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Monitoring and remote control with LoRa as tools to improve energy efficiency.

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***Summary*: This article has been derived from a research project whose main objective is to make an analysis of energy consumption to implement power supply techniques applied to energy saving. A hardware platform based on LoRa protocol is also exposed, which has a very practical result for the monitoring and management of the measurements made in this research. As part of this project, a low-cost device will be designed and developed using open-source tools with the aim of achieving an economical communication and measurement mechanism for environmental variables, which can be replicated on a large scale and serves as a substitute for another class of IoT devices that make use of technologies such as Wi-Fi or Bluetooth.**

***Keywords*: IoT, LoRa, Embedded Systems, ESP32, Monitoring, Power Consumption, LPWAN.**

I. INTRODUCTION

In the present years, energy consumption has become a main issue not only in the industry for the manufacture of products, but also in domestic consumption, offices, both private and public, which provide their services for long periods of time. Derived from this, every day strategies are presented focused on reducing the consumption of electrical energy appropriate to the area where they will be used. Always with the premise of reducing the cost of the electricity bill that in recent years has grown considerably due to the low capacity we have to obtain energy from clean and renewable sources compared to what we get with coal or gas, which on the contrary are more expensive and polluting.

The sharp increase in the costs of oil, natural gas and coal combined with the increase in the costs of other raw materials and supply chain disruptions has led to an increase in the interest in energy savings and efficiency of governments, companies and individuals. However, energy savings are not only intended to reduce the overall cost we pay for electricity, but also to reduce the influence that the use of mineral resources has on the generation of emissions and waste, water, air and subsoil pollution. . In recent years, IoT has become one of the most important technologies of the 21st century [1]. Now that we can connect everyday objects, appliances, cars, thermostats, baby monitors, to the Internet through embedded devices, fluid communication between people, processes and things is possible.

Through low-cost computing, cloud, big data, analytics, and mobile technologies, physical things can share and collect data with minimal human intervention. In this hyper-connected world, digital systems can record, monitor, and adjust every interaction between connected things. The physical and digital worlds go side by side and cooperate with each other. However, to get to this point it has been necessary to develop technologies such as cloud computing platforms, machine learning, artificial intelligence, connectivity, and access to powerful and low-cost sensor technology.

When we apply IoT in large projects we must consider the type of communications network that best suits the requirements of the project. Some examples of IoT networks are WiFi, mobile, LPWAN or Bluetooth and we will choose one of them based on some fundamental aspects such as bandwidth capacity, power consumption, coverage range, cost, scalability, location of deployment among others.

Our project is proposed in an academic scenario without availability of network connection since the Autonomous University of Nuevo León (UANL) and the Faculty of Mechanical and Electronic Engineering (FIME) restrict access to the WiFi network to any user who is not part of the university and therefore to any electronic device outside it. The objective of this project is to be able to make a scalable model that allows the monitoring of as many rooms as possible, both students, teachers, and laboratories. This will require a technology with a medium-high coverage range.

For the initial proposal, the monitoring of three atmospheric variables (temperature, humidity, and luminosity) is proposed, in addition to the measurement of presence and current. Being a small amount of data to transmit it is not necessary to use systems with large bandwidths, therefore, we will choose a system that fits the right amount of data. As for the energy consumption for the prototype it will not be necessary to take it into account, however, since the objective is that a device can be implemented in each room, it will be essential that it does not have a high energy consumption.

Considering all the premises mentioned above, we have decided to opt for the LPWAN option (Low Power Wide Area Network) and specifically for the use of LoRa as a communication mechanism [2]. LoRa (LOngRAnge) is the modulation technology of Lorawan networks that is a type of LPWAN (Low power Wide Area Network). It allows connected IoT devices to exchange small amounts of data at low speed with a long range and low power consumption. The main advantages are low cost, low maintenance, low battery consumption, long range, low transmission rate, global coverage, and safety. Thanks to LoRa technology we can create a network of sensors and actuators that allows us to control the electrical consumption of a surface remotely, without the need to use cables or the WiFi network.

