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Presentation of the content

In the first article we present, *Design of an app for a module of practices of basic electrical installations*, by HERNANDEZ-SANCHEZ, Juan Fernando, CASTILLO-QUIROZ, Gregorio, LUNA-CARRASCO, Claudia Yadira and TORRES-JIMENEZ, Jacinto, with adscription in the Instituto Tecnológico Superior de Huauchinango, in the next article we present, *Design and validation of a control for a BLDC motor to be applied on a solar water pump*, by HERRERA-VELÁZQUEZ, Rene, RODRIGUEZ-MEJIA, Jeovany Rafael, LÓPEZ-MÁRTINEZ, Alfonso, and ARAIZA-ESQUIVEL, Ma. Auxiliadora, with adscription in the Universidad Autónoma de Zacatecas and the Tecnológico Nacional de México Campus Ciudad Juárez, in the next article we present, *Advances in the design of an alternative power generation device using piezoelectric*, by MUNGUÍA-NAHUÁCATL, Karen Jazmín & FRANCO-MARTÍNEZ, David, with adscription in the Facultad de Estudios Superiores Aragón, and Centro Tecnológico, Facultad de Estudios Superiores Aragón, UNAM, in the next article we present, *Indoor* CO_2 *monitoring system using a microcontroller via Bluetooth for coronavirus prevention*, by MARTÍNEZ-HERNÁNDEZ, Haydee Patricia, CORTES-MALDONADO, Raúl, MORALES-CAPORAL, Roberto and ISLAS-CERÓN Alejandro, with adscription in the Instituto Tecnológico de Apizaco.

Content

Article

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Design of an app for a module of practices of basic electrical installations

Diseño de una app para un módulo de prácticas de instalaciones eléctricas básicas

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Abstract

Currently, electrical installations of any kind must comply with minimum safety standards taken into account at the time of their construction and use. This article aims to present the design and construction of a series of practices as well as the design of a mobile application for the improvement of learning in the training of residential electrical installations of the "Mahatma Gandhi" High School of Xilocuautla, Huauchinango, Puebla, through a practice module "ElectriBasic App". The App will serve as a didactic support, since it is a graphic and technical instruction for students who wish to carry out practices related to residential electrical installations. With this module, students will be able to identify, through various previously organized practices, the types of connections and different types of accessory arrangements of a residential electrical installation, as well as identify concepts from basic to intermediate that they do not know within the topics of electricity.

Application, Tool, Teaching

Resumen

En la actualidad las instalaciones eléctricas de cualquier tipo deben cumplir con unos estándares mínimos de seguridad tenidos en cuenta al momento de su construcción y su uso. El presente artículo tiene como objetivo presentar el diseño y construcción de una serie de prácticas, así como el diseño de una aplicación móvil para el mejoramiento del aprendizaje en la capacitación de instalaciones eléctricas residenciales del Bachillerato "Mahatma Gandhi" de Xilocuautla, Huauchinango, Puebla, mediante un módulo de prácticas "ElectriBasic App". La App servirá como apoyo didáctico, dado que es un instructivo gráfico y técnico para los alumnos que deseen realizar prácticas relacionadas con las instalaciones eléctricas residenciales. Con este módulo los alumnos podrán identificar mediante diversas prácticas previamente organizadas los tipos de conexiones y diferentes tipos de arreglos de accesorios de una instalación eléctrica residencial, así como también identificar conceptos desde básicos hasta intermedios que no conocen dentro de los temas de la electricidad.

Aplicación, Herramienta, Enseñanza

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Introduction

Currently in Mexico there are hundreds of thousands of schools, some with easy access, others with difficult access due to the geographical area where they are located, including other factors. According to the National Institute for the Evaluation of Education (INEE), in rural localities, that is, with fewer than 2,500 inhabitants, 57% of the schools are for basic education and 30.4% are for upper secondary education. Indigenous and community preschools are the ones with the greatest presence in this type of locality (87.3 and 97.4%, respectively).

Within the different educational levels we find many deficiencies due to the lack of updating of teaching methods. In the rural environment in Mexico is where the highest levels of educational inequality exist, and for this reason the educational level of people who develop academically in the rural environment are low compared to the urban environment, where there are greater possibilities.

Over time things change, currently the management of ICTs in the educational field would be allowing the modernization of the teaching methods previously adopted in the educational system in Mexico. The global pandemic that began in the first months of 2020 and that spread worldwide left us with many good and bad things, due to this health problem in Mexico, the teaching method radically changed due to the risk that was presented, according to data provided by the National Institute for the Evaluation of Education (INEE) approximately 30 million students had to stop going to educational centers in person due to the health contingency.

With the passage of time and now that the country is gradually returning to normality with a hybrid educational system, which is a form of teaching that includes face-to-face and remote teaching methods. There are two modalities to impart the hybrid model, one of them is in the blended modality, which is based on the traditional teaching methods that we have applied for decades and on the other hand there is the disruptive modality in which most of the educational activities are carried out through digital platforms.

In a certain way, this model has been accepted by the majority of students and parents, since it has many advantages, among which are promoting interaction between students and teachers, learning becomes active again by contextualizing real activities, as well as that students have greater control over their own learning, which could translate into having autonomy and being self-taught. And it is that this is the importance that should be entrusted to students today, because J. Dewey and his teaching principles gave way so that in educational systems trust is placed in the student, this so that he is able to challenge his fears and help him solve his problems in such a way that the learning process would be almost autonomous.

And another of the pioneers in the area of education and teaching on residential electrical installations was Ing. Gilberto Enríquez Harper who obtained the title of electrical engineer in 1976 and throughout his career he wrote more than 215 publications of which are 75 books about engineering in various branches and one of the most important was the electrical installations detailing in each of his books the clear procedures with everyday examples as well as illustrations and diagrams that are of great help today in the teaching of electrical installations for both students and people who are interested in the area of electrical installations.

It should be noted that at the upper secondary level, learning efficiency is not the same since there are various study plans such as those offered by the (National College of Technical Professional Education) Conalep, General Directorate of Technological and Industrial Education (DGETI) are very different from the general high school, it is clear that in the basic subjects it is the same but there are special subjects which are very useful for the student's future since this type of technological learning opens the way to a clearer vision that the student has to have at the end of their studies and continue with their professional vocation.

On the other hand, it is clear that there is a lot of difference that could be shortened if the schools focused on an area that is closest to reality and that they reinforce concepts and techniques that will serve them even if the student does not follow the path to which their studies are being focused.

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Have basic knowledge that you could apply in your daily life or better yet, get the most out of it and earn a living for your family. We have realized that currently many students do not have defined what are basic concepts that were already seen in previously studied subjects such as physics, chemistry, mathematics, etc. These concepts are essential, but for each of the students to grasp the meaning of preparation, it is necessary to use a more practical teaching method from which they take more advantage using technology as an aid tool, as well as others using interactive additives that make them think about how to solve a real problem and with this the students would have more self-confidence when going out to work or when something similar happens to them.

The present project consists of the development of a mobile application that helps the technical review of residential electrical installations, within the same application it contains different sections with useful information as well as diagrams which facilitate the student the correct understanding of what an installation is. Residential electricity and in this way get the student interested in carrying out the practices in a didactic way using technology.

The development of this project is divided into the following sections:

1. Methodology: The steps followed for the development of the project are described.

2. Results: In this section, the results are analyzed to determine if the mentioned objective has been achieved.

3. Acknowledgments: Thanks to the people and institutions that allowed the development of this research.

4. Conclusions: It speaks of the objectives achieved satisfactorily.

Methodology

The project presented below was carried out in the "Mahatma Gandhi" high school, in the town of Xilocuautla, Huauchinango, Puebla (see Figure 1). This community has approximately 1,302 inhabitants.

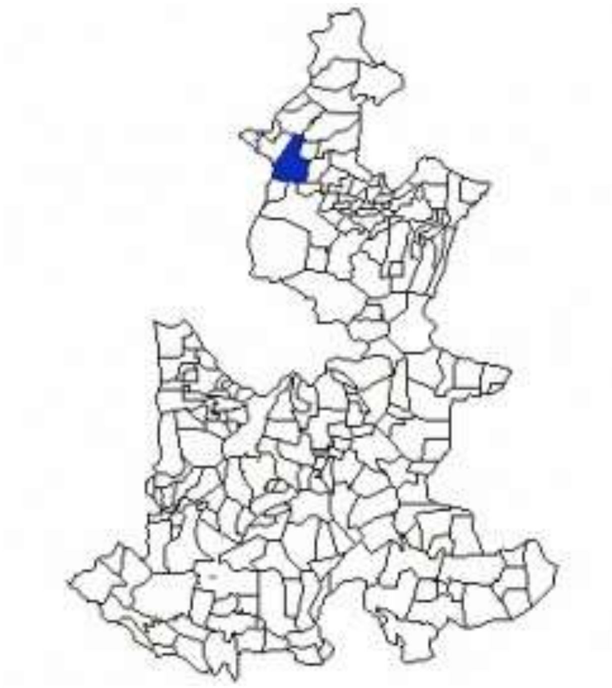


Figure 1 Geographical location of Huauchinango, Puebla.(Auditoria Superior del Estado, 2020)
Source: https://www.auditoriapuebla.gob.mx/sujetos-de-revision/informes/informes-individuales/itemlist/category/354-huauchinango

Before making the design and projection of the prototype, a survey was carried out on the students of the aforementioned high school to see the aptitudes of each one of them and to be able to detect the deficiencies in terms of knowledge about residential electrical installations, such as basic concepts of electrical installations and electrical circuits.

A. Requirements

Next, the questions of the survey carried out to the students of the "Mahatma Gandhi" high school are presented, as well as the results of the survey (see Graph 1):

1. Do you know what electrical circuits are?

2. Do you know the classification of electrical circuits?

3. Do you know the serial connection?

4. Do you know the parallel connection?

5. Do you know how to connect an electrical switch?

6. Do you know how to connect an electrical switch?

7. Do you know what an energy source is?

8. Do you know what an electricity generation system is?

9. Do you know what a lighting system is?

10. Do you know what electrical installations are?

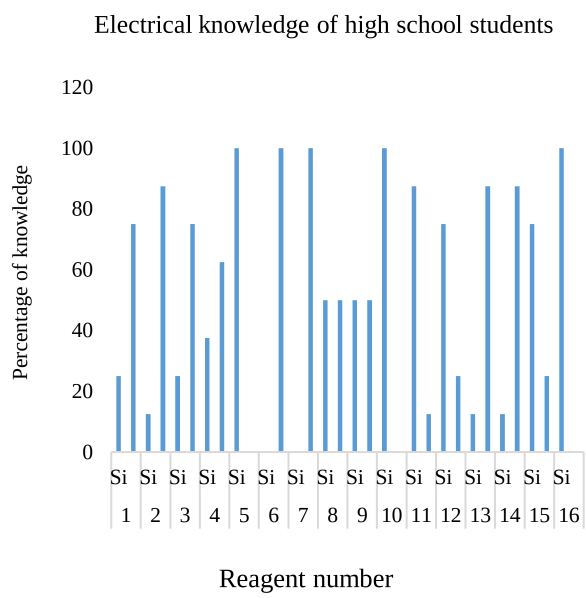
11. Do you know the importance of residential electrical installations?

