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Monitoring System for Doors and Windows of a Data Center with IoT

Sistema de monitorización de puertas y ventanas de un centro de datos con IoT

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Abstract

This paper presents the construction of a prototype of a door and window monitoring system through an IoT platform. The objective was to design a system that reports to a server in the cloud the change of state, open or closed, of three doors and two windows of the equipment room of the data center. The changes of state are registered by the server, and by means of a user interface the status of doors and windows is displayed online. The architecture of the system is based on a wireless sensor network, integrated by a central node and five monitoring nodes. The monitoring nodes consist of a PyBoard card, two digital Hall effect sensors and a WiFi wireless interface. When detecting a change of state in doors and windows, the monitoring nodes notify it to the central node, and this transmits it to the server through a WiFi access point. When a door or window remains open for more than a configurable period of time, an SMS and WhatsApp message is sent to a mobile phone. The reach achieved in the WiFi transmission on the network was 47 meters with line of sight.

Keywords: Data center, Hall effect, monitoring, PyBoard, SMS, WiFi.

Resumen

En este trabajo se presenta la construcción de un prototipo de un sistema de monitorización de puertas y ventanas a través de una plataforma IoT. El objetivo fue diseñar un sistema que reporte a un servidor en la nube el cambio de estado, abierta o cerrada, de tres puertas y dos ventanas de la sala de equipos del centro de datos. Los cambios de estado son registrados por el servidor y por medio de una interfaz de usuario se muestran en línea los estados de las puertas y ventanas. La arquitectura del sistema se basa en una red inalámbrica de sensores integrada por un nodo central y cinco nodos de monitorización. Los nodos de monitorización están compuestos por una tarjeta PyBoard, dos sensores digitales de efecto Hall y una interfaz inalámbrica wifi. Al detectar un cambio de estado en puertas y ventanas, los nodos de monitorización lo notifican al nodo central, y este lo transmite al servidor por medio de un punto de acceso wifi. Cuando una puerta o ventana permanece abierta más de un período de tiempo configurable, se envía un mensaje SMS y de WhatsApp a un teléfono móvil. El alcance logrado en la transmisión wifi en la red fue 47 metros con línea de vista.

Palabras clave: centro de datos, efecto Hall, monitorización, PyBoard, SMS, wifi

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1. Introduction

A data center houses equipment for processing and storing information, and telecommunication equipment of companies and organizations. Since the productivity of clients and users depend on such equipment, it is important to keep it safe. The data centers should have highly reliable security systems, which enable the controlled access to the rooms that concentrate the computing equipment. These rooms have a reduced number of doors and windows, and the entrance to authorized administration and maintenance personnel is only allowed, who should keep them locked at all times. When, for any reason, a door or a window remains open for longer than a certain configurable period of time, an audible and luminous signal is activated to warn security personnel [1].

The data centers are periodically and permanently audited by institutions and companies that certify, among other things, the access mechanisms and procedures, to guarantee the quality of the services offered. One of the audited actions is the remote monitoring of the state, either closed or open, of doors and windows [2].

With the current development of technology, it is required that data centers are enabled for remote monitoring of variables, processes and procedures from the Internet, thus allowing people responsible for security and certifying institutions to revise, both online and historically, the operation of the data center [3]. This requirement can be fulfilled with the development of solutions and applications of the Internet of Things (IoT).

1.1. The Internet of Things

The IoT is a concept according to which the information read by electronic sensors used at households, offices, industries, laboratories, mobile phones, automobiles, infrastructure of cities and data centers is transmitted to a central monitoring device. This central device is located in the Internet, thus allowing the connection to it of digital objects of daily used, i.e. it connects the physical and digital worlds by means of computers and web platforms in the cloud, which store and process the information transmitted by sensors [4].

The recent technological advances in electronics, digital systems and communications, as well as the availability of providers of services of information storage and analysis in the cloud, have boosted the development of the IoT. These services enable receiving, storing and processing information from sensors, to perform a remote action on a process. In addition, there are services that can be used to transmit voice, text, video or Whatsapp alert messages to a mobile phone [5], to notify an event.