II. HYPOTHESIS

Once all the premises required by this research have been analyzed, it is believed that the design and implementation of electrical measurement instruments is possible, using economic open-source technologies, to enhance energy savings in the university and make responsible use of energy and the environment.

III. METHODOLOGY

Before developing the control device, it has been necessary to evaluate the scenario where we are going to test the initial hypothesis of the project. The place where the research has been carried out has been the Digital Systems II laboratory of building 7 of the Faculty of Mechanical and Electrical Engineering (FIME) of the Autonomous University of Nuevo León (UANL). This laboratory has 4 rooms and an office. For the course of the investigation, two classrooms and a corridor have been monitored. Each of the classrooms has an air conditioning and 5 low consumption lights, therefore, in total the measurement of 2 air conditioners and 11 lights was made counting on that of the corridor.

Once the area where it will be implemented has been studied, we proceed to evaluate the different microcontroller alternatives available to design the prototype. To decide which device best met the characteristics of the project and was best suited to the environment, the following considerations were taken. The device had to be able to work remotely, without using the university's WiFi network since we did not have this service. It had to be able to store data in the internal memory for cases of power outages. It needed to be compatible with all sensors used for data collection and the most important condition is that it had to be economical and versatile.

Among the options evaluated were the Photon, Argon, ESP32 and ESP32+LoRa devices. Both Photon and Argon did not meet the needs of the project since there were not all the necessary libraries to control the sensors, as another point against is that we could not make wireless connections other than through Wi-Fi and Bluetooth. Once this technology was discarded, we began to evaluate the ESP32 microcontrollers, an economical alternative to Arduino. The ESP32 module itself allowed us to connect to the Wi-Fi network, however, like the rest of the devices it was necessary to implement a medium-long range form of communication other than Bluetooth. Therefore, it was decided to use microcontrollers ESP32 with LoRa technology including, specifically, the Heltec WiFi LoRa 32 (V2) model. [3] The following table shows a summary with the most important characteristics of each microcontroller.

Device	WiFi	Bluetooth	Compatibility	Price	Range
Photon	Yes	Yes	No	€ 25,00	Mid
Argon	Yes	Yes	No	€ 35,00	Mid
ESP32	Yes	Yes	Yes	€ 10,00	Mid
ESP32+LoRa	Yes	Yes	Yes	€ 20,00	High

Table 1 Features Microcontrollers available.

Once the ideal microcontroller model has been chosen, the next objective is to choose that environmental variable that will be collected to test the hypothesis of the project. The main variables that were raised were temperature, humidity, presence, current and luminous intensity. Thanks to these values we could determine if there is an excessive energy expenditure in the classrooms of the university. Through the information of temperature and humidity we can determine if the air conditioning is on or off, thanks to the luminosity sensor we can know if the lights of the classroom are still on once the student or teacher has left. The presence sensor helps us to know if the classroom is empty or on the contrary is in use and finally the current sensor allows us to know the consumption of connected devices in the department where the experiment was carried out.

Finally, the materials chosen to form the hardware are an ESP32+LoRa microcontroller, two resistors of 4.7 Kohm, a reference indicator LED and the sensors Adafruit Si7021 (Temperature and humidity sensor), Adafruit Si1145 (Light intensity sensor), Stemedu HC-SR501 (PRESENCE PIR sensor) and finally a two-channel I2C current sensor [4].

IV. IMPLEMENTATION

Once all the materials have been chosen, we have designed a prototype in addition to the code that manages it. To this end, it has been connected all sensors via I2C ports of the microcontroller, except for the presence sensor connected to one of the microcontroller's digital inputs, just like the led. In the following figure is displayed the connection diagram of the designed prototype.