12. Do you know any symbols used for the graphic representation of a residential electrical installation project?

13. Do you know NOM-001-SEDE-2012?

14. Do you know any tool as a simulator for residential electrical installations?

15. Would you like to learn more about residential electrical installations?



Graph 1 Graph of the results of the survey carried out on the students
Source: Own Elaboration

B. Design

The ElectriBasic App module is aimed at reinforcing in a technical and practical way the knowledge previously acquired in electrical installations and concepts from the basics to the most complex, since said prototype is accompanied by a mobile application which, first of all, has useful information that the The student can consult instantly without the need to have an internet connection.

This information was previously selected and analyzed so that the student can learn in a simple way, within the information it contains, topics such as the definitions of electrical installations and issues related to the installation and connection of an outlet, a switch, on the other hand a fundamental part is ohm's law, which is a case study that is applied on many occasions when making calculations, concepts of electricity that are important to the when addressing issues such as energy efficiency and other issues, electrical safety, which is the work base of every electrician since it is of great importance to know the procedures in the handling of tools as well as the safety equipment necessary to carry out work with a live line, definitions of electrical circuits to analyze the connections in series and parallel, circuits and also do some mixed calculations and analyzes of them.

To make these calculations within the application there will be a calculator section in which you can calculate the electrical power, the current, the voltage, the calculation of conductors, energy consumption, etc. And it is then the use of technology so that students become familiar with the theory of electrical installations in order to apply their acquired knowledge in a practical way.

This prototype will serve to connect the necessary arrangements according to the previously described practice, this will be based on the current official standards of electrical installations so that the student becomes familiar with the colors used in the conductors within an electrical installation, type of used switches, but this will also be possible thanks to the help of the mobile application, because when doing the practice this module will be linked and will send information in real time about the status of the connections, which will be helpful for the student who will verify if the connection made is correct or not, in this way and with the verification of the type of connection recorded by the system, the student will be able to learn in a simple way what electrical installations are and the importance of adhering to the standards in force, likewise you can also identify various daily problems in electrical installations such as short circ uites, system failures, among other cases and will be able to make the appropriate decisions to provide a solution to the problem..

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1. App inventor

This platform is an application development environment for all kinds of android devices. To develop a mobile application with App Inventor, you only need a web browser and an Android phone, this platform is very easy to use even if you do not have extensive programming knowledge.

When developing an application, you work with two tools; App Inventor Designer in which the user interface will be built in this way each of the elements with which the user will interact is chosen and placed, on the other hand, in the App Inventor Blocks Editor tool the behavior of each of the elements is defined the components, or in other words, it is the part that is in charge of giving the instructions.

Creating applications from this platform has many advantages, among which are:

- 100% free tool.
- Allows you to create applications from the web browser and the changes are saved automatically.
- Visual learning by blocks of code.
- Applications can be created for Android or iOS operating systems.
- Easy verification of the operation of the application.

C. Application development using App Inventor

App Inventor is a Google Labs platform which is accessed through the following link http://appinventor.mit.edu/ to then create a user account to access. Once the page is open, in the upper right part there is the "create apps" button (see Figure 2), for this it will ask us for a google account.

Figure 2 Home screen to create an account in App Inventor. (Screenshot)
Source: http://appinventor.mit.edu/

Once the google account has been accessed and verified, a new project must be created (see Figure 3) in addition to giving it a name and pressing "accept" so that the project as it changes and progresses, these changes are automatically saved.

Figure 3 Process to create a new project in App Inventor. (Screenshot)
Source: http://appinventor.mit.edu/

Once this procedure is done, we move on to the next point, which is the design of the application's home interface in the "designer" section (see Figure 4), in which the name of the application's home screen will be given. Once this is done, 4 main buttons will also be added to access the theory sections, the calculator where you can insert values to the different formulas presented to calculate the total resistance in series and parallel, energy consumption in KWH, on the other hand, also find the section of the tests proposed for the practices that are going to be carried out, as well as the section where electrical connection diagrams.

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Figure 4 Application home screen. (Screenshot)
Source: Own Elaboration

Pressing the theory button will open a window where you can view important information about electricity (see Figure 5), within these important topics include electrical safety, what are the basic concepts, laws and regulations in electrical matters, power plants, types of electrical connections in series and parallel, protection devices, among many other topics that the student can consult in this application without the need to be connected to an internet network.

Figure 5 Window corresponding to the theory regarding the “basic concepts” section. (Screenshot)
Source: Own Elaboration

The above actions are achieved through control, that is, in the “block editor” section, it is where the actions that the application must perform when interacting with it are declared. It is here that each of the windows is brought to life, indicating its function through simple blocks that are built using logic. These blocks for the theory section were the most basic (see Figure 6), since they are functions of the buttons that were added and when declaring that the button is pressed, another window is displayed with the selected information, either about security electricity, basic concepts, measuring instruments, etc.

Figure 6 Block editor corresponding to the theory section. (Screenshot)
Source: http://appinventor.mit.edu/

For the calculator section we add the design (see Figure 7) in which we can calculate various factors one of them and the best known within electricity is Ohm's law, within which we can calculate the resistance, the current and voltage substituting the values depending on what is required to be calculated.

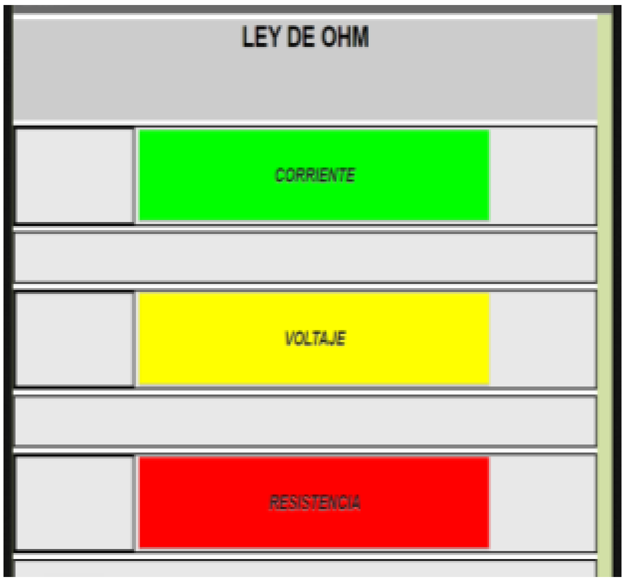

Figure 7 Calculator interface design with respect to Ohm's law. (Screenshot)
Source: http://appinventor.mit.edu/

Once the main window is done, each one of the functions is programmed in the block editor as it has been worked with the other windows of the application, in this almost the blocks determine that when substituting the value in each window, the value of the block is calculated window that is free, that is, if I want to calculate the resistance I have to fill in the voltage and current fields so that it executes the corresponding operation (see Figure 8).

In this way, the student will understand and analyze the mathematical formula, as well as be able to check his calculations until he is able to perform them manually and quickly with the calculator and thus speed up his mentality when analyzing mathematical formulas and make the student become more and more interested in the world of electricity.

Figure 8 Programming of functions related to the calculator using the block editor. (Screenshot)
Source: http://appinventor.mit.edu/

Results

As for the practice module (see Figure 10) which was previously discussed and in which the corresponding practices will be developed, it is mainly made up of the control module which will be linked via bluetooth through a "Bluetooth Communications Module HC-05" which will be in charge of processing the signal generated by the devices to the module controlled in the same way by an arduino nano. In this way we will have the control system that is going to process the signals converted to 1 or 0 which, through indicators, is going to determine if the constructed circuit is correct according to the practice that is being carried out. Next, we present the circuit design with solid-state relays (see Figure 9) which will be interconnected to the practice module, because the system works with 127 V AC and 5 to 9 V DC.

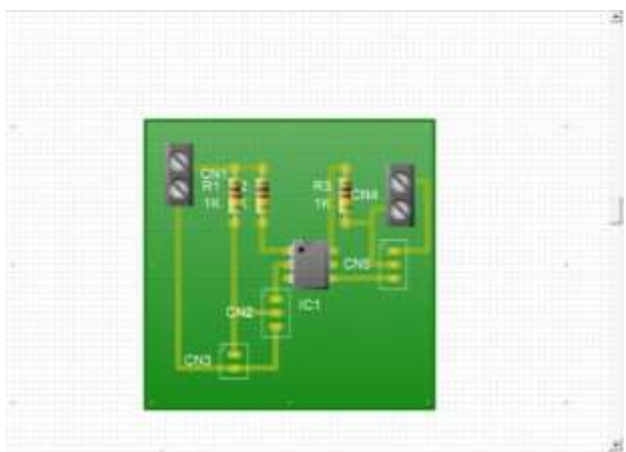

Figure 9 Design of the solid state relay circuit. (Screenshot)
Source: Own elaboration

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The components of the practices module are described below, which are the most used in residential electrical installations in accordance with current regulations on residential electrical installations.

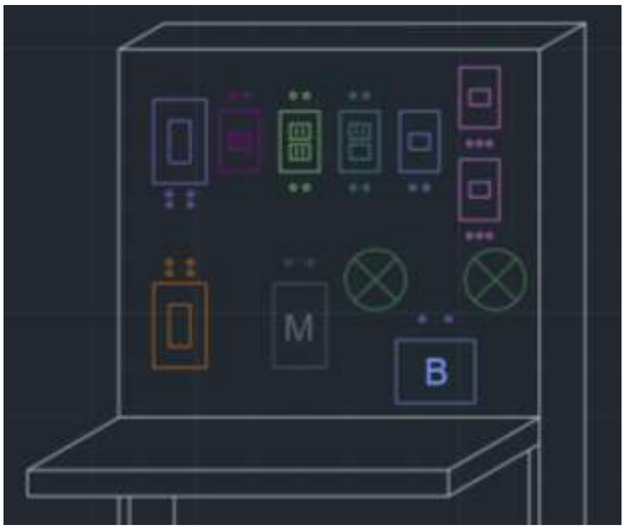

Figure 10 Modeling in AutoCad of the practice module
Source: Own Elaboration

Likewise, by showing the components we are determining some practices that are applied repeatedly in a home, since some design structures are different according to use or requirements.

Figure 11 Illustration of assembly of accessories of the first practice. (Truper, 2022)
Source: Truper Catalog 2022

One of the most common cases in electrical installations is the connection of a contact and a switch together, for this the module will have an ABS and polypropylene plate armed with a two-pole contact and a ground (see Figure 11).

As well as a simple Volteck Basic switch, in the same way the switch will be connected to a luminaire, of these components the students must be able to analyze and correctly connect these two components physically and check their operation through the application making the connections correctly with banana cables inside the connection terminal blocks that each accessory has.

Figure 12 Illustration of assembly of accessories of the second practice. (Truper, 2022)
Source: Truper Catalog 2022

Regarding the second practice, we see that the arrangements are different since this time it includes an ABS and polypropylene plate armed with two contacts with two poles and a ground, as well as a switch (see Figure 12), this arrangement is very common in electrical installations, which is why the students will be able to analyze well when making the connections.

Figure 13 Illustration of assembly of accessories of the third practice.(Truper, 2022)
Source: Truper Catalog 2022

It is very common that in residential electrical installations there are always two independent switches together with a contact (see Figure 13) since it is common to control two lights independently in this way, that is why in this practice the different types of switches will be analyzed arrangements for connecting such accessories.