The present work results from the requirement of a company which owns a data center. The request consisted of developing a system with the purpose of transmitting to a server located in the cloud, the change of state, open or closed, of three doors and two windows in the equipment room of the data center. The changes of state, as well as the date and time, should be stored by the server. The system should have a user interface, accessible from the Internet, which online shows the state of doors and windows and displays a history of the changes of state. In case that a door or window remains open for longer than a configurable period of time, alert SMS and Whatsapp messages should be sent to the mobile phone of the administrator of the system. A Wi-Fi point to access the Internet is installed in the data center, located at a distance of 35 meters from the farthest window.

1.2. Recent research works

An important number of works have been carried out, to remotely monitor environmental variables in data centers. Since IoT is a fast growing area, Wireless Sensor Networks (WSN) have been installed for this purpose in recent years, and almost all of them use Wi-Fi technology [6]. A large number of these applications monitor environmental variables such as temperature and relative humidity [7, 8], other monitor cooling systems [9], air flow in cabinets of computing equipment [10, 11] and electrical supply systems [12]. Some wireless networks use ZigBee [13] and LoRa technologies.

On the other hand, a great variety of applications have been designed using IoT platforms in areas of monitoring vital signs [14–17], health care [18], industrial processes [19], environmental and atmospheric parameters [20], traffic control [21], bridges [22] and flooding prevention systems [23] in intelligent homes and cities, animal feeding systems in farms [24] and infant location at home [25], among others. The majority of these applications use Wi-Fi transceivers, and few utilize LoRa [26, 27] and GPRS [28] technologies.

The system developed in this work is constituted by a network with five monitoring nodes, one for each door and window, and a central node. The monitoring nodes wirelessly transmit the state of the sensors of doors and windows to the central node, which sends them to the server in the cloud through a Wi-Fi access point. The user interface was implanted in the central node using a web server. The two types of nodes were realized based on a PyBoard card. Using the Internet service provider ThinkSpeak, the information transmitted by the monitoring nodes is stored and accessed from the user interface. On the other hand, the Internet service provider Twilio was used to send the SMS and Whatsapp messages. Both the sensors and Wi-Fi transceivers used are of low energy consumption.

1.3. ThingSpeak and Twilio

ThingSpeak is a service platform for information analysis in the cloud, which is used to collect, store, visualize and analyze data from sensors installed in intelligent devices. For applications that transmit to the server up to 3 million messages per year, the ThinkSpeak service has no cost. Twilio is a service platform based on Application Programming Interface (API), which enables the transmission of voice, video and text messages to web, mobile and desktop applications. The free use of Twilio allows sending up to one hundred messages per month.

1.4. Contribution of the work

Taking into account what has been previously stated, no IoT application similar to the one presented here has been developed for a data center. The ones that have been carried out are of greater cost, because they utilize development cards of high price, in which many of its elements are not used, and because they require to install, configure and maintain the server in the cloud. In addition, the maintenance of the system proposed in this work is simpler and faster than others of similar type, since all programming has been done in MycroPython. The contribution of this work it that it solves a real security need, monitoring from the Internet the state of doors and windows, as requested by certifying institutions. Current systems if this type do the monitoring locally.

2. Materials and methods

The methodology that was utilized to develop the system comprised two phases. In the first phase the system was designed, divided in three modules: monitoring nodes, central node and user interface, as indicated in the block diagram in Figure 1. The monitoring nodes and the central node constitute the wireless network of sensors.

Afterwards, the second phase comprised the selection of the appropriate components to perform the function of every module of the system

2.1. The monitoring nodes

Fives monitoring nodes were built, all having the architecture shown in Figure 2.

The monitoring nodes are constituted by a PyBoard card, the cards of the sensors of doors and windows opening, and the wireless interface.

