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Monitoring of Critical Variables in the Imaging Service from the Internet of Things (IoT)

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Abstract. The simultaneity between the current information and communication technologies (ICT), which with the current industrial revolution classified as 4.0, aims that all the everyday objects with which a person interacts allow to provide relevant information of a specific environment through Internet. The field of medicine and more specifically, medical devices allow us to contemplate a shared vision of interconnected sensors that can improve medical care services, with the possibility of the appearance of new technologies such as the Internet of Things (IoT) promise to be the field to follow in the near future. This paper offers an approach to the implementation of a real-time monitoring system on the main variables of a Computerized Axial Tomography (CAT) in the imaging service of a fourth level hospital through the IoT. The information obtained about the different sensors implemented in the medical team, suggested relevant information about the importance of monitoring the main variables that are directly related to the operating specifications suggested by the manufacturer of the medical equipment. The data collected were analyzed using the "regression" diagnostic test as a probabilistic strategy to look for a predictive value that suggests a possible failure of the medical team. The results showed that the information collected suggests the importance of monitoring the operating parameters of the CAT continuously given the behavior of some atypical data that were obtained, although there was no failure in the time window where the CAT was performed.

Keywords: Internet of Things · Computerized axial tomography · Clinical engineering · Bioinstrumentation

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1 Introduction

The term Internet of Things (IoT) was defined for the first time by Kevin Ashton in 1999, as the connection of multiple sensors and intelligent objects whose purpose is to communicate information from different environments where physical and digital entities can be linked looking for new applications and services [1]. What makes intelligent and connected products fundamentally different is not the Internet itself, but the changing nature of "things". Things, also called entities can be intelligent devices, sensors and any other object that is able to recognize their context and can communicate with other things, making it accessible at any time and anywhere [2].

Internet of things is part of a new and current paradigm that is generating new applications in the field of modern wireless communications. This is how the range of opportunities for implementing intelligent systems based on information from "intelligent objects" allows us to understand how data is currently used and processed [3]. It can be said that data is the main raw material that is processed and converted into information, in such a way that it is possible to identify trends and patterns that allow predicting possible behaviors of a system. The basic concept of IoT is the interaction between electronic devices, sensors and software among other technologies, which intend to interact with each other for a common goal, generating new applications and services for the people benefit [4].

In [5] it is explained as currently, medical care is increasingly difficult given the different technologic factors such as coverage, which tend to be insufficient and less effective in the face of growing population trends in terms of aging and chronic diseases, among others. This document focuses on the implementation of different sensors that allow to monitor environmental variables in the location of a computerized axial tomography. The variables captured are the temperature and relative humidity of the environment, the vibrations in the chassis of the equipment, the noise level and current consumption of the equipment.

This paper shows the specific construction of both hardware and software in key aspects of the medical equipment instrumentation process in the imaging service; since it is one of the services of greater demand in the hospital and, on the other hand, only one of these equipment is available to attend to more than 48 daily patients who need to be examined.

Accordingly, it is presented an IoT solution focused on the supervision of the different parameters of the physical environment of the service where the equipment is located, looking for a non-invasive alternative that allows to monitor in a parallel way, the area of biomedical engineering and some variables that allow to relate the operating conditions indicated by the manufacturer. The purpose is to identify how the external or internal factors affect the performance of the equipment and if the alteration of these, are correlated with the failures of the biomedical equipment as an innovative study under a recent technology [6].

2 Materials and Methods

The implementation of the system has a sensors network and programming board that are currently used in applications under the IoT technology. Mainly, sensors of low cost, size, connectivity characteristics and sensitivity were taken into account to obtain relevant information from the medical team (CAT). In accordance with the above, an assembly was made in the diagnostic imaging service where the CAT is located to monitor 5 external variables of the equipment.

In this aspect, as can be seen in Fig. 1, the main variables that were monitored in the equipment are: temperature, humidity, vibration, sound and current according to the most representative variables that the manufacturer presents in its technical operating manual of the TAC for its proper functioning.

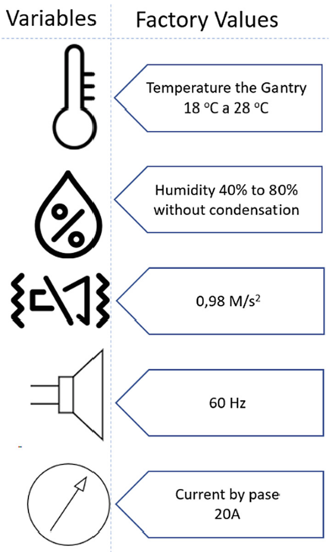

Fig. 1. Main variables of the CAT medical team.

It should be noted that the sensors used for this application were selected according to the values indicated by the manufacturer in each of its operating variables. Table 1 presents the technical data of each of the sensors used; its accuracy, costs and ease of acquisition were key characteristics for the implementation of the monitoring system.