Figure 14 Illustration of ½ HP peripheral water pump.(Truper, 2022)
Source: Truper Catalog 2022

We know that inside a house it will always be essential to have a water pump (see Figure 14), but for these cases we cannot connect the pump directly to a contact due to the current it consumes, for this reason the students must analyze and understand the type of arrangement for the power supply of the pump as well as a thermomagnetic switch and calculate it through formulas which contains the theory part in addition to being able to calculate it also through Ohm's law in the application calculator.

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Conclusions

The "ElectriBasic" mobile application has been a way to revolutionize learning and the approach to what residential electrical installations are according to dynamic learning methods so that high school students acquire solid knowledge and help them choose their true vocation, promoting and getting the best out of each one of them in a rational way with the practices that will be developed physically until a concrete analysis and improvement in decision-making is achieved. The use of technology today is already very advanced and using said technology for common learning purposes, many goals can be achieved together with teachers, since both teachers and students will have growth in terms of theoretical knowledge and practical. Over time and as students and teachers become familiar with the application and what residential electrical installations are, students will be able to carry out electrical work at home and even better, they can fully enter the labor field of the installations and with the passage of time they will become great experts in electrical matters.

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Article

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Design and validation of a control for a BLDC motor to be applied on a solar water pump

Diseño y validación de un control para motor BLDC para aplicarse en una bomba solar de agua

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Abstract

This paper presents the design and implementation of a speed control for BLDC motors; This is considered a high-capacity actuator mainly because of its operation, power, and control characteristics. BLDC motors require digital tools for good practices in position and speed control; as well as the power electronics for optimal performance. In order to take better advantage of the characteristics in this type of motor, a control strategy is presented that allows integrating the internet of things, to monitor and satisfy the needs when applied to a BLDC motor, which will also allow driving a submersible pump. Based on these characteristics, it will be possible to have a greater range of operation of the same, consequently, a better regulation of the speed, so that the desired water flow can be provided in the application of solar pumping systems. The results obtained validate the control designed for speed regulation in the system.

BLDC Motors, Control, Arduino, IGBT

Resumen

En este trabajo se presenta el diseño e implementación de un control de velocidad para motores BLDC; este es considerado como un actuador de alta capacidad principalmente por sus características de operación, alimentación y control. Los motores BLDC requieren de herramientas digitales para las buenas prácticas en el control de posición y velocidad; así como de la electrónica de potencia para su óptimo desempeño. Con el objetivo de aprovechar mejor las características en este tipo de motores se presenta una estrategia de control que permite integrar el internet de las cosas, para monitorear y satisfacer las necesidades al aplicarse en un motor BLDC, el cual además permitirá accionar una bomba sumergible. En base a estas características será posible tener un mayor rango de operación de la misma, en consecuencia, una mejor regulación de la velocidad, de forma que se pueda proporcionar el caudal de agua deseado en la aplicación de sistemas de bombeo solar. Los resultados obtenidos validan el control diseñado para la regulación de velocidad en el sistema.

Motores BLDC, Control, Arduino, IGBT

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I. Introduction

Electric motors are an integral part of industrial, residential and commercial plants, which mainly use conventional technologies to power them [1], [2]. Typically, the machines found in these appliances are single-phase induction motors or brushed direct current (DC) machines which are characterized by low efficiency and high maintenance requirements.

Brushless Direct Current (BLDC) brushless DC motors have reached a level of utility of great importance in industrial applications (robotics, aviation and automation) [3], they do not use brushes to energize the coils. Instead, they switch is done electronically; avoiding losses due to friction and wear. Furthermore, the torque and size ratio is much higher, making them useful in work environments with reduced space.

Induction motors have limitations in applications with little space. Moreover, they generate significant heat, which results in lower efficiency [2], [3]. Some of the advantages in BLDC motors compared to conventional DC motors are [4]: better speed-torque ratio, better dynamic response, higher efficiency and useful life, lower noise, higher speed range. Resulting in better performance than DC and induction motors, this type of motor is rapidly gaining popularity.

The main disadvantage of BLDC motors is their higher cost and a relatively higher degree of complexity of the power electronic converter used to power the motor [5]. For most applications, proportional-integral (PI) speed and current compensators are sufficient to establish an acceptable speed/torque controller. In other cases, state feedback control is needed to achieve more precise control of the BLDC motor [6]. Hysteresis current control and pulse width modulation (PWM) together with continuous control theory have generated the most widely used BLDC motor control techniques [7]. Complementarily, the discrete control theory allows such controllers to be implemented digitally with microcontrollers, microprocessors or digital signal processors (DSP) [6].

The objective of the proposed control strategy is that the BLDC motor achieves a regulation speed such that the drive pump provides the desired flow rate.

This work is organized as follows. Section 2 presents the structure and operation of the BLDC engine. Section 3 shows the mathematical model of the BLDC motor to design a controller. Sections 4 contains the results of a controller designed and implemented. Finally, section 5 shows the conclusions.

II. Structure and operation of the BLDC motor

BLDC motors are synchronous type motors whose magnetic fields exist in the stator and in the rotor rotate at the same frequency. Out of the different configurations, the triphasic is mostly used [8]. Fig. 1 shows the characteristic waveforms for a three-phase BLDC motor with trapezoidal flux distribution. A three-phase bridge with MOSFETs is necessary to energize the coils so that they commute as shown in Fig 2.

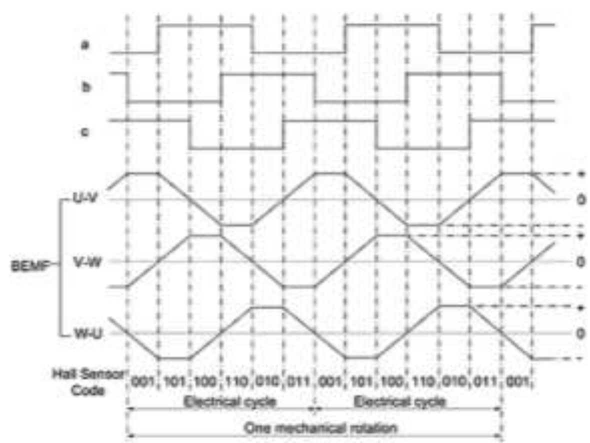

Figure 1 Hall Effect & Back EMF Signals
(https://www.digikey.com/es/articles/how-to-power-and-control-brushless-dc-motors)

The control technique used in the BLDC motor is the six step mode [9]. This strategy allows to control the current that circulates through the terminals of the motor coils, activating 2 coils at the same time and leaving the third one off [10]. The pair of on-coils are successively alternated until completing the six possible cases. as shown in Fig. 2. The output stage consists of a three-phase inverter composed of MOSFETs as shown in Fig. 3.

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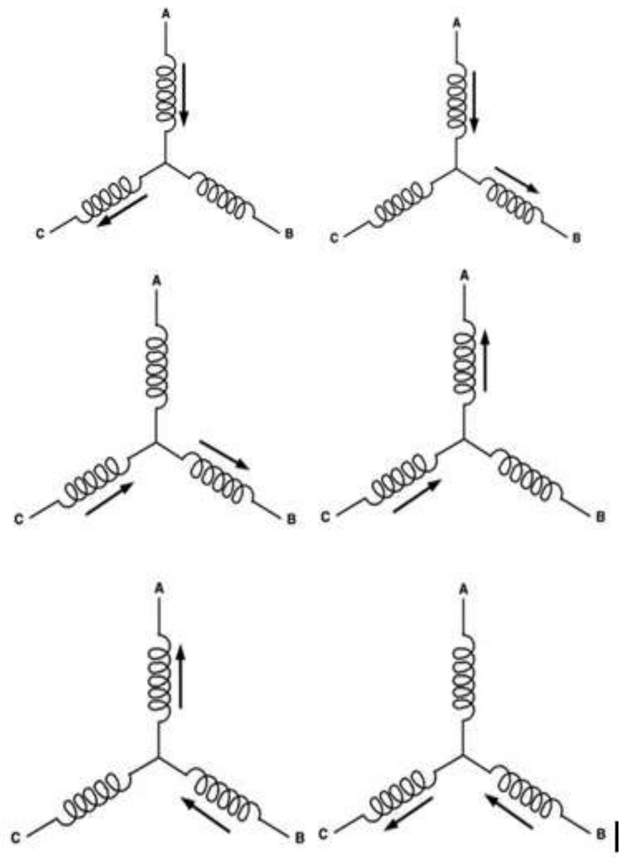

Figure 2 Coil commutation in three-phase bridge
(https://www.digikey.com.mx/es/articles/controlling-sensorless-bldc-motors-via-back-emf)

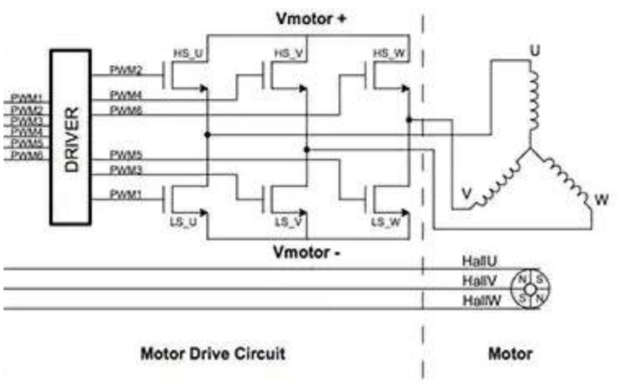

Figure 3 Three-phase bridge
(https://www.digikey.com/es/articles/how-to-power-and-control-brushless-dc-motors)

In the case of the BLDC motor, it contains a fixed part (stator), where the windings are located, and a moving part (rotor) of permanent magnets [11]. The BLDC motor requires an electronic circuit that acts as a commutator, which allows control of the position and direction of rotation, see Fig. 4.

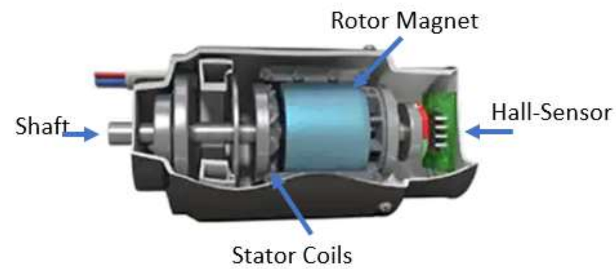

Figure 4 Motor BLDC diagram
(https://www.digikey.com/es/articles/how-to-power-and-control-brushless-dc-motor)

III. Mathematical model of the BLDC motor

The mathematical model of the BLDC motor does not differ much from that of a conventional DC motor, as represented by the three-phase configuration shown in Fig. 5.