The PyBoard PYBV1.0 card used in this module, is the most commonly used card of its type to execute programs written in MycroPython. It comprises the following hardware resources: STM32F405RG microcontroller with CPU Cortex M4 of 168 MHz and floating point, USB port, flash ROM memory of 1024 KB, RAM memory of 192 KB, slot for Micro SD card, real-time clock, 29 general purpose input/output terminals, 3 analog/digital converters of 12 bits, 2 digital/analog converters of 12 bits, 2 UART ports, 4 USART ports, bootloader program for firmware updating, and is energized with 3.3 V.

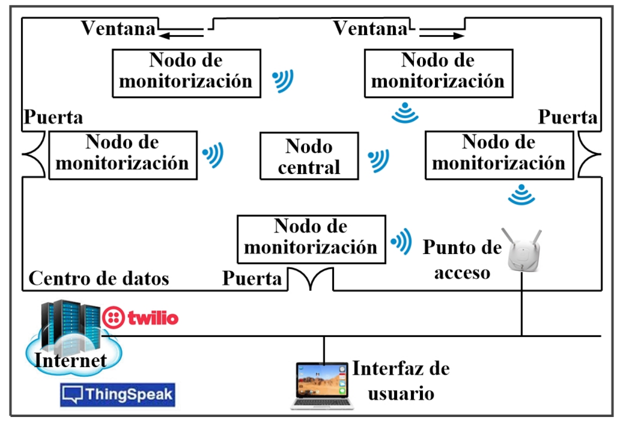

Figure 1. Block diagram of the developed system.

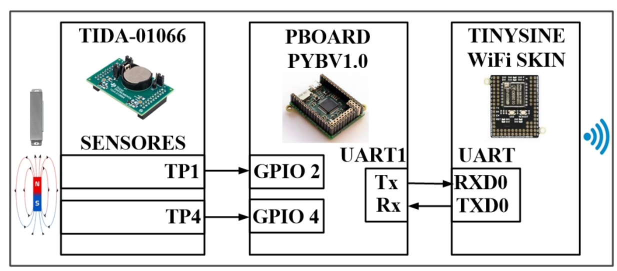

Figure 2. Architecture of the monitoring nodes.

The PyBoard card was used because its microcontroller executes programs written in MycroPython, which simplified the programming by avoiding the use of a complex low level language, and because many functions libraries of free use and open code are available in the cloud, to carry out a variety of tasks.

Two types of devices, namely Reed switches and Hall effect sensors, are commonly used in applications for monitoring the opening of doors and windows. Both devices detect the presence or absence of magnets installed in doors or windows. Reed switches use a physical switch that closes in the presence of a magnetic field, and opens when such field is removed. Due to their mechanical nature, their life time is limited, there is a bouncing effect when closing or opening, and its operation is affected by vibrations. The installation of this type of switches increases the cost of the application, since they should be commonly soldered in the door or window, which may damage the glass encapsulation. When opened, Reed switches consume no current; when closed, a small current flows through the pull-down or pull-up resistance connected in the output. The magnitude of this current is significant in systems energized by batteries.

In contrast, Hall effect sensors have no moving parts. They detect the presence or absence of a magnetic field in their range, using the voltage difference (V) produced in a conductor when an electrical current (I) flows through it in the presence of such magnetic field (B). They are immune to vibrations and do not bounce. Hall effect sensors have compact size, resistant encapsulating, and consume less current than Reed switches. They activate their output at low level, logical 0, when the magnetic flow density produced by a magnet close to it, exceeds an operating threshold BOP. This output is used as a switch to connect to the input terminal of a controller, which can be in sleep mode or of low energy consumption, and awake when the output of the sensor changes.

