System for Monitoring Environmental Variables in a Pharmacy Area Using an Alternative IoT Architecture (a Pilot Study)

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Abstract. Hospitals and health centers that own a pharmacy area require continuous and safe monitoring of environmental variables. The rigorous control of temperature and relative humidity allows the physical and chemical properties of the medicines to be conserved, according to the suggestion of suppliers and current laws that regulate the conservation of medicines. The Internet of things (IoT) allows for monitoring and controlling specific areas by obtaining and publishing relevant data directly in the cloud, enabling intelligent systems to make early decisions when an abnormality is present in the area. However, for the IoT to fulfill its purpose, there must exist a permanent connection of things to the Internet, which is a challenge when there is low or no connection. Therefore, the purpose of this work is to implement a monitoring system for environmental variables under the condition of low or no Internet connectivity, using alternative technologies such as (GSM) for transferring data to the cloud. As a result of this work, the design and implementation of a continuous monitoring system for environmental variables in the hospital pharmacy area is presented. This system guarantees the integrity and security of the acquired data due to the standardized communication protocols that were implemented and the alternative IoT architecture under which the system was designed.

Keywords: Internet of Things · IoT architecture · GSM · Clinical engineering · Hospital

1 Introduction

Although the concept of the Internet of Things (IoT) has existed for about only a decade [1, p. 3], it has become a fundamental element in what is now called the fourth industrial revolution because of its important advances in applications related to smart devices with Internet connection. It is estimated that by the year 2035, approximately one trillion "things" will be connected to Internet, thus generating an extensive volume of data to be processed and enough information to contribute to the automation of

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processes and decision making in real time [2]. The IoT paradigm intends that all everyday objects that provide us with relevant information from a specific environment are connected to Internet. Therefore, the IoT has an exponential growth not only in the consumer sector but also in the industrial sector in fields such as transportation, manufacturing, agriculture, telecommunications, energy and health [3].

Most IoT applications that focus on health are related to the remote monitoring of patients; these include applications that measure vital signs via remotely generating alerts for detecting an abnormality in the human body, applications that address the elderly and active aging [4], and IoT applications that focus on hospital management regarding medical equipment or hospital areas.

Hospital environments and health centers require constant monitoring in the pharmacy area that is responsible for the acquisition, preservation, delivery and, in some cases, manufacturing of medication. Environmental and specifically temperature and humidity controls must be carried out, as these variables are important in guaranteeing the safety, purity and efficacy of the medicines [5]. Previous works attempted to address temperature and humidity controls by implementing a system based on an IoT architecture using an Internet connection; however, due to the lacking availability of an Internet connection, this was not possible at the hospital.

The purpose of this work is to design and implement a temperature and humidity acquisition system for managing information in the hospital pharmacy area, which allows for transmitting these variables in an environment with low or no Internet connectivity.

2 Materials and Methods

In this paper, an architecture composed of two stations was proposed: one for the collection and sending of data located in the hospital pharmacy area and another for the reception, storage and visualization of information located in the laboratories of the Universidad del Rosario, which have networks for IoT applications. Both stations are separated by a geographical distance of 4.2 km.

2.1 Data Capture and Sending Station

This station was responsible for the continuous monitoring of temperature and humidity variables. The variables were acquired every minute; after an hour, the data was averaged, and the result was sent to the reception station. This station consists of an MKR 1400 board developed by Arduino company and whose primary feature is to use GSM technology and connectivity with the powerful Microchip ATSAMD21 and U-blox SARA-U201 GSM module [6], an activated SIM card featuring a country communications operator and the temperature and humidity sensor DHT 22 developed by Adafruit company and characterized by its high accuracy: ±0.5 °C for temperature and ±2% for relative humidity [7]. The connection schematic is illustrated (see Fig. 1).

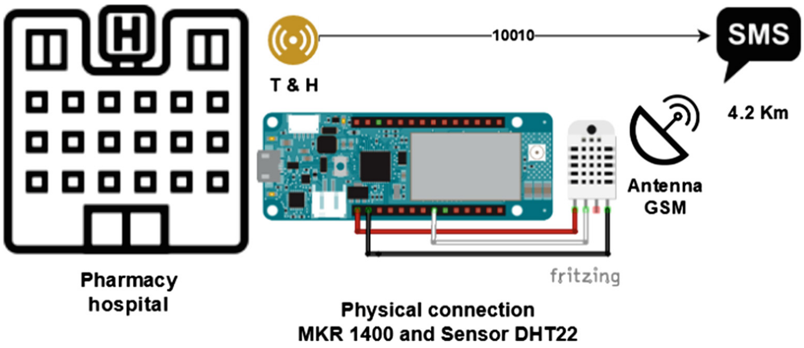

Fig. 1. Architecture of the sending station.