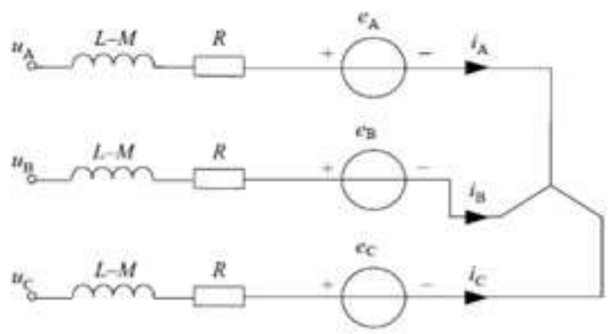

Figure 5 Equivalent circuit of a BLDC motor
Source: Own Elaboration

The equations that describe its electromechanical behavior are:

$$u_A = Ri_A + (L - M)\frac{di_A}{dt} + e_A \quad (1)$$

$$u_B = Ri_B + (L - M)\frac{di_B}{dt} + e_B \quad (2)$$

$$u_C = Ri_C + (L - M)\frac{di_C}{dt} + e_C \quad (3)$$

$$i_A + i_B + i_C = 0 \quad (4)$$

Where the voltage of the phases A, B, C are given by (1), (2) and (3), Since the windings are symmetric the resistance R, the inductance L and the mutual inductance M for these phases are the same. [12]. Likewise, the currents of the three phases i_A,i_B,i_C must fulfill the conditions of (4) . Applying Kirchhoff's voltage law to the circuit, the line voltages u_{AB}, u_{BC}, u_{CA} are obtained.

$$u_{AB} = R(i_A - i_B) + (L - M)\frac{di_A}{dt} + (M - L)\frac{di_B}{dt} + (e_A - e_B) \quad (5)$$

$$u_{BC} = R(i_B - i_C) + (L - M)\frac{di_B}{dt} + (M - L)\frac{di_C}{dt} + (e_B - e_C) \quad (6)$$

$$u_{CA} = R(i_C - i_A) + (L - M)\frac{di_C}{dt} + (M - L)\frac{di_A}{dt} + (e_C - e_A) \quad (7)$$

where the counter-electromotive forces (EMF) induced in the stator windings and the electric torque are expressed as:

$$e_A = \frac{K_e}{2}F(\theta) \quad (8)$$

$$e_B = \frac{K_e}{2}F(\theta - \frac{2\pi}{3}) \quad (9)$$

$$e_C = \frac{K_e}{2}F(\theta - \frac{4\pi}{3}) \quad (10)$$

$$T_e = \frac{K_e}{2}(F(\theta)i_A + (F\left(\theta - \frac{2\pi}{3}\right)i_B + F\left(\theta - \frac{4\pi}{3}\right)i_C \quad (11)$$

where K_e is the constant for the counter electromotive force [12], [13]. The counter electromotive force presents a trapezoidal waveform along the electric angle θ, and is defined by the function F(θ) that is bounded in the interval [-1,1]. A period of this function is defined as:

$$F(\theta)\begin{cases} 1 & 0 \le \theta < \frac{2\pi}{3} \\ 1 - \frac{6}{\pi}\left(\theta - \frac{2\pi}{3}\right) & \frac{2\pi}{3} \le \theta < \pi \\ -1 & \pi \le \theta < \frac{5\pi}{3} \\ -1 + \frac{6}{\pi}\left(\theta - \frac{5\pi}{3}\right) & \frac{5\pi}{3} \le \theta < 2\pi \end{cases} \quad (12)$$

where the electric angle θ of the electric field induced in the stator is directly related to the mechanical angle θ_m which is determined on the circumference of the motor. Thus, we have:

$$\theta = \theta_m \frac{p}{2} \quad (13)$$

where ρ is the number of poles. Therefore, the speed of the rotor and its position is related as:

$$\frac{d\theta}{dt} = \frac{p}{2}w_m \quad (14)$$

If the electric torque is defined as:

$$T_e = \frac{i_A e_A + i_B e_B + i_C e_C}{w_m} \quad (15)$$

then the electromagnetic power is equivalent to the power transferred to the rotor, being equal to the ratio between the electrical torque and the mechanical speed.

$$P_e = T_e w_m \quad (16)$$

Finally, there is the mechanical subsystem, which does not vary with respect to that of the conventional DC motor [14].

$$T_e = K_f w_m + J\frac{dw_m}{dt} + T_L \quad (17)$$

IV. Results

Using the Proteus application, the construction of the control circuit was carried out, in this application the scheme was designed: the electronics, software programming, simulation set-up, debugging, documentation and construction (Proteus has a library that allows the mounting of the programming code on the Arduino virtual board in Proteus). In the Fig. 6 electronic part (hardware) IR2101 are the drivers used to amplify the applied voltage in the gates of the MOSFETs.

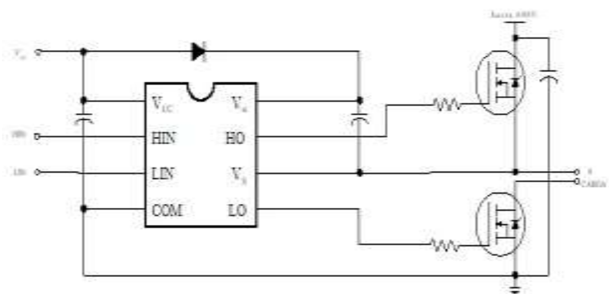

Figure 6 Typical connection for IR2101 driver (*Data Sheet No. PD60043 Rev.O www.irf.com)*

Fig. 7 shows the circuit design and the assembly of the same.

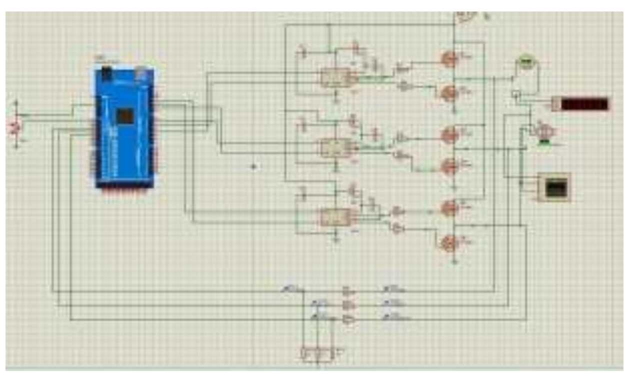

Figure 7 Simulation of the circuit in proteus
Source: Own Elaboration

Once the circuit is ready, the code is loaded into the Virtual Arduino. Next, the simulations were performed and the signals were obtained as shown in Fig. 8.

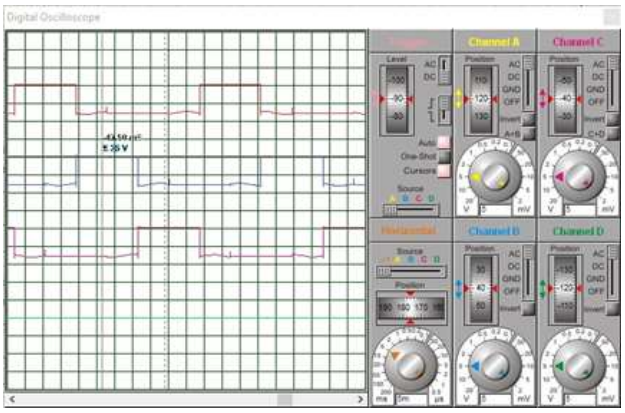

Figure 8 Simulated pulses in proteus
Source: Own Elaboration

The simulations allowed the verification of the Programming code operation. As shown in figure 9, the circuit was printed. It was programmed in PCB programming. The assembled components were three IR2101 drivers and six MOSFETs.

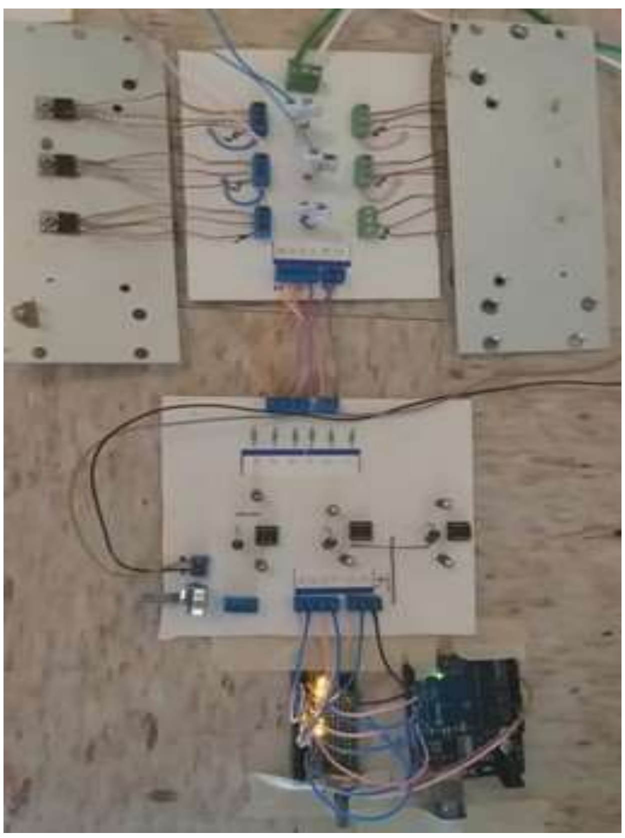

Figure 9 Circuit implemented with IR2101 drivers
Source: Own Elaboration

Fig. 10 shows the outputs of the implemented system, It can be seen that the signals obtained approximate. Those obtained in the simulation; allowing the verification of the control expectations and the correspondence of the prototype signals with the simulation signals.

Figure 10 Output signals of the IR2101 drivers
Source: Own Elaboration

The results in Table 1 show the efficacy of the Controller. Observing that, by varying the frequency the engine speed increases and decreases; noting that the system adjusts to the frequency change and stabilizes the RPM smoothly. It also maintains its speed until it is necessary to vary again. Correspondence is found by observing the phase time of the signals arriving to the engine; since the output of the system and the simulation these signals are similar.

Velocity (RPM)	Freq. (Hz)	Time of Fase (µs)
518	57.48	29.97
735	69	24.44
833	81.5	21
910	92.34	17.96
1008	103.9	16.24
1106	125.1	13.38
1197	148.8	12.24
1350	166.4	11.67
1393	171.5	10.9
1463	197.1	9.57
1624	205.5	9.13
1729	222.5	8.19

Table 1 Data of obtained parameters of controller BLDC
Source: Own Elaboration

Table 2 shows the engine's RPM, these are defined as value read with the encoder sensor (RPMM), and value obtained in simulation or expected value (RPMS) respectively. The root mean square error (RMSE) presents the difference between these two values, between the set of RPMM and RPMS data. The standard deviation and the Pearson's correlation coefficient are also shown. It is also noted an index of low dispersion, maintaining the parameters statistics within standard ranges.

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Dispersion Statistics	RPM_O	RPM_S	$RPM_S - RPM_O$
	518	535	-17
	735	663	72
	833	788	45
	910	874	36
	1008	992	16
	1106	1194	-88
	1197	1289	-92
	1350	1394	-44
	1393	1432	-39
	1463	1585	-122
	1624	1652	-28
	1729	1719	10
Standard deviation	370.58	400.51	
RMSE			66.70
Pearson's´Coefficient			0.991

Table 2 RPM, RMSE and SDV
Source: Own Elaboration

Fig. 11 graphically shows the behavior of the motor at different values of frequency, which demonstrates that the controller complies with the regulatory expectations of engine speed.

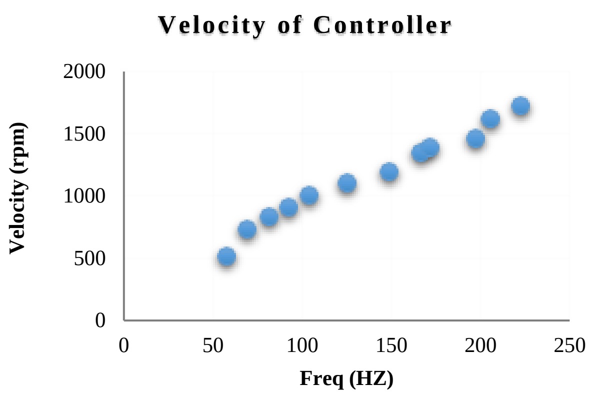

Figure 11 RPM vs Frequency curve
Source: Own Elaboration

V. Conclusion

In this work it was possible to verify that the control proposal made for the BLDC motor was satisfactory since a better range of speed variation was achieved both in the simulated design and in the built system. In addition, the system did not present RPM stability problems when intentionally varying the frequency.