Due to the aforementioned reasons, the TIDA-01066 card was used for the implantation of the monitoring nodes. This card includes two Hall effect digital sensors of ultra-low energy consumption, and a CR2032 coin-type battery. These sensors detect the presence of the magnetic field of the magnets installed in the doors and windows. This card also integrates two DRV5032X sensors, to avoid detecting false negatives and to maximize the distance between sensors and magnets. The X indicates the sensitivity of the sensors: high, medium and low. The operating threshold for each sensitivity is 3.1 mT, 7.5 mT and 50 mT, respectively. The sensors are energized by a source of 1.65 to 5.5 V that consume 0.57 µA in average, and operate at a sampling frequency updating the output at 20 Hz or 5 Hz for the low energy consumption. The response of these sensors is omnipolar, which enables them to detect the north or south pole of the magnet, thus simplifying its installation.

In security systems based on sensors wireless networks, one of the main limitations is the electrical supply. It the sensors of the network are energized with batteries, the replacement cost of these batteries becomes a problem. The CR2032 battery of the TIDA-01066 card has a life time of 10 years, which keeps its sensors operating during a prolonged period of time before replacing the battery. This was another reason by which the TIDA-01066 card was used in the monitoring nodes. The CR2032 battery is an ion-lithium small cell that, as opposed to alkaline batteries, keeps the output voltage stable until the end of its life time. It operates in the temperature range between -40 °C and 85 °C, and can be used indoors and outdoors.

The monitoring nodes were installed in the fixed part of the windows and the magnets in the sliding part, separated by a distance of 20 mm. The doors of the data center have two panes, with the monitoring nodes installed in one of them and the magnets in the other, such that when the door or window is closed, the output of the Hall effect sensor shows low level. The outputs of the sensors were connected to the GPIO 2 and GPIO 4 terminals of the PyBoard card. The microcontroller of the PyBoard is in sleep mode, or low energy consumption, most of the time. When a door or window is open or closed, the level change in any of the GPIO 2 and GPIO 4 generates and interruption that awakes the microcontroller. The Interrupt Service Routine (ISR) that serves this interruption, transmits the state of the sensor to the central node.

On the other hand, there is a great amount of magnet types and providers in the market. K&J Magnetics is the provider with the greater variety of magnets, having available Neodymium magnets of N35, N38, N40, N42, N45, N48, N50 and N52 grades, different dimensions, shapes and reach of the magnetic field. The grade indicates level of intensity or strength of the magnetic field of the magnet; N35 is the lowest level. A calculator to determine the appropriate magnet depending on the necessary features, is available in the K&J Magnetics web site. Magnets BZX0X08-N42 with length 101.6 mm, width 25.4 mm, thickness 12.7 mm, magnetic field intensity and reach 3,424 Gauss and 10 mm, respectively, were utilized in this work. The reach of the magnetic field determines the maximum distance for which the intensity of the magnetic field is maintained, before it decreases. The sensors wireless network implanted in this work is a wye network, in which the central node is the coordinator. The central node operates collecting information of the monitoring nodes, and receives messages from them when the associated sensors change of state.

The monitoring nodes use the TinySine Wi-Fi Skin module for PyBoard, as wireless interface to communicate with the central node. This module operates based on the ESP-07S circuit, which belongs to the ESP8266 family. The UART of the ESP-07S was connected to the UART1 port of the PyBoard card, to carry out the serial communication.

The microcontroller program of the monitoring nodes performs the following activities: 1) Configures terminals GPIO 2 and GPIO 4 as inputs, initializes the UART1 and configures the wireless interface, 2) Transmits the message to the central node to join the network and 3) Activates the sleep mode or low energy consumption, from which it exits after receiving an interruption from terminals GPIO 2 or GPIO 4. When the microcontroller awakes and exits this mode, it transmits the message to the central node indicating the value of the output or state of the sensors, and returns to the sleep mode. Figure 3 shows the flow diagram used to create this program.