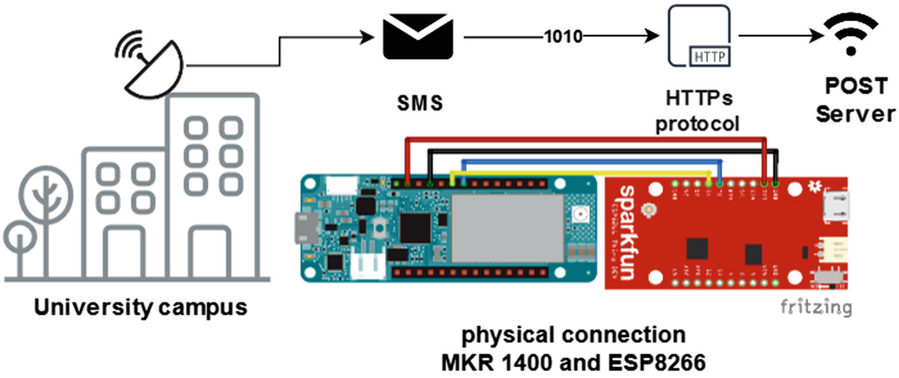

Fig. 2. Architecture of the station for receiving.

2.2 Station for Receiving

The station was responsible for receiving the data sent by the information capture station, using a GSM communication network (*Global System for Mobile*), receiving temperature and humidity data via text messaging or SMS (*short message service*) (see Fig. 2). This station uses an MKR 1400 board, which guarantees that the information comes from a reliable source. Once the information is received, it is sent through a serial communication to the development board ESP8266, developed by Sparkfun company, whose primary characteristic is its easy and safe connection to the Internet [8]. Finally, this board sends the data received using an Internet connection, an HTTP communication protocol, and an SSL security certificate to a web application hosted on a server in the cloud (see Fig. 3).

2.3 Storing and Displaying Information

Likewise, a web application was designed to store and query the data in a MySQL relational database for IoT [9, p. 195]; in addition, the application uses the Google Chart API to display the temperature and humidity status [10] of the last 12 h on a chart and two-gauge charts. Finally, the application offers a service of early alerts via email when abnormalities are present in the measurements. A preview of the developed interface can be observed in Fig. 3, and a demo of the application can be viewed at https://urbiomedeng.com/FarmaciaMederi/.

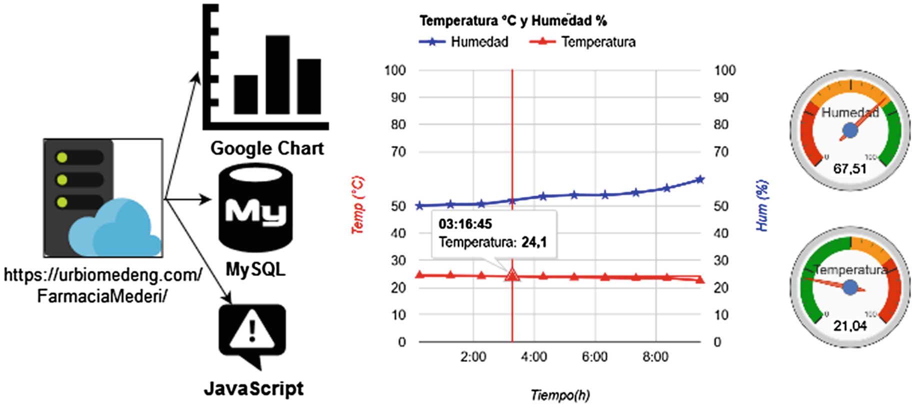

Fig. 3. Architecture for web application.

A statistical analysis was performed on the data collected by the system and the data collected manually. In the first instance, a descriptive analysis of the variables temperature and humidity was developed. Afterward, an inferential analysis of the data was conducted, the Shapiro Wilk normality test was applied, and a comparison of means was made between the data collected manually and the data measured by the system, for which a *t*-test was used. Finally, the error between the data collected manually and the data measured by the system was calculated. Statistical analysis was performed using the software SPSS V 25.