In conclusion, due to the characteristics of the BLDC motor that submersible water pumps have, the simplicity and low cost of the controller that was designed, simulated, built and validated make it attractive for use in application systems. of solar pumping in the regions of Zacatecas.

In addition, it is noteworthy to say that the design of the controller can be integrated into systems with monitoring and industry 4.0 applications where the use of the Internet of Things makes it more efficient and adds value to solar pumping irrigation systems. Therefore, the use of platforms such as Arduino allows us to expand the capabilities of a control system in such a way that using a complement that includes internet (WiFi) it can be monitored or reprogrammed through the use of the internet of things and the new trend of I 4.0.

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Article **Journal of Technical Invention**
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Advances in the design of an alternative power generation device using piezoelectric

Avances del diseño de un dispositivo de generación de energía alternativa por medio de piezoeléctricos

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Abstract

This article will give the progress of the project of design of a device of alternative energy generation using piezoelectric, applied in the improvement of the lighting of an urban dwelling. Giving the background of the piezoelectric effect, a diagnosis of the conditions of the housing unit in terms of the energy demand for lighting, its vehicular capacity and road conditions, as well as the proposed solution to the demand for electrical energy, indicating the necessary electronic components in the first proposal and ending with the initial design and technical analysis, to conclude with the results of the research project. It is also important to consider that within the 13 modules that are required to form the speed reducer when a vehicle passes it will not pass through the 13 modules, but only a few, so the energy generated will also have variations in the results; unless a way is sought that when the vehicle passes over the reducer, all modules are pressed at the same time.

Piezoelectric, Energy harvesting, Alternative energy

Resumen

En el presente artículo se darán los avances del proyecto de diseño de un de un dispositivo de generación de energía alternativa por medio de piezoeléctricos, aplicado en el mejoramiento del alumbrado de una vivienda urbana. Dando los antecedentes del efecto piezoeléctrico, un diagnóstico de las condiciones de la unidad habitacional en cuanto la demanda de energía por alumbrado, su aforo vehicular y condiciones viales, así como la propuesta de solución a la demanda de energía eléctrica, señalando los componentes electrónicos necesarios en ta primera propuesta y terminando con el diseño y análisis técnico inicial, para concluir con los resultados del proyecto de investigación. También es importante considerar que dentro de los 13 módulos que se requieren para formar el reductor de velocidad, cuando pase un vehículo no pasara por los 13 módulos, sino solamente por unos cuantos, por lo que la energía generada también tendrá variaciones en los resultados; a menos que se busque la manera de que cuando el vehículo pase sobre el reductor, todos los módulos sean presionados al mismo tiempo.

Piezoeléctrico, Cosecha de energía, Energía alternativa

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Introduction

The growth and concentration of the population in the city have led to the development of the expansion of urban housing, so in the main cities housing complexes have been built, where the lack of public lighting has caused various problems such as the deterioration of common areas, the vulnerability of passers-by to criminal acts, inappropriate use of the collective areas for which they were designed and their progressive appropriation of illegal trade (SEDATU, 2014).

Such is the case in the housing unit: Arcos de Aragón, located in the Gustavo A. Madero mayor's office, Mexico City; since due to the lack of lighting in different areas of common use has been limited to their use of them and insecurity has been affected.

This article will give the progress of the project of design of a device for alternative energy generation using piezoelectrics. Giving the background of the piezoelectric effect, a diagnosis of the conditions of the housing unit in terms of the energy demand for lighting, its vehicular capacity and road conditions, as well as the proposed solution to the demand for electrical energy, indicating the necessary electronic components in the first proposal and ending with the initial design and technical analysis, to conclude with the results of the research project.

1. Background

The piezoelectric effect was discovered in 1880 by the Curie brothers and was first used by Paul Langevin in the manufacture of sonars during World War I using quartz crystals coupled to metal masses to generate ultrasound in the tens of kHz belt. (Venet Zambrano & Alves Pereira, 2004).

These materials have the peculiarity of generating electrical charge when external pressure is applied on them, which works under the piezoelectric effect. Piezoelectricity consists of the presence of an additional electric charge, due to the application of this force.

This principle is based on the change of polarization of the material due to the deformation generated by a force applied on the crystals.

The functioning of these crystals depends on the individual molecules that compose them, normally, when the crystal is not under any type of external stress, the charges are uniformly dispersed in the molecules through the crystal. But when quartz is stretched or squeezed, the order of the atoms changes slightly. This change causes negative charges to accumulate on one side and positive charges to accumulate on the opposite side.

2. Initial proposal

The initial proposal contemplates the housing unit: Arcos de Aragón, and aims to propose a system to generate electricity, taking advantage of the vehicular traffic of the housing unit, harvesting the energy through piezoelectric devices whose operation is based on exerting pressure on them and have the advantage that they do not produce polluting emissions. The energy generated will be stored in batteries and distributed in the lighting of the outdoor areas of the housing unit, that is, in the spaces of transit and common use such as recreational centers and parking.

2.1. Site information

The Arcos de Aragón housing unit is located on the San Juan de Aragón road and Av. Rio de Guadalupe and as a reference, it is located between Av. Eduardo Molina and Av. Gran Canal, in the Gustavo A. Madero delegation, this unit is divided into 3 sections that have independent accesses and exits from each other, but are part of the same unit. (See Figure 1).

Figure 1 Location and distribution of the sections of the Arcos de Aragón housing unit
Source: Elaboration with capture of Google maps 2022

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Different sections are made up of a set of Rinconadas with 9 towers of buildings (FIGURE 2) each, in the center of each Rinconada there are 34 parking drawers, and there are others outside, Rinconada is along the entire housing unit that is for use by the owners.

Figura 2 Distribución de las secciones de la unidad habitacional Arcos de Aragón
Source: Elaboration with capture of Google maps 2022

Sections 1 and 2 share a parking lot that is located between the 2 sections, and 3 recreation areas, the first located at the access on Av. Eduardo Molina has a multipurpose court and a children's play area, this area does not have much lighting, the second is followed by parking between both sections and has 3 multipurpose courts, an area of exercise equipment and children's games, despite having a luminaire in this area, it has been observed that not enough maintenance has been given and the luminaire system does not work completely, and the third is at the bottom of section 2 which is a pet park where there is no luminaire. Because section 1 has a larger surface area and habitability, the study will be carried out only in this area.

2.2. Characteristics of energy demand

On the other hand, the electrical service of the Arcos de Aragón housing unit is divided into domestic and collective, which is for domestic use refers to the consumption of the department of each owner, and collective use includes the lighting of the parking lot in each Rinconada the use of water pumps that is an independent expense of the maintenance of the facilities and services of the entire unit (common areas, gardening, parking lighting, surveillance, etc.)

Will be important to capture the distribution of the currently active luminaires in the housing unit, as well as those in poor condition and those not in operation.

In each Rinconada are distributed 4 luminaires around each Rinconada, these luminaires are incandescent lamps, and it is observed that some of them are not in operation; due to this, the inhabitants of the unit have been forced to place lamps whose consumption runs through their homes to illuminate these areas. These types of luminaires are also found in recreation areas that are in the same situation.

In the parking lot there are halogen pendant luminaires placed on the roofed levels of the parking lot, and on the upper-level luminaires with incandescent lamps.

Finally, on the main roads of circulation, there are 2 types of luminaires; incandescent lamps that are in poor condition and some are not in operation, and luminaires with solar panels and LED lamps that in the same way are not all in operation.

Kind of luminary	quantity	Operation		Efficiency		Useful life	Time on
		Yes	No	lm	W	(hours)	(minutes)
LED with solar panels	22	18	4	80	100	50,000 a 100,000	Instant
Luminary VSAP	51	37	14	45	150	24,000	3-5
Combined	4	3	1				

Table 1 Capacity of existing luminaires in section 1 of the Housing Unit
Source: Own Authorship 2022

2.1. Vehicle capacity

The objective of making a vehicular capacity, is to know the number of vehicles that transit within the housing unit, will be carried out using a vehicular capacity, in the access and exit of the unit, and the movement of the vehicles, that is, the route they make within the unit to the main parking lot and the other Rinconada.

Data collection by direct observation

This observation was made at different times and seasons, it was observed that vehicular traffic is continuous and constant, and varied according to the types of vehicles, since not only the vehicles of the owner's transit, given that it is a complex with an area of almost 10 hectares.

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It has been observed that the circulation made by the vehicles of the owners of the unit is multiple, since some have a parking drawer in the main parking lot, away from their home, so when they make purchases or make family trips, they first make a stop to the parking lot of the Rinconada, either to load and/or unload for convenience to the proximity of their home, and finally make another move to exit the unit or take your vehicle to the designated parking drawer (as the case may be).

Regarding other vehicles that enter the housing unit, it has been observed with medium frequency those that provide maintenance services (telephone-internet, electricity, gas, construction, etc.) these vehicles go directly to the place that is requested and are removed from the unit. Mobility and parcel service vehicles have also been observed with a high frequency and at very varied times during the day. Finally, heavy-duty vehicles are considered, such as removals and delivery of low-frequency furniture stores, as well as some suppliers of groceries with a very low frequency.

La vialidad principal de la unidad habitacional cuenta con 2 sentidos de circulación con un carril cada uno delimitado con señalamiento horizontal y vertical, el cual se refiere a la pintura en el piso para delimitar los carriles de circulación y el control de la circulación con señalamientos de cruce peatonal, alto, límite de velocidad y reductores de velocidad y así evitar accidentes entre conductores y peatones.

In the main parking lot, there is a ramp for access and delimited direction of circulation with horizontal signaling to know the direction of circulation and avoid conflicts, as well as vertical signaling which are mostly restrictive signs of the speed limit and high, and preventive pedestrian crossing.

Data collection

To obtain accurate data on the vehicles transiting in the housing unit, a continuous accounting of vehicles was carried out during a typical day. For this case, these capacity points were in the accesses of section 1, accounting for the access and exit of the vehicles in a period from 6:00 a.m. to 24:00 p.m. at intervals of 15 min, taking into account the type of vehicle registering it in a log.

Likewise, directional flow sampling was carried out, to detect the movements made by the vehicles once they enter the housing unit and made them go to their Rinconada.