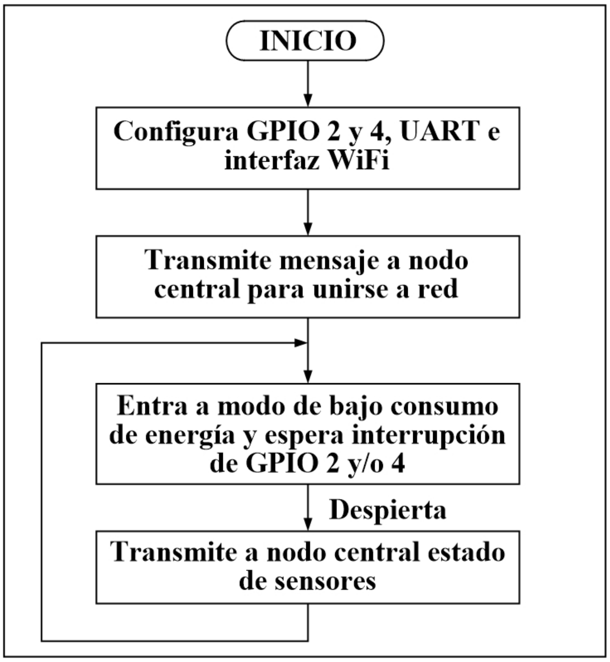

Figure 3. Flow diagram of the monitoring nodes program.

2.2. The central node

The central node is constituted by the PyBoard card and the wireless interface. The central node uses the circuit TinySine Wi-Fi Skin for PyBoard as wireless interface, to communicate with the monitoring nodes and the Internet.

The functions of the central node are the following: 1) Initializes the sensors network, 2) Receives messages with information transmitted by the monitoring nodes, to send it to the server in the cloud and 3) Implants the user interface.

These functions are performed through the program executed by the microcontroller of the PyBoard card, which carries out the following tasks: A) Configures the UART1 and the wireless interface, establishes the value of the timer of open door or window and establishes the mobile phone number of the administrator of the data center and B) Enters in a cycle in which it invokes the function that implants the graphical user interface, and waits for the interruption from the UART1.

The function that serves the interruption from the UART1 is responsible for receiving the information from the nodes of the network, and transmitting it to the server in the cloud. This function uses the write REST API to transmit the message a ThingSpeak. The message contains the identifier of the monitoring module, the state of the associated sensor and the date and time. If the sensor is deactivated, the door or window is open. In this case, the function starts a timer, which interrupts the microcontroller when it expires. The function that serves the interruption of the timer, verifies if the central module received the message that indicates the change of state of the sensor. If this is the case, the door or window has been closed, and the function ends. If this is not the case, it transmits the SMS and Whatsapp alert messages using the Twilio REST API. These messages sent to the mobile telephone of the administrator of the data center, indicate that the door or window has exceeded the allowed opening time.

2.3. The user interface

The user interface is constituted by the web server and the corresponding site. Through the user interface, the state of the sensors of doors and windows can be visualized online, and the historical information collected by the system may be downloaded to a text file. The implantation of the web server was based on the library of open code functions uasyncio. This library was designed to realize web servers with microcontrollers, known as picowebs, using the minimum amount of RAM memory. Figure 4 shows the main screen of the created user interface.

Figure 4. User interface.

3. Results and discussion

Two groups of tests were carried out. The objective of the first group was to determine the type of magnet to be used, considering that the separation between the monitoring node and the magnet is 10 mm. Using the K&J Magnetics calculator of magnetic field, a magnet with block shape with a magnetic field reach of 10 mm was requested. The calculator indicated 7 types of magnets of different grades, dimension, magnetic field intensity and price. To carry out the tests, each of the 7 magnets were placed on a door and on a window, and the distance at which the monitoring node detected its opening was measured. Although the magnetic field reach of the magnets used is of the same magnitude, the results of the tests showed reaches which were slightly different than the nominal value, as can be seen in Table 1.

