Energy Consumption Monitoring System (kWh) and Load Control Through Messaging Applications

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Abstract. In the city of Barranquilla (Colombia), the company that provides residential energy services uses analog meters to mea- sure energy consumption. These meters are not user friendly and keeping track of energy consumption based on their reading is a tedious task. In addition, it is not generally known how this energy consumption is calculated in money, especially considering that the calculation changes depending on the socioeconomic status of the user. For this reason, most users do not know how much they have consumed, nor the economic cost of the service, until they receive the bill. There are solutions that use the IoT and that offer the user a more accessible and easy way to keep track of energy consumption, but they do not offer an ac- curate representation of the monetary value of energy consumption, since they do not take into account the Colombian con- text. In this work, a solution that takes this into account is expo- sed. The PZEM-004T multiparameter meter and the PZCT-02 current sensor were used to measure energy consumption in a home. These are connected to a microcontroller with a Wi-Fi module, the NodeMCU ESP8266, which communicates with a Telegram application messaging bot for data visualization and user interaction. Through the messaging bot of the Telegram application, the user can set alarms, check in real time the estimate of their energy consumption and its monetary value, make adjustments to the parameters used to calculate the energy value, as well as exercise control of some of the loads that demand more power in the home. The result obtained by the developed system deviated by -1.37% with respect to the energy service provider's bill.

Keywords: Energy monitoring · Load control · Telegram · Messaging BOT

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1 Introduction

Using energy intelligently by reducing its consumption without decreasing the quality of life is a sign of energy efficiency. The consumption of energy is constant, applicable to commerce, industry, mining, means of transport, housing, etc. [1]. There are two types of energy, renewable energy sources such as wind, hydroelectric, oceanic and solar, which use resources that do not affect the environment. On the other hand, non-renewable energy sources are those that are consumed and depleted when transformed and exploited into useful energy. The most widely used sources are: oil, natural gas and carbon.

Energy consumption speaks of well-being and social growth, but the use of fossil resources brings with it a very high price to pay because the consumption of these resources generates a direct impact on the environment, "global warming". Such is the importance of achieving a rational consumption of energy, that the CIGEPI, of the Superintendence of Industry and Commerce of Colombia, publishes a technological bulletin for the measurement and management through the use of innovative techniques at a global level for this purpose [2]. Contributing to energy efficiency through responsible and well-informed decision-making