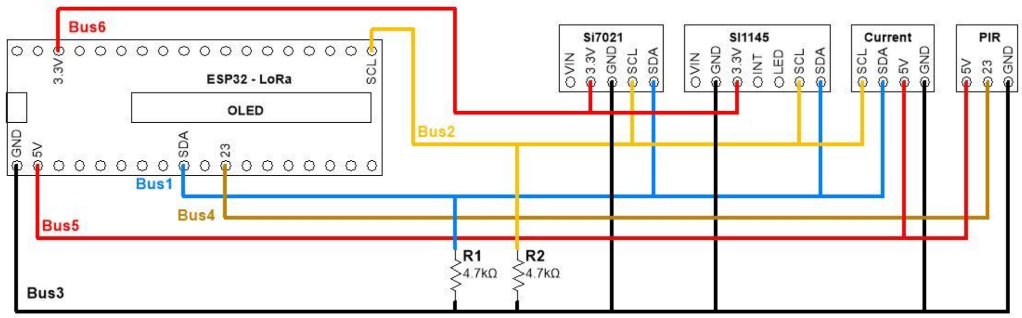

Figure 1 Hardware Transmitter Diagram

Once the connection of the microcontroller with all the sensors has been made, the software in charge of managing all the information and adapting it as it best suits us has been programmed.

For the management of the I2C ports and therefore the control of the current sensor, the libraries "Heltec.h", "Wire.h" and "SPI.h" have been used. For the control of the internal memory of the device the library "EEPROM.h" has been used, for the management of the temperature and humidity sensor the library "Adafruit_Si7021.h" has been used, for the luminosity sensor the library "Adafruit_SI1145.h" has been used, for time management an internal clock has been used through the library "TimeLib.h".

The communications frequency band of 915MHz has been established as it is a free frequency for USA and Mexico, the 0x2D address for serial communication of the current sensor and the size of the EEPROM memory has been defined as 4096 since the memory of the microcontroller has a maximum size of 4Mbyts.

Once all the variables related to the sensors and processes that are performed in the program have been declared. The flowchart in Figure 1 is proposed as an algorithm for collecting data and sending information to the receiver. It should be noted that the information is sent every hour. however, with a total of six samples taken, three samples are sent since then an average is made every two samples taken, to minimize the amount of information that we are provided with to store in our receiving device.

Once we have the transmitter device ready to make the measurements and send them periodically, we can go on to configure the receiver [6]. For this device we have made use of only one Heltec WiFi LoRa 32 microcontroller (V2) [3]. as it will only be necessary receive and store the information from of the transmitter device.