3 Results

To verify the reliability of our system, an analysis of the data collected for four days was performed. The manual records contain the measurements provided by the institution's thermohydrometer, which were compared with the measurements captured by the proposed system. In Tables 1 and 2, one can observe the descriptive statistics of the data manually acquired by the healthcare personnel in addition to what was registered by the proposed system.

Table 1. Descriptive statistics of manual temperature and humidity records

n	Mean ± SD[a]	Median	Shapiro-Wilk (***p*-value**)
12	23.66 ± 1.61 °C	23.50 °C	0.60
12	54.75 ± 4.04%	55%	0.86

[a]SD: Standard Deviation

Table 2. Descriptive statistics of temperature and humidity measured by the system

n	Mean ± SD	Median	Shapiro-Wilk (***p*-value**)
12	23.94 ± 1,70 °C	24.37 °C	0.183
12	55.18 ± 5.14%	54.34%	0.709

The value of statistical significance in the above tables is greater than 5%; for this reason, the null hypothesis is not rejected. This indicates that the temperature and humidity values for the mentioned cases follow a normal distribution. Therefore, a *t*-student test (see Table 3) of related measures was used to determine the degree of significance.

Table 3. Manual records against those measured by the system

Variable	Statistical T	gl	*p*-value
Temperature	−1.252	11	0.236
Humidity	−0.445	11	0.665

Based on the above table, it can be concluded that no statistically significant differences are found between the temperature and humidity measurements taken manually against the temperature and humidity measurements recorded by the system. This allows us to confirm the measurements delivered by the IoT system with a range of error lower than the 10% in each of the variables measured hourly (see Table 4).

An alternative IoT architecture applicable to any type of environment or industry in which the Internet connectivity is low or zero was designed and implemented (see Figs. 1 and 3). This system is presented with an open-source technologies solution that assures the traceability of temperature and humidity variables in a defined time interval, in addition to making a secure and reliable record in a database hosted in the cloud, which guarantees correct information management. The distribution of temperature and humidity data per day is presented in Fig. 4.

It can be observed in Fig. 4 above that the system detects that normal temperature values are between 23 °C and 25 °C; besides, it detects other temperature values within the limits established by the guidelines for the storage of medicines [11].

Likewise, in the humidity chart (see Fig. 5), some outliers were presented in the measurements, which indicates that on May 10, 13 and 14, some values were presented outside the average of the other values. However, these are contemplated in the regulations as tolerable values.

Table 4. Error manual records against those measured by the system

Month	Day	Hour	T Manual	T System	H Manual	H System	Error T	Error H
May	10	8	21	19.93	62	66.69	5%	8%
		12	24	24.71	56	56.73	3%	1%
		21	25	24.71	55	53.38	1%	3%
	11	8	22	21.96	58	58.15	0%	0%
		12	23	23.28	58	60.59	1%	4%
		21	26	25.42	54	54.39	2%	1%
	12	8	22	23.48	53	52.05	7%	2%
		12	25	25.01	49	49	0%	0%
		22	24	25.42	45	47.58	6%	6%
	13	8	23	23.38	57	56.53	2%	1%
		12	23	24.04	55	54.3	5%	1%
		21	26	26.03	53	52.8	0%	0%
	14	8	21	19.83	65	67.3	4%	6%
		12	23	23.48	56	56.73	1%	2%
		21	24	25.4	54	54.39	1%	6%

****T***: Temperature, ***H***: Humidity

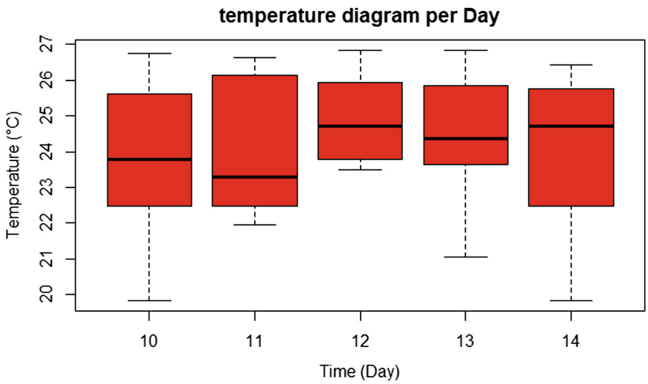

Fig. 4. Distribution of temperature per day.