Table 1. Types of magnets used in the tests

Type of magnet	Dimensions (mm)	Magnetic field (Gauss)	Price (USD)	Reach (mm)
BZ0Z0X0-N52	76.2x76.2x25.4	3798	294.82	14
BZ0Z08-N52	76.2x76.2x12.7	2125	151.36	13
BZ0Z04-N52	76.2x76.2x6.35	1098	79.43	12
BZ0Z02-N52	76.2x76.2x3.17	554	43.34	11
BZX0X0X0-N42	101.6x25.4x25.4	4871	100.15	14
BZX0X08-N42	101.6x25.4x 12.7	3424	43.34	10
BZX0Y04-N42	101.6x50.8x6.35	1152	51.86	12

For this application, it was necessary to use a magnet that activates the sensors at a distance of 10 mm. It was not necessary to use a strong magnet, with a large intensity of magnetic field. For this reason and due to the results obtained in these tests, a BZX0X08 magnet of grade N42 was used, with low price and real reach of 10 mm. No tests were carried out to measure the intensity of the magnetic field, because the function of the magnets is to activate the sensors, and not to attract a metallic element.

Even though there were no communication problems of the network nodes with the Wi-Fi 802.11 n access point, a second group of tests was conducted to determine the reach of the network. To carry out these tests, a monitoring node was located at different points of the data center, including places more distant to the farthest window with respect to the access point. Results showed that the reach of the network is 47 meters with line of sight at a velocity of 230 Mbps, smaller than the 300 Mbps that can be theoretically obtained using the 802.11 n standard. At a distance greater than 47 meters, the power of the received Wi-Fi signal (RSSI- Received Signal Strength Indicator) in the monitoring node decreased in an accelerated manner, and the link was lost when the strength fell to -86 dBm, as shown in the plot of Figure 5.

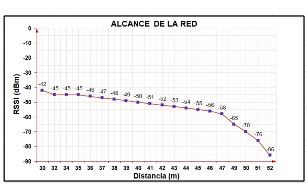

Figure 5. Reach of the sensors network.

The inSSIDer tool installed in a portable computer by the monitoring node, was utilized to measure the RSSI level.

4. Conclusions

The result of this work was a system to monitor doors and windows through the IoT platform, which reports to a server in the cloud the change of state of three doors and two windows in the equipment room of a data center. This system has a user interface that shows online, the state of doors and windows. The installation is non-intrusive, because it uses wireless communication and it does not modify the cabling of the data center. It was programmed using MicroPython and libraries of free use open code functions, which reduced the time and complexity of the implantation. It uses IoT platforms recently created in the cloud, that provide an efficient and reliable service to store information and transmit the alert messages to a mobile telephone, thus implementing an application that fulfills the established requirements. The reach achieved in the Wi-Fi transmission was 47 meters with line of sight.

References

[1] P. A. Lontsikh, V. A. Karaseva, E. P. Kunakov, I. I. Livshitz, and K. A. Nikiforova, "Implementation of information security and data processing center protection standards," in *2016 IEEE Conference on Quality Management, Transport and Information Security, Information Technologies (IT&MQ&IS)*, 2016, pp. 138–143. [Online]. Available: https://doi.org/10.1109/ITMQIS.2016.7751923

[2] Z. Han and L. Yu, "A survey of the bcube data center network topology," in *2018 IEEE 4th International Conference on Big Data Security on Cloud (BigDataSecurity), IEEE International Conference on High Performance and Smart Computing, (HPSC) and IEEE International Conference on Intelligent Data and Security (IDS)*, 2018, pp. 229–231. [Online]. Available: https://doi.org/10.1109/BDS/HPSC/IDS18.2018.00056

[3] D. Achmadi, Y. Suryanto, and K. Ramli, "On developing information security management system (isms) framework for iso 27001-based data center," in *2018 International Workshop on Big Data and Information Security (IWBIS)*, 2018, pp. 149–157. [Online]. Available: https://doi.org/10.1109/IWBIS.2018.8471700

[4] H. Hejazi, H. Rajab, T. Cinkler, and L. Lengyel, "Survey of platforms for massive iot," in *2018 IEEE International Conference on Future IoT Technologies (Future IoT)*, 2018, pp. 1–8. [Online]. Available: https://doi.org/10.1109/FIOT.2018.8325598