The points that were considered were the accesses to each Rinconada and the main parking lot, counting in the same way the number and type of vehicle. Below is an outline of how such capacity will be carried out. (Figure 3)

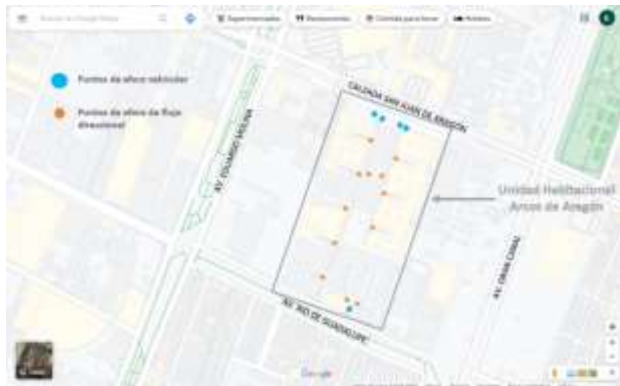

Figure 3 Scheme of vehicular and directional flow gauging stations in the Arcos de Aragón housing unit
Source: Own Authorship 2022

The results obtained are shown in the following board, extract from the log where the capacity was recorded, which shows the number of total vehicles entering and leaving; the type of directional flow movement was considered for entry vehicles concerning Figure 3, but without accounting for the movements of motorcycles.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				[illegible]										[illegible]
				[illegible]						[illegible]				[illegible]

Table 2 Result of vehicular capacity including directional flows of entry vehicles
Source Own Authorship 2022

3. Alternative selection

What is intended is to satisfy the energy demand of the exterior lighting of the housing unit, so the electronic devices within the initial energy harvesting device are considered to use piezoelectrics to meet that objective.

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3.1. Types of piezoelectric materials

These devices come from natural materials such as quartz, tourmaline and Rochelle salt, these materials are very small, so materials with improved properties have been developed such as polycrystalline ferroelectric materials such as Barium Titanate (TiBaO3) and Lead Zichromate Titanate (PTZ), the latter are available in many variations and are the most used today. The crystal structure of this element is cubic centered on the faces before polarization and after polarization exhibits tetragonal symmetry below the Curie temperature, which is the one where the crystal structure changes from piezoelectric to non-piezoelectric shape. (Cúpich & Elizondo, 2000, p.2)

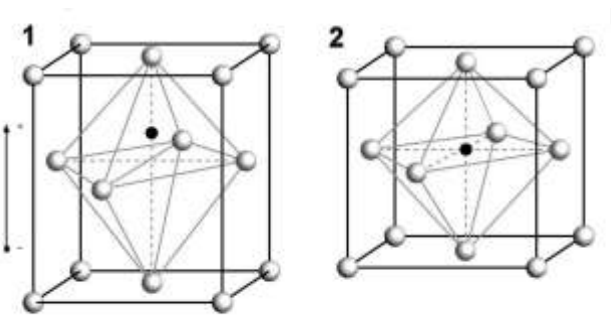

Figure 4 Structure of a piezoelectric ceramic type PTZ, below and above the Temperature of Curie
Source: *Cúpich & Elizondo, 2000*

3.2 Required electronic components

For the operation of the system that will be elaborated in the research work, it is important to know the necessary electronic components to be used, which protect and distribute the energy generated correctly.

First it must be identified that a piezoelectric material according to its properties, produces a current when external pressure is applied to them, transforming mechanical energy into electrical energy; that happens by changing the order of the atoms of these materials, and the negative charges accumulate on one side and the positive ones accumulate on the opposite side, if one end of the crystal is connected to the other, the potential difference is used to produce an electric current. To convert this mechanical energy to electrical energy by piezoelectric devices and to be able to store it, an electronic system is required; which is a set of interrelated circuits that interact with each other to obtain a result, which is made up of 3 stages:

a) Inputs
b) Signal processing circuits
c) Outputs

Inputs can be sensors or transducers that take a physical signal and convert it into a current or voltage signal.

Signal processing circuits consist of electronic parts connected to manipulate, interpret, and transform voltage and current signals coming from transducers.

Outputs can be actuators or other devices such as transducers that convert current or voltage signals into physically useful signals.

The different electronic components that make up an electronic circuit are classified according to the following board.

Information type	Regime type	Signal type	Configuration
-Analog -Digital -Mixed	-Recurring -Transient - Permanent	-Direct current -Alternating current -Mixed	-Series -Parallel -Mixed

Table 3 Classification of components within an electronic circuit
Source: Own authorship 2022.

Regarding the research topic, and the objective to be achieved, the following scheme is considered:

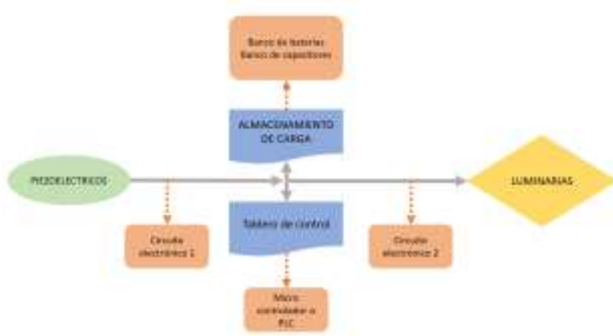

Figure 5 Electronic circuit operating scheme
Source: Own Authorship 2022

For the above, in the first step of the piezoelectrics to the first circuit, the following components are considered:

– Components: Cables.
– Analog devices: diode, Zener diode, transistor, inductor, op-amp.
– Power devices: Fuse.

– TRIAC, transformer, varistor.
– Transducers: piezoelectric transducer

For cargo storage and control board will be required:

Components:
– Cables
– Switch
– Battery
– Speaker

Analog devices:
– Diode
– Zener diode
– Potentiometer
– Relay
– Resistor
– Transistor

Digital devices
– Memories
– Microcontrollers
– Logic gates

Power devices
– TRIAC
– Varistor

Transducers
– Photoelectric transducer
– Thermoelectric

Power supplies (UPS)
– Interactive line

Control system
– Electronic

Measuring equipment
– Galvanometer
– Ammeter
– Ohmmeter
– Voltmeter
– Oscilloscope

4. Design and technical analysis

According to the background mentioned above and the current conditions of the study site, in this section, the first proposal of the prototype and the solution to the energy demand of the housing unit with the chosen energy harvesting materials is made.

4.1. Initial prototype

The proposal is made with devices for traffic control and road safety, in recent years these prefabricated devices of recycled tire rubber have been occupied, these are placed on the rolling surface, by modules that facilitate and speed up the installation of them. They have yellow reflective tapes to increase visibility even in places with low lighting. They also have a superficial pattern, which ensures a correct grip of the tires of the vehicles avoiding any skidding. (Figure 6).

Figure 6 Electronic circuit operating scheme
Source: https://gnrmexico.com.mx/reductor-de-velocidad-safety-rider-v/

As said above, it is important to consider the use of these prefabricated elements that help with the implementation of what is intended to be developed in the present research, adapting these reducers with piezoelectric devices.

Below, 2 possible solutions with different numbers of piezoelectrics are shown, which is not yet a definitive model, since the electricity consumption of the exterior lighting of the housing unit and the existing vehicular flow has yet to be considered. (Figures 6 and 7).

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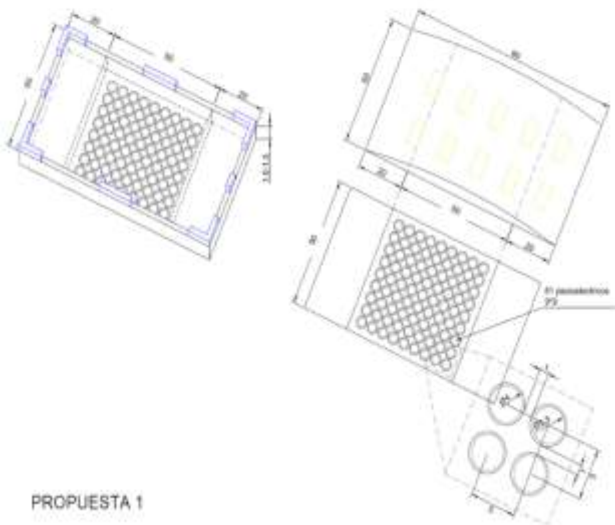

Figure 7 Electronic circuit operating scheme
Source: *Elaboration using AutoCAD 2022 software*

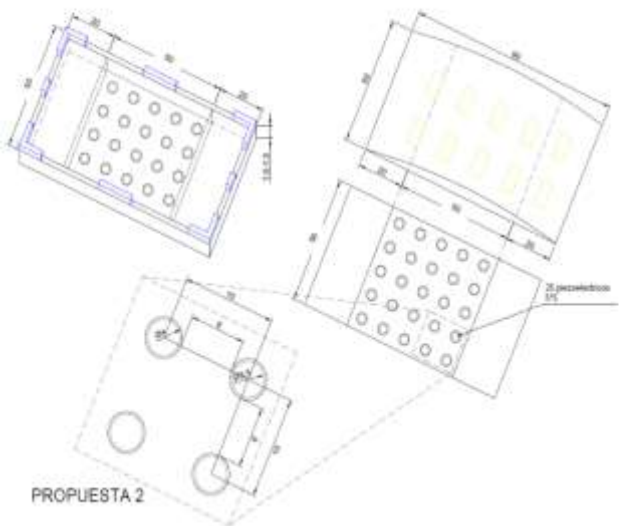

Figure 8 Electronic circuit operating scheme. Source: *Elaboration using AutoCAD 2022 software*

The previous arrangement considers one of the modules for a speed reducer; in a road stream of (x) linear meters so the number of modules will be variable, according to the road stream of the access and exit of the housing unit which is 6.50m wide and according to the measurements of the modules that is 0.50m wide, for this case 13 modules are needed to form a speed reducer, which is connected for energy storage and therefore a total of 1,053 piezoelectrics would be projected in proposal 1 and 325 piezoelectrics in proposal 2.

4.2. Amount of energy generated.

To obtain the power of the system will be obtained by the following formula:

$$Power\ (Watts) = I * V \quad (1)$$

Considering a series arrangement of 4 parallel-connected piezoelectrics of 35 mm in diameter; was generated by manually pressing a voltage of 1.8 V, as measured with a multimeter.

Therefore, we can calculate the power for the arrangement of 4 piezoelectric devices connected in parallel:

$$Power\ (Watts) = 0.02\ A * 1.8\ V$$

$$\mathbf{Power\ (Watts) = 0.036\ Watts}$$

To check or make a comparison of what was obtained, a technical sheet of a stainless steel piezoelectric device of 20 mm in diameter is presented below.

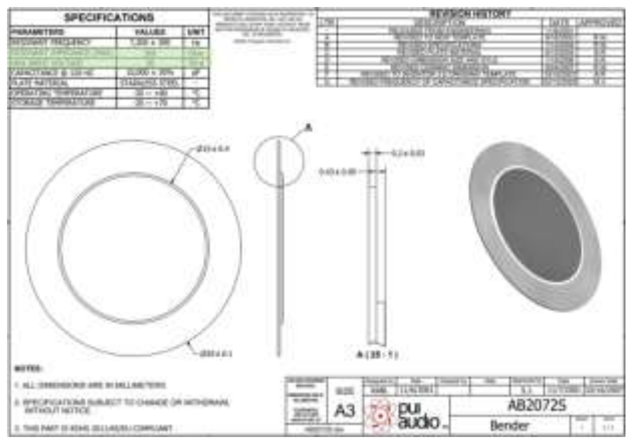

Figure 7 Technical data sheet of stainless steel piezoelectric device
Source: https://www.digikey.com.mx/es/products/detail/pui-audio-inc/AB2072S/1464747

With the data you have of the resistance and the maximum input voltage, you can get the power that a device would generate. It is worth mentioning that these data are specifications of the device and are the maximum of operation, so the results obtained are with a significant clearance.