Similarly, we used a set with special cards for data transmission such as the Arduino ESP8266 Thing, which is one of the most used programming cards in IoT applications, given its Wi-Fi connection characteristics. In this regard, the architecture used was implemented in a centralized manner, in such a way that the sending of information from each of the sensors to a local "broker" was managed, using a programming card known as Raspberry pi, which allows to store and manage by means of communication protocols, the acquired data of each one of the variables. Subsequently,

Table 1. Technical specifications of the sensors

Sensor	Measuring range	Measurement accuracy	Acquisition time
DTH22 (temperature)	−40 °C a 80 °C	<±0.5 °C	2 s
DTH22 (Humidity)	0 a 100% RH	2% RH	2 s
Sound KY-038	0 a 150 MHz		
Vibration	1.1 V/g	260 pC/g	+/−1%
Current	0 a 100 A	0 mA a 6 mA	+/−3%

we proceeded to store it in a database hosted in the cloud, to be analyzed by means of different statistical tools and finally to be presented or visualized in an interface designed for this purpose, which can be consulted through a web page [7].

The ESP8266 thing (Arduino) and Raspberry Pi 3 programming systems have been used successfully in other similar data collection efforts, including monitoring networks and evaluation of environmental variables in different enclosed spaces or urban areas as presented in [8]. In the same way, it has been implemented for intelligent health systems [9] and adaptive environments for the care and supervision of older adults [10]. Many of these studies have demonstrated the reliability and ease of use of programming cards (ESP8266 Thing and Raspberry pi 3) for data collection remotely.

One of the purposes is to show the application made and how through a platform on the web different applications can be developed in a specific field. This is how part of this work focuses on the use of the MQTT (Message Queue Telemetry Transport) protocol [11], recently used for different IoT-related projects, although it is unusually considered in medical devices. On the other hand, most health systems based on IoT focus on physical sensors. Some commercial sensors used in the industry for the monitoring of electronic and mechanical equipment are considered for this project. From the above, in Fig. 2 the description of the implemented system is presented in a general way:

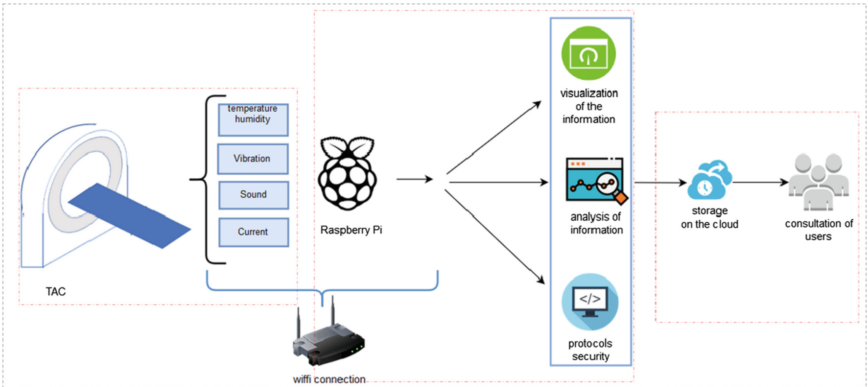

Fig. 2. Summary of the implemented system layers. (a) CAT data acquisition, (b) information processing, (c) data storage and query

It is important to highlight that the implementation of each of the modules (sensor/esp8266), was made under the interconnection by means of a Wi-Fi network to the local server (Raspberry pi). For this project, a centralized architecture was implemented where all the information is stored in a single place called Broker, a system that is installed in the Raspberry pi card. By means of specialized communication protocols such as MQTT, they make possible the flow of information in dynamic IoT systems [12].

Each one of the registers of the sensors used was transmitted under a sampling time of around 5 s. In this way, an average was made per minute, not without first establishing the factory operating ranges and obtaining a relative value per hour, which allows greater reliability in each of the captured measurements.

Finally, the acquired data were analyzed using descriptive statistics in order to find values that allow us to infer the correlation between the set of measurements taken. The data visualization is presented through densities diagrams and histograms using the programming language Python 3.

3 Results

Then, different visualizations were made to analyze the possible relationships between the variables of temperature and current consumption as the main critical variables in the continuous operation of the CAT according to the behavior of the acquired data. As shown in Fig. 2, we can observe similar values of current that oscillate between 4.6 to 4.75 A (amperes). It is common in temperature values (Fig. 3).

