94.66
B-704	Air Lock	71.1	70.0	1.1	98.45
B-706	Clean Corridor	72.7	70.0	2.7	96.29
B-707	Blending-1	66.9	68.0	1.1	98.36
B-708	Blending-2	67.2	64.0	3.2	95.24
B-709 1	Filling	73.4	76.0	2.6	96.46
B-709 2	Filling	75.9	78.0	2.1	97.23
B-710	Air Lock	70.6	72.0	1.4	98.02
B-711	Capping	69.0	69.0	0	100.00
B-712	Decon	71.0	71.0	0	

4.2 Drive Test

The drive test is used to determine the RSSI parameters obtained by the end device. The RSSI parameter represents the signal strength received by the device, measured with an RSSI tool device namely Rising HF with 10 times sampling. The results are quite satisfactory, where the minimum RSSI found is −90.1 dBm and the maximum is −66 dBm. It is because an indoor gateway is used, nearby distance with each sensor. The drive test result is written in Table 4.

Table 4. Average RSSI with 10 times drive tests

Room Number	Room Name	Avg RSSI (dBm)
B-127	Decon	−73.4
B-128	Unpack Aluminium Cap	−76.5
B-129	Labeling & Packaging	−72.6
B-130	Label Temp. Storage	−84.7
B-131	Material Temp. Storage	−90.1
B-135	Unpacking	−70.7
B-136	Vial temp. Strg	−70
B-701	Buffer	−73.5
B-701A	MAL	−73.3
B-704	Air Lock	−74.5
B-706	Clean Corridor	−72.9
B-707	Blending-1	−73.8
B−708	Blending-2	−72.7
B-709	Filling	−66
B-710	Air Lock	−72.8
B-711	Capping	−79.8
B-712	Decon	−84.3

5 Conclusion

The pharmaceutical industry is an industry that is sensitive to temperature and humidity to guarantee the quality of its products. This research discusses the implementation of temperature and humidity sensors in a pharmaceutical company using LoRaWAN connectivity. LoRaWAN offers some benefits like low power, low cost, and a wide area for IoT systems. In this research, 20 sensors are used to measure, and then data will be sent through the LoRa network with an indoor LoRa gateway in the building. The result shows that for temperature and humidity, sensor performance is great since their accuracy for temperature measurement is 91.75% or above, while for humidity, the accuracy is 95.24% or above. As for the LoRa's signal strength, it is quite reliable as well since the range of the RSSI is -66 until -91 dB, or the signal strength is very good.

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