According to Ohm's law, we can obtain the current as follows:

$$A = V/\Omega \quad (2)$$

So to get the power:

$$Power\ (Watts) = 0.1\ A * 30\ V$$

$$\mathbf{Power\ (Watts) = 3\ Watts}$$

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Considering that the specifications are with maximum and optimal values, the experiment with four piezoelectric devices is acceptable.

For the projection of the system, the number of vehicles that travel in the housing unit will be considered, and the 13 modules would be placed along the road stream.

Considering that the specifications are with maximum and optimal values, the experiment with four piezoelectric devices is acceptable.

For the projection of the system, the number of vehicles that travel in the housing unit will be considered, and the 13 modules would be placed along the road stream. Therefore, in the following board, the projection of what was obtained with the experiment will be made, and the number of piezoelectrics of proposals 1 and 2, are mentioned above. (Board 4).

# Piezo	V	A	W	Modules	Cars in	Total W
4	1.8	0.02	0.036	13	1251	585.47
25	11.25	0.02	0.225	13	1251	3,659.18
81	36.45	0.02	0.729	13	1251	11,855.73
100	45	0.02	0.9	13	1251	14,636.70
150	67.5	0.02	1.35	13	1251	21,955.05

Table 4 Estimation of power obtained from different numbers of piezoelectrics from both proposals 1 and 2
Source: Own Authorship 2022

5. Proposal of luminaires

Considering an outdoor luminaire that has a power of 25 W up to 100 W with an average life of 75,000 hrs, the projection of how many piezoelectric devices would be needed to operate this luminaire was made. (Figure 8).

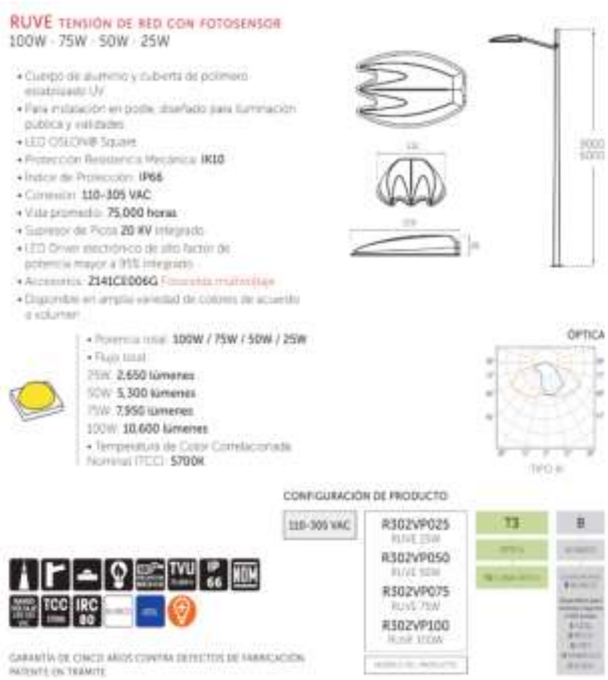

Figure 8 Technical sheet of luminaire for outdoor lighting, LED technology
Source: Zaraus lighting catalog 2020-2021

Now, to know the energy consumption of the luminaires, according to the technical sheet they have 25 W, 50 W, 75 W and 100 W, since the total power was considered according to the daily vehicular flow, therefore, the results obtained reflect the hours a day that the luminaires would be on in the day. Board 5.

Number lamps					
Number piezo	W	25	50	75	100
4	585.47	23	12	8	6
25	3659.18	146	73	49	37
81	11855.73	474	237	158	119
100	14636.70	585	293	195	146
125	18295.88	732	366	244	183
150	21955.05	878	439	293	220

Table 5 Estimation of the number of lamps of different numbers of piezoelectrics
Source: Own Authorship 2022

Acknowledgment

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Conclusions

According to the results that were obtained, it seems that the system is optimal and viable to implement, however, many other factors remain to be considered, such as the other components that will make up the system, the storage battery and the distance at which the luminaire will be placed from the speed reducer, these elements could make that amount of power affected and be lower.

It is also important to consider that within the 13 modules that are required to form the speed reducer, when a vehicle passes it will not pass through the 13 modules, but only a few, so the energy generated will also have variations in the results; unless a way is sought that when the vehicle passes over the reducer, all modules are pressed at the same time.

Regarding the materials for the harvesting of energy, it is important to address, that the importance of the study of them, in recent years is very beneficial, since one of the main challenges of the planet today is to find new sources of energy that do not affect the environment, and reduce the greatest amount of polluting gases, as well as the exploitation of natural resources.

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Indoor CO_2 monitoring system using a microcontroller via Bluetooth for coronavirus prevention

Sistema de monitoreo de CO_2 para interiores utilizando microcontrolador vía Bluetooth para la prevención de coronavirus

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Abstract

This work describes the design and implementation of the CO_2 meter, operated with the PIC18F45K50 microcontroller; which detects the concentration of the gas in parts per thousand (ppm); also, this instrument has an-App downloaded on a mobile device with Android operating system, communicating with the microcontroller via Bluetooth. This to measure the concentration of CO_2 which is a colorless gas compound of carbon and oxygen. The measurement of CO_2 concentration is a strategy that can warn of the risk of COVID-19 contagion in an enclosed place where a group of people are gathered. In the return to classroom, because the risk of contagion by COVID-19, which is spread through CO_2, persists. Also, there are very crowded places due to the daily activities developed by the human being, so now it is not a luxury to take care of the air we breathe to have a healthy life.

CO_2 Sensor, Microcontroller, Bluetooth, App

Resumen

Este trabajo describe el diseño y la implementación del medidor de CO_2, operado con el microcontrolador PIC18F45K50; el cual detecta la concentración del gas en partes por millos (ppm); además este instrumento cuenta con una App descargada en un dispositivo móvil con sistema operativo Android, comunicándose con el microcontrolador mediante bluetooth. Esto con la finalidad de medir la concentración de CO_2 el cual es un compuesto de gas incoloro de carbono y oxígeno. La medición de la concentración del CO_2 es una estrategia que puede advertir el riesgo de contagio del COVID-19, en un lugar cerrado donde se encuentre reunido un grupo de personas. En el retorno a clases presenciales, debido a que aún persiste el riesgo de contagio por COVID-19 mismo que se propaga a través del CO_2. Por lo que también, existen lugares muy concurridos debido a las actividades diarias desarrolladas por el ser humano, por lo que ahora no es un lujo cuidarnos del aire que respiramos para tener una vida saludable.

Sensor de CO_2, Microcontrolador, Bluetooth, App

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† Researcher contributing as first author.

Introduction

In ancient times, electronic devices were not part of people's daily lives. It was not until the 19th century, with the advent of the Industrial Revolution, that the rise of machines began. With the arrival of these, problems also arose such as the preservation and prolongation of their useful life, as well as the search for their improvement, to facilitate and increase the daily life of people. Thus, for example, in 1980 the hepatitis B vaccine was created [1], in 1983 the first cell phone was implemented [2], it was not until 1984 that the CD-ROM was invented, from this invention Microsoft built the Windows platform in 1985 [3], and seven years later in 1992 the Smart Pill was created, an ingestible capsule that measures blood pressure, pH, temperature and as it passes through the gastrointestinal tract [4]. By 1997 the first vaccine for Hepatitis A was developed [5], by 1995 the DVD was invented, and in 2000 wireless Internet became available.

This has been achieved thanks to the constant technological advances that have allowed us to have new technologies for industrial processes, as well as extremely necessary and useful small tools such as detectors of different substances or gases.

As is well known, a gas of great abundance on the planet is Carbon Dioxide (CO_2), this is found in industries or in everyday life which according to the magazine: The Pacific Forest Trust (2016), CO_2 is a colorless, odorless and non-combustible gas found in low concentration in the air we breathe [6], which is generated when any substance containing carbon is burned, as well as obtained as a product of respiration and fermentation of fruits and vegetables.

The detection of the concentration of this gas in a given area is essential to know and know how to act in the event of a leak or large concentrations of this gas, so that there are no risks to the people who are in the place.

However, different investigations carried out during the year 2021 have shown that the main route of transmission of coronavirus is airborne. According to the Center for Disease Control (CDC) it is spread by microparticles, small respiratory droplets, called aerosols [7].

Although it is also transmitted by large droplets, when talking, shouting, coughing, etc., these fall at a distance of less than 2 meters.

The main problem is the aerosols. They also originate from talking, coughing, sneezing, etc. but are smaller and remain suspended in the air for hours. If you are healthy and inhale air with these microparticles you run a higher risk of contagion.

It is for this reason that we propose the present research, which aims to detect high levels of CO_2 gas through an application easily accessible and usable by anyone with a mobile device, which is available to all users of enclosed spaces and thus can take the decision to ventilate the place or withdraw from it, at the time that exceeds a maximum concentration of 3,000 parts per million (ppm), causing among other ailments: headaches, lack of concentration, drowsiness, dizziness and respiratory problems.

Several investigations have been conducted to examine the correlation of these parameters with CO_2 concentration. Li, et al. analyzed CO2 concentration at different altitudes in the atmosphere [8]. To do this, the authors placed a CO_2 sensor in an air balloon. The results showed that the CO_2 concentration is lower at higher altitudes in our atmosphere. This means that altitude is inversely correlated with CO_2 concentration. Katarzyna et al. in 2013, analyzed the correlation of indoor CO_2 concentration and air humidity [9]. Lazovic et al. also studied the correlation of air humidity and air temperature [10]. Another correlation study was conducted by Soares who analyzed the correlation between CO_2 and temperature to analyze global climate change [11]. While Montero Gutierrez performed a data sampling and correlation test for CO_2 [12].

Objective

To design and implement a system to detect CO_2 levels within a given area, by means of a bluetooth alert system, in a mobile device, using a microcontroller.

Methodology

The CO_2 measuring instrument, operated with a microcontroller via Bluetooth for the prevention of coronavirus, as shown in the block diagram in Figure 1, consists of:

– The control unit via microcontroller PIC18F45K50,
– CO_2 sensor, MQ-135
– Bluetooth module HC-06
– LCD display
– Relay stage for indicator output.

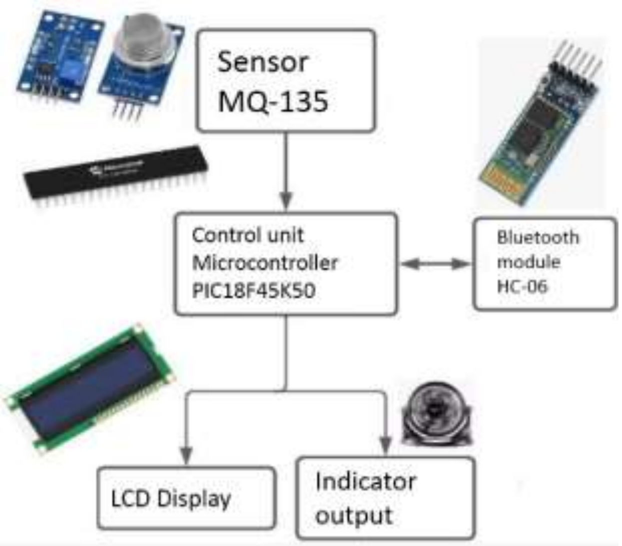

Figure 1 Block diagram of the CO_2 Monitoring System

The high-performance 16-bit PIC18F25K50 microcontroller reads the information provided by the MQ-135 gas sensor, which is composed of a small alumina (aluminum oxide) ceramic tube with a thin layer of tin dioxide. The sensor element is encapsulated inside a steel mesh that, in addition to protecting the sensitive layer, protects the outside in case of an internal explosion in the device (which can happen if the sensor is exposed to flammable gases).