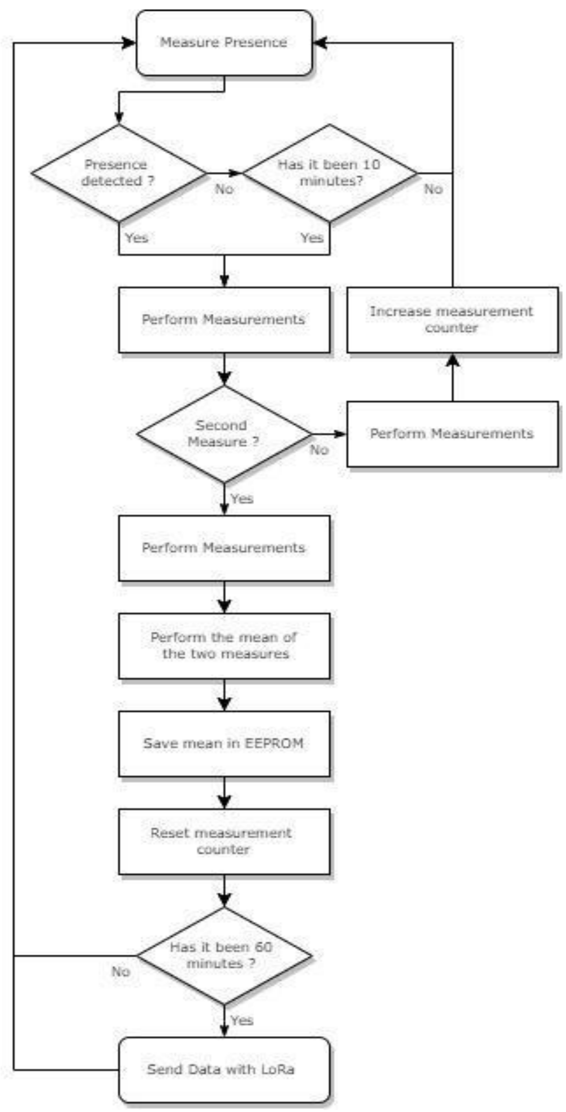

Figure 2 Transmitter Flowchart

To program this device, we have made use of two libraries, the library that allows us to communicate with the microcontroller and display data on the OLED screen ("Heltec.h") and the library that allows us to save data permanently in memory if for some reason the microcontroller is turned off ("Preferences.h"). Through the library "preferences.h" we create a space in memory where we will store the data and six key values where each of the variables that are measured in the transmitter will be stored (human resistance, ambient temperature, current of channel 1, current of channel 2, humidity and light intensity). Through these keys we can through another program collect when it is convenient all the information stored in the microcontroller.

Through the analysis of the data collected by our system we can appreciate the following results.

V. RESULTS

- *Electricity consumption analysis:*

The first part of the project was to determine if there is a higher energy expenditure than necessary, either by turning on lights or by using air conditioning when there is no presence in the rooms. A follow-up of 144.7 hours has been carried out in which data have been collected both night and day spaced every 10 minutes as explained in the previous section of methodology. During this time the air conditioners and lights have been operating for a total of 63.7 and 38 hours, this represents 44% and 26% of the total time respectively.

During this period the presence sensor shows that 64% of the time the air has been used there was no presence of people in the room, therefore, the air conditioners have been on 40.7 hours longer than they should. Regarding the study of the lights, it has been observed that 32% of the total time on has not been detected presence, therefore, there has been an excess of 12.3 hours in lighting. Figure 3 shows a fragment of the temperature measurements against the presence measurements and figure 4 shows for that same period the light intensity compared to the presence data.

For the calculation of the power spent in excess, the consumption of the air and lamps has been measured. For this, by means of a current meter, it has been observed that each of the airs consumes 12A and that each lamp consumes 0.7A, therefore, the power consumed by the air conditioning is 1.4kWh and 0.84kWh for each of the lamps. In our scenario the total power consumed if all the devices are on at the same time is 3,804kWh.

Considering the excess time calculated before we can see how the air conditioners have consumed 117 kW compared to the 12 kW consumed by the lights, only in a period of 145 hours (6 days) and two classrooms evaluated. For this reason, it is essential to remotely control both light and heating to avoid high energy waste.

All this data is collected in the following table:

	Tiempo Medido (h)	Tiempo Encendido (h)	Tiempo Exceso (h)	% Exceso	Gasto Exceso (W)	Gasto total excedido (W)	Gasto total (W)
Clima	144,7	63,67	40,67	64%	117120	128516	
Luz	144,7	38,00	12,33	32%	11396		
	Tiempo Medido (h)	Tiempo Encendido (h)	Tiempo Uso (h)	% Uso	Gasto mínimo (W)	Gasto total mínimo (W)	218472
Clima	144,7	63,67	23,00	36%	66240	89956	
Luz	144,7	38,00	25,67	68%	23716		

Table 2 Results Electricity consumption analysis

In the following figures is displayed a fragment of 31 h where different atmospheric variables are represented depending on the presence.