[5] P. Datta and B. Sharma, "A survey on iot architectures, protocols, security and smart city based applications," in *2017 8th International Conference on Computing, Communication and Networking Technologies (ICCCNT)*, 2017, pp. 1–5. [Online]. Available: https://doi.org/10.1109/ICCCNT.2017.8203943

[6] E. A. Kadir, S. M. Shamsuddin, S. Hasan, and S. L. Rosa, "Wireless monitoring for big data center server room and equipments," in *2015 International Conference on Science in Information Technology (ICSITech)*, 2015, pp. 187–191. [Online]. Available: https://doi.org/10.1109/ICSITech.2015.7407801

[7] S. Saha and A. Majumdar, "Data centre temperature monitoring with esp8266 based wireless sensor network and cloud based dashboard with real time alert system," in *2017 Devices for Integrated Circuit (DevIC)*, 2017, pp. 307–310. [Online]. Available: https://doi.org/10.1109/DEVIC.2017.8073958

[8] K. Nayak, K. Nanda, T. Dwarakanath, H. Babu, and D. Selvakumar, "Data centre monitoring and alerting system using wsn," in *2014 IEEE International Conference on Electronics, Computing and Communication Technologies (CONECCT)*, 2014, pp. 1–5. [Online]. Available: https://doi.org/10.1109/CONECCT.2014.6740348

[9] M. R. C. Truşcă, Ş. Albert, and M. L. Soran., "The benefits of data center temperature monitoring," in *2015 Conference Grid, Cloud & High Performance Computing in Science (ROLCG)*, 2015, pp. 1–3. [Online]. Available: https://doi.org/10.1109/ROLCG.2015.7367417

[10] R. Lloyd and M. Rebow, "Data driven prediction model (ddpm) for server inlet temperature prediction in raised-floor data centers," in *2018 17th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm)*, 2018, pp. 716–725. [Online]. Available: https://doi.org/10.1109/ITHERM.2018.8419650

[11] T. Akiyama, M. Matsuoka, K. Matsuda, Y. Sakemi, and H. Kojima, "Secure and long-lived wireless sensor network for data center monitoring," in *2018 IEEE 42nd Annual Computer Software and Applications Conference (COMPSAC)*, 2018, pp. 559–564. [Online]. Available: https://doi.org/10.1109/COMPSAC.2018.10295

[12] M. Wiboonrat, "Developing diagnostics and prognostics of data center systems implementing with condition-based maintenance," in *IECON 2018 - 44th Annual Conference of the IEEE Industrial Electronics Society*, 2018, pp. 4901–4906. [Online]. Available: https://doi.org/10.1109/IECON.2018.8591203

[13] S. P. Patil and S. C. Patil, "A real time sensor data monitoring system for wireless sensor network," in *015 International Conference on Information Processing (ICIP)*, 2015, pp. 525–528. [Online]. Available: https://doi.org/10.1109/INFOP.2015.7489440

[14] B. Ashish, "Temperature monitored iot based smart incubator," in *2017 International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC)*, 2017, pp. 497–501. [Online]. Available: https://doi.org/10.1109/I-SMAC.2017.8058400

[15] S. Mandala, S. N. Anggis, M. S. Mubarok, and Shamila, "Energy efficient iot thermometer based on fuzzy logic for fever monitoring," in *2017 5th International Conference on Information and Communication Technology (ICoIC7)*, 2017, pp. 1–6. [Online]. Available: https://doi.org/10.1109/ICoICT.2017.8074640

[16] K. A. Zilani, R. Yeasmin, K. A. Zubair, M. R. Sammir, and S. Sabrin, "R^3hms, an iot based approach for patient health monitoring," in *2018 International Conference on Computer, Communication, Chemical, Material and Electronic Engineering (IC4ME2)*, 2018, pp. 1–4. [Online]. Available: https://doi.org/10.1109/IC4ME2.2018.8465482