For proper operation of the sensor, it must be preheated to at least 20°C, so the housing has a small heater that keeps the sensor at an optimum operating temperature.

The operating principle of the MQ-135 sensor is by varying the relative resistance of the sensing device, so a voltage divider must be used. The board used for the realized meter has such a voltage divider integrated along with an operational amplifier that keeps the output voltage stable invariant of the load applied at the output.

The microcontroller receives the voltage from the sensor and sends it to a receiving unit (based on the same control unit) via the Bluetooth module HC-06.

The information received is analyzed and, depending on the result obtained, approximately 800 parts per million (ppm), some corrective action can be taken in the environment to decrease the CO_2 concentration. Such corrective action can be assisted by a relay module in which the connection of extractors, fans, or alarms indicating that the place should be ventilated or evacuated can be performed. The electronic diagram of the monitoring system is shown in Figure 2**.**

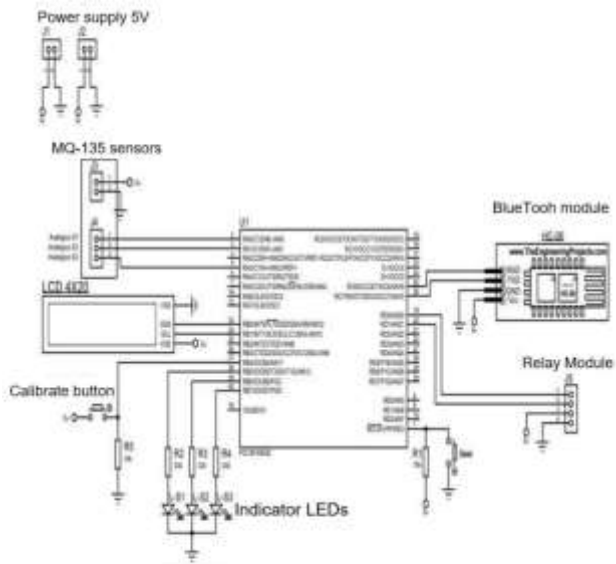

Figure 2 Electronic diagram of the CO_2 monitoring system

The User Interface to monitor the environment CO_2 level, on a mobile device with Android operating system, via Bluetooth, is carried out with the Bluetooth Electronics App.

The editing of this App is carried out with the initial configuration by pressing the "Edit" button in "Default Text", to place the names of "Sensor 1", "Sensor 2" and "Sensor 3". The text color is chosen by sliding the Red, Green and Blue primary color selectors.

Three text boxes were then added, displaying the amount of CO_2 in parts per million (ppm) read by the sensors. In its configuration, the "Default Text" box is left blank and the justification will be Left. The text color is set to all blue and the "Receive Character" is set to "1". It is important to set this data as it helps with the data transmission between the microcontroller and the APP. The same is done for the corresponding boxes of Sensor 2 and Sensor 3, placing in "Default Text" the number "2" and "3" respectively.

Subsequently, another text box is added, the largest one available, in which additional information text will be displayed. In its configuration the "Default Text" is left blank and the justification is in the center, the color of the text will be green and the "Receive Character" is "D". Subsequently, light indicators are added for each sensor, the "Receive Character" for the indicator of sensor 1 is "L", for sensor 2 it is "M" and for sensor 3 it is "N". The color of the indicators does not need to be adjusted as it will change color when the APP is running. A sound indicator is also added, which will work with the phone's speaker.

The "Receive Character" is "S", one of the available sounds provided by the APP is selected and the vibration can be activated or deactivated. A button is also added, which will help with the sensor calibration function, to set it, the letter "c" (lower case) is placed in the "Press Text" box and the other box is left blank. Finally, a text box is added that will simply help to indicate the function of the button added earlier. After configuring the interface, it must be linked with the bluetooth module.

To do this, return to the main screen and press the "Connect" button. Subsequently a screen appears showing the connection method, due to the characteristics of our HC-06 module, select the "Bluetooth Classic" mode and then click on "Next". In the next screen, press the "Discover" button to search for available Bluetooth devices, then select the name of the module, which in this case is "BT04-A" and then click on the "Connect" button to start the pairing.

A legend appears at the top of the screen indicating that both devices have been successfully paired. If this does not happen, it is recommended to turn off and turn on again the bluetooth of the mobile device and repeat the procedure described above. To return to the main screen click on "Done".

Once the interface has been configured and the devices have been paired via Bluetooth, the next step is to perform the functional tests. To do this, select the panel where our interface is located in the App and click on the "Run" button. Finally, the configured interface will appear on the screen. As shown in figure 3.

Figure 3 CO_2 monitoring system, implemented in a box and the App on a cell phone

Results

CO_2 gas (also known as carbon dioxide) existing in our atmosphere in the right amount balances the atmosphere, i.e. if it 'inhabits' the atmosphere at an average ratio of 380 parts per million it is favorable. However, when this figure rises, it facilitates the persistence of SARS-CoV-2. However, in recent years, CO_2 concentration has increased worldwide with an increase of 21.12 ppm from 2006 to 2015 [13]. It is reiterated then, that normal parameters in non-industrial indoor environments such as schools, offices and services in general have values of 500 to 700 ppm. On the other hand, the large increase in CO_2 concentration in our atmosphere could cause an unbalanced air composition, which could lead to several chronic diseases.

These diseases include respiratory problems, vision problems, and other complications [14]. In addition, the increase in CO_2 concentration could also cause an increase in global temperature. The agricultural sector could also be affected by the increase in CO_2 concentration since an excessive amount of CO_2 processed during plant photosynthesis could reduce the nutrients contained in crops [11, 12, 13,14].

To aid the data analysis process, additional parameters are required to provide a detailed understanding of the exact state of the environments.

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These parameters include temperature, air humidity and light intensity. For this, a correlation assessment between the parameters and CO_2 concentration is necessary.

To address this problem, more detailed monitoring of CO_2 concentration is required. The data obtained from the monitoring process will be used for decision making to identify the CO_2 concentration. For this, we need to have a state-of-the-art CO_2 monitoring system.

A feasible solution is to use a WSN wireless sensor network to acquire this CO_2 concentration data. The sensors are placed at certain locations to collect data, which is then shared with the other sensors in the network to analyze the CO_2 data.

Once the locations with the highest CO_2 rates are identified, strategies are established with the implementation of renewable energy, energy efficiency, waste treatment, reforestation and improved agricultural practices.

Our contribution to the identification of carbon dioxide is "The monitoring system with CO_2 sensors which were implemented inside a box made in 3D printing, as shown in Figure 4, for better handling.

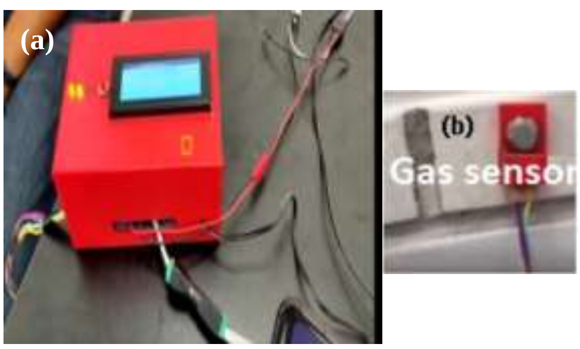

Figure 4 (a) CO_2 monitoring system, implemented in a box. (b) MQ-135 gas sensor

The CO_2 monitoring system, already implemented in its box and calibrated at 800 ppm maximum for relay activation, was placed to evaluate its operation inside the auditorium gymnasium of the TecNM/ITApizaco, during the graduation, with a capacity of approximately 70% of its maximum capacity, i.e., approximately 700 people.

The three sensors were placed in different locations; the first sensor was placed two meters away from the authorities, the second sensor four meters away from the graduates and the third sensor six meters away from the family members, obtaining the results shown in Table 1. And the corrective action, i.e. the relay module was connected directly to the switch box (placing them in normally open) of the extractors already installed previously in the gymnasium-auditorium.

Time	Sensor 1	Sensor 2	Sensor 3
10:30	434.05	628.89	391.02
10:40	434.05	899.19	232.12
11:00	444.23	831.24	31.28
11:10	454.67	888.85	120.61
11:20	439.11	888.85	148.7
11:40	444.23	999.19	90.3
11:50	470.82	1000.47	67.73
12:00	454.67	1116.11	50.97
12:10	454.67	1188.6	76.56
12:20	454.67	1181.18	49.61
12:30	459.98	1181.18	49.61
12:40	470.82	1177.37	40.84
12:50	454.67	1177.37	37.45
01:00	459.98	1177.35	45.7
01:10	454.67	1100.47	45.7

Table 1 Measurements of the 3 CO_2 monitoring sensors

According to the readings in Table 1, it is assumed that the measurement of the 1st sensor (2 m. distance) did not activate the extractors, because there were very few people in the podium, and everyone was wearing their mouth cover and respected the healthy distance. Not so with the 2nd sensor (4 m. distance) which did activate the exhaust fans because as time progressed the CO_2 levels exceeded 1000 ppm. While the readings of the 3rd sensor (6 m. distance), due to the distance of the cable which is not meshed, it is considered that there was much loss of information, assuming that these readings are even acceptable.

Understanding then that it is convenient to change all the cables for a meshed cable to have greater reliability in the data provided. Therefore, we consider that from the readings in Table 1 there is an error of 18% of these measurements, however, the readings of the first two sensors did provide the expected results for the protection of the attendees of the aforementioned event.

Conclusions

Currently, it is essential to keep work environments free from the possibility of contagion of coronavirus. Prevention is achieved with the sum and correct application of different strategies. Among them, the monitoring of CO_2 indoors, placing extractors or fans as a corrective action of SARS-CoV-2 contagion. This is a technological, avant-garde and economical way to keep healthy the population that needs to coexist for long periods of time inside closed buildings.

Thanks

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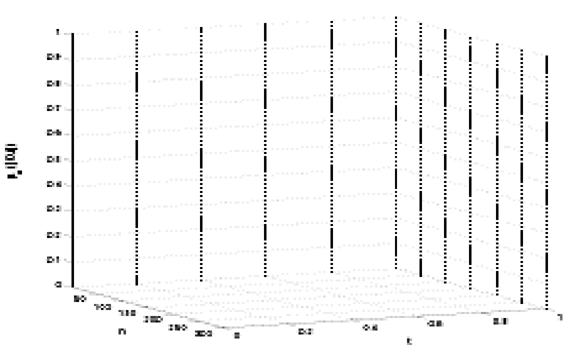

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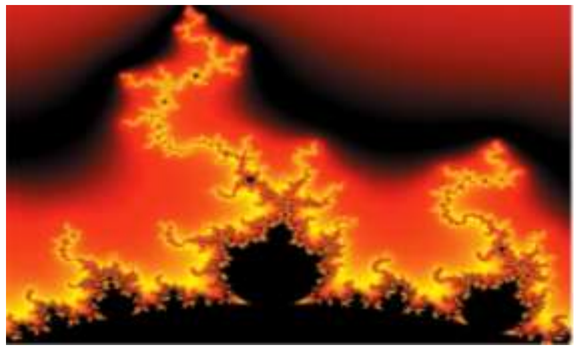

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