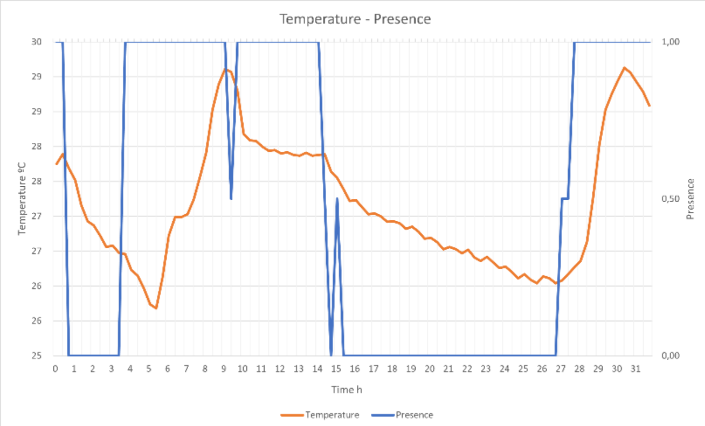

Figure 3 Relation Temperature – Presence, measure of 31 h

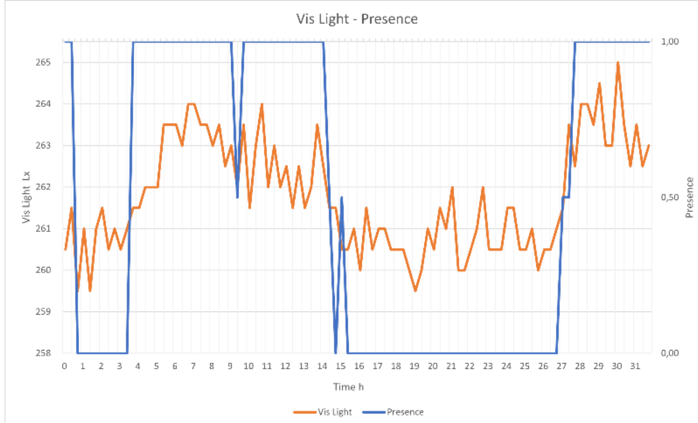

Figure 4 Relation Visible Light – Presence, measure of 31 h

The Figure 3 shows the relationship between the temperature and the presence in the room where the investigation has been carried out. The results of excess energy from the air conditioning have been obtained by analyzing the moments in which the temperature decreased, and no presence was detected. In the case of Figure 4, the procedure has been similar, at times when no presence and light intensity were detected it was high it is producing an extra expenditure of energy. Last, Figure 5 shows the relationship of presence to recorded current, a value of 1 refers to that the air conditioner is on, a value of 1.5 corresponds to the activation of both air and lights and therefore a value of 0,5 it assumes that only the lights are off.

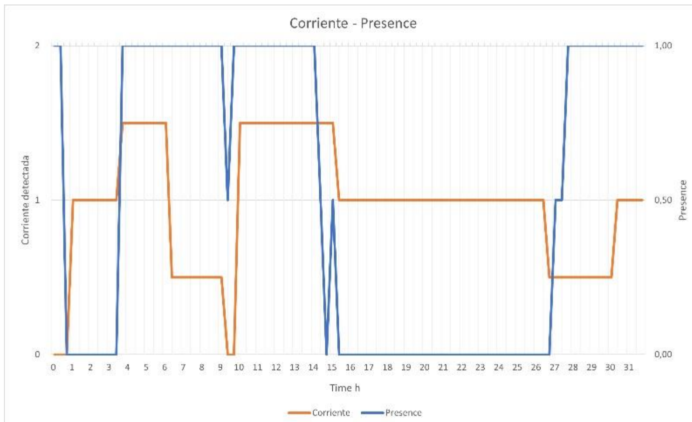

Figure 5 Relation Current – Presence, measure of 31h

- *LoRa protocol efficiency:*

The second part of the project is to assess the viability of LoRa as a tool for device communication. The stage where the tests have been carried out is building 7 of the Faculty of Mechanical and Electrical Engineering (FIME) of the Autonomous University of Nuevo León (UANL). It is a building that has classrooms and laboratories, as well as teachers' offices and rest areas, therefore, it is not an ideal scenario of free space but, but we find a high density of obstacles that considerably reduce the maximum surface that could be covered using LoRa, for this reason we have carried out a coverage study to determine the limit point at which our receiving device leaves to receive information. As shown in Figure 2, a maximum distance of 60m has been reached. It should be noted that the transmitting device was not located at the central point of the building, but on one side, therefore, the building under study could be covered with only one receiving device and multiple transmitters from any position in a radius smaller than the previously mentioned. If we have a star network, it is important that the central node is well configured and protected against possible failures in the system.