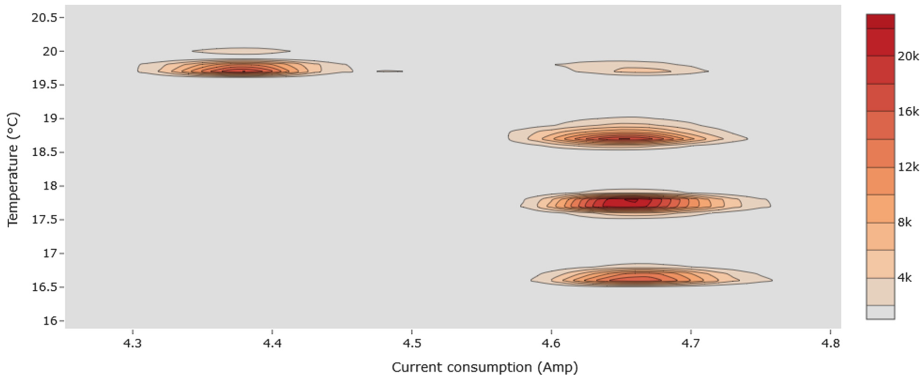

Fig. 3. 2D-Histogram of current consumption and temperature frequencies in a TAC in proper operation during two months.

The distribution of current consumption and temperature is depicted in 5 zones as presented in Fig. 2. The most interesting result is related to the two zones in the top of the figure presented the same temperature, but with two different ranges of current consumption. Durante el mes de adquisición se realizaron alrededor de 1,9 millones de mediciones en el CAT, y en los reportes no se reportó ningún fallo en el equipo analizado.

The current consumption of the CAT is bounded in two normal distributions with mean of 4.39 and 4.66 amps as presented in Fig. 4. On the other hand, the temperature was clustered in four big groups with values ranged between 16 and 20° as presented in Fig. 1. This result could be useful to evaluate the proper operation of a CAT, if the temperature measured by a maintenance technician is within this range.

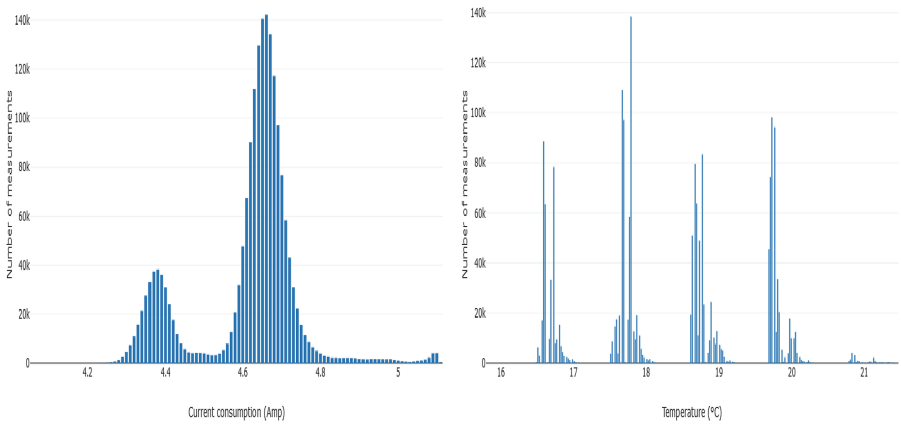

Fig. 4. Histograms showing the most common values of [Left] current consumption in a CAT; [Right] temperature in a CAT

4 Conclusions

This work developed a new approach for the design and implementation of an IoT system that helps in the capture of data on a large scale, in such a way that it allows to combine paradigms, finding patterns of operation of a medical team under the supervision of different variables in a hospital environment. It also allows to generate new or alternative options to carry out a predictive maintenance, based on the behavior of each one of the variables, in such a way that it allows to avoid in some way a corrective failure.

This process was carried out in two fundamental phases, which helped to channel the activities by executing several processes in parallel without interfering with each other, in such a way that the working group was divided into main tasks such as: the selection of the different variables that were the object of this study was carried out under the criteria of the group of engineers of the hospital and the researchers of the university. Likewise, the point of view and experience of the team of doctors of the diagnostic imaging service was taken into account.

The test phases of the system allowed to identify the behavior of the data and the identification of the veracity and reliability of each of the tests, thus determining the average values of operation and anticipating whether the solution has a real value or not. In this way, it was identified if the captured values could be good indicators of deterioration or malfunctioning of the equipment, allowing foreseeing failures.

To conclude, these systems can greatly increase the quality of the service, allowing constant control and improvement in the use of medical equipment. Two implications directly related to this work could be: the creation of a continuous monitoring system in real time, accessible and intelligible by means of low-cost technology, integrated in a non-invasive manner in the equipment.

On the other hand, there is an environmental design approach to detect different variables separately, its synergy can be used in a more extensive study on the architecture, characteristics and suggest new improvements in the connection of intelligent objects.

The acquisition of a greater number of CAT devices or devices from different manufacturers, other variables and a longer acquisition time could confirm the results presented in this study. On the other hand, the need for a quick and reliable forecast of possible failures in medical equipment and the reduction of corrective maintenance in these, will be two interesting topics of study in future work

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

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