[17] Y. Uomoto and A. Kajiwara, "Heartbeat monitoring uwb sensor robust to body movement," in *2018 IEEE 4th World Forum on Internet of Things (WF-IoT)*, 2018, pp. 280–285. [Online]. Available: https://doi.org/10.1109/WF-IoT.2018.8355194

[18] S. Shaikh, D. Waghole, P. Kumbhar, V. Kotkar, and P. Awaghade, "Patient monitoring system using iot," in *2017 International Conference on Big Data, IoT and Data Science (BID)*, 2017, pp. 177–181. [Online]. Available: https://doi.org/10.1109/BID.2017.8336594

[19] E. Kadiyala, S. Meda, R. Basani, and S. Muthulakshmi, "Global industrial process monitoring through iot using raspberry pi," in *2017 International Conference on Nextgen Electronic Technologies: Silicon to Software (ICNETS2)*, 2017, pp. 260–262. [Online]. Available: https://doi.org/10.1109/ICNETS2.2017.8067944

[20] S. H. Kim, J. M. Jeong, M. T. Hwang, and C. S. Kang, "Development of an iot-based atmospheric environment monitoring system," in *2017 International Conference on Information and Communication Technology Convergence (ICTC)*, 2017, pp. 861–863. [Online]. Available: https://doi.org/10.1109/ICTC.2017.8190799

[21] S. Wang, Y. Hou, F. Gao, and X. Ji, "A novel iot access architecture for vehicle monitoring system," in *2016 IEEE 3rd World Forum on Internet of Things (WF-IoT)*, 2016, pp. 639–642. [Online]. Available: https://doi.org/10.1109/WF-IoT.2016.7845396

[22] J.-L. Lee, Y.-Y. Tyan, M.-H. Wen, and Y.-W. Wu, “Development of an iot-based bridge safety monitoring system,” in *2017 International Conference on Applied System Innovation (ICASI)*, 2017, pp. 84–86. [Online]. Available: https://doi.org/10.1109/ICASI.2017.7988352

[23] T. Perumal, M. N. Sulaiman, and C. Y. Leong, “Internet of things (iot) enabled water monitoring system,” in *2015 IEEE 4th Global Conference on Consumer Electronics (GCCE)*, 2015, pp. 86–87. [Online]. Available: https://doi.org/10.1109/GCCE.2015.7398710

[24] L. Nóbrega, A. Tavares, A. Cardoso, and P. Gonçalves, “Animal monitoring based on iot technologies,” in *2018 IoT Vertical and Topical Summit on Agriculture - Tuscany (IOT Tuscany)*, 2018, pp. 1–5. [Online]. Available: https://doi.org/10.1109/IOT-TUSCANY.2018.8373045

[25] R. Kamalraj and M. Sakthivel, “A hybrid model on child security and activities monitoring system using iot,” in *2018 International Conference on Inventive Research in Computing Applications (ICIRCA)*, 2018, pp. 996–999. [Online]. Available: https://doi.org/10.1109/ICIRCA.2018.8596771

[26] C.-S. Choi, J.-D. Jeong, I.-W. Lee, and W.-K. Park, “Lora based renewable energy monitoring system with open iot platform,” in *2018 International Conference on Electronics, Information, and Communication (ICEIC)*, 2018, pp. 1–2. [Online]. Available: https://doi.org/10.23919/ELINFOCOM.2018.8330550

[27] F. Wu, C. Rudiger, J.-M. Redouté, and M. R. Yuce, “We-safe: A wearable iot sensor node for safety applications via lora,” in *2018 IEEE 4th World Forum on Internet of Things (WF-IoT)*, 2018, pp. 144–148. [Online]. Available: https://doi.org/10.1109/WF-IoT.2018.8355234

[28] A. Kekre and S. K. Gawre, “Solar photovoltaic remote monitoring system using iot,” in *2017 International Conference on Recent Innovations in Signal processing and Embedded Systems (RISE)*, 2017, pp. 619–623. [Online]. Available: https://doi.org/10.1109/RISE.2017.8378227