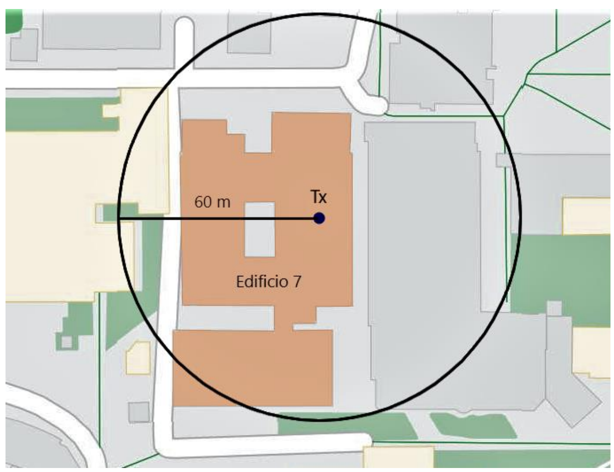

Figure 6 LoRa coverage area

VI. DISCUSSION

In this work, the feasibility of using low-cost technologies such as esp32 modules along with communication protocols such as LoRa to design efficient energy monitoring and management systems has been tested. It has been shown that in the scenario studied an excess of energy is being produced that could have been avoided by using sensors such as those proposed in this work.

We have tested the possibility of using this technology in home environments as shown in other articles [7] despite the drastic decrease in theoretical coverage achievable by LoRa. It has also been proven that this technology can be very useful for the development of control systems, where large amounts of information to be transmitted are not required, helping to reduce electricity consumption and therefore the carbon footprint and monetary expenditure as has been proven in other articles [8].

Once the viability of this technology for the implementation and management of control networks has been demonstrated, the future challenge is the development of a mechanism that can manage many devices, sending orders based on the data it receives from the sensors.

VII. CONCLUSIONS

The current need to efficiently manage devices to avoid excessive waste of energy and therefore affect climate change more than necessary is appreciable, for this reason the use of IoT devices that can react to their environment is being promoted [9].

In this research we have verified that the consumption of electrical energy in the laboratories of the faculty of mechanical and electronic engineering is not being optimized, to be precise, in just two classrooms 60% more energy is being consumed than would be necessary for that space. Therefore, it seems indisputable to argue that there is a real need to provide intelligence through sensors to classrooms.

The possibility of using alternative technologies to conventional wireless networks such as Wi-Fi or Bluetooth for the management of remote-control devices has been discussed. To perform this task, the use of LoRa technology has been chosen, since it allows a wide range of coverages with respect to its competitors, in addition to being a device with low energy consumption. A device has been developed capable of collecting information from your environment and sending it to another receiving device that stores it for further analysis. All this with the aim of testing the real need to implement sensors in the classrooms of the school where the research is developed to save electrical energy.

After analyzing the results of the research, we can conclude that LoRa technology is a very good tool to manage devices remotely, if the condition of low amount of information sent is met. We can also ensure that it is one of the best solutions for situations where there is no internet connectivity and there are no power sources that constantly power the devices. We have observed that it would not be necessary more than a receiving equipment to cover the entire building 7 of the faculty of mechanical and electrical engineering of the autonomous university of Nuevo León, therefore, which is equivalent to approximately 1000 m2, LoRa is a good alternative to cover large distances with a reduced cost.

Finally, we concluded that a large-scale implementation of the developed technology would be possible and that it would have a great impact on the economy of the faculty where the research has been developed, as well as for the rest of the campus and the Autonomous University of Nuevo León.

VIII. THANKS

Spatial thanks to Dr. Héctor Gilberto Barrón González for his help and collaboration in this research project.

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