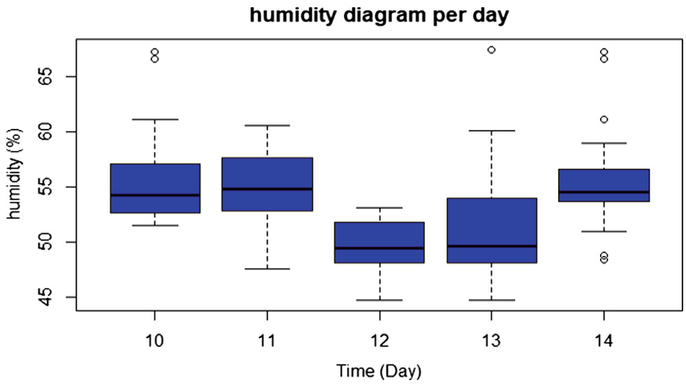

Fig. 5. Distribution of humidity per day.

To better detail the distribution of the temperature and humidity data per hour delivered by the system, an analysis was performed by means of a box diagram that is presented in the following graph.

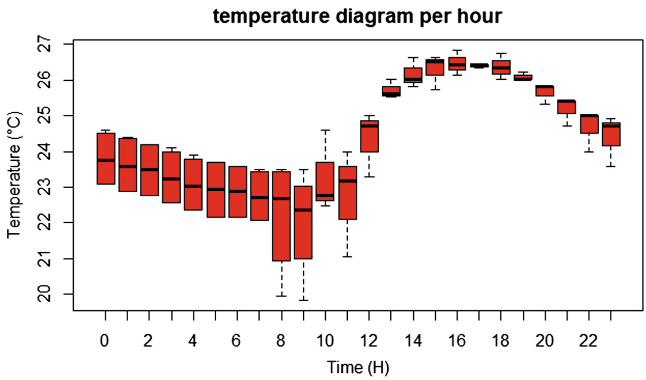

Fig. 6. Distribution of temperature per hour.

The box diagrams displayed in Fig. 6 reveal that, during the afternoon hours, the system detected a considerable increase in the environment's temperature, with ranges between 25 °C and 27 °C; in the night and morning hours, however, are ranges between 21 °C and 24 °C.

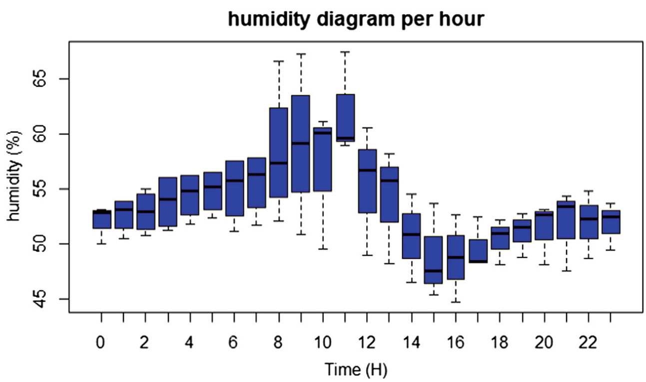

Fig. 7. Distribution of humidity per hour.

Similarly, the environment's relative humidity (see Fig. 7) ranged from 50% to 65% humidity and from 45% to 50% humidity during the afternoon.

4 Conclusions

It was possible to develop and implement a prototype system that guarantees the traceability of temperature and humidity in the pharmacy area, as it is continuously operated in the hospital, allowing for safely storing information in the cloud. Likewise, the system generates alerts to the responsible personnel in the event of an unusual change in these two variables. Moreover, Fig. 1 displays the proposed architecture expandable to all industrial sectors in which there is little or no Internet connectivity. The system is currently in operation in the hospital and continues capturing information to generate a statistical report of the accuracy and sensitivity of the system.

One of the limitations presented in this study is the amount of data with which the statistical tests were conducted. In future work, we intend to perform this same analysis using a minimum of six months of acquired data that will guarantee the accuracy, precision and sensitivity of the system and conduct a safety study.

Conflict of Interest. The authors report no conflicts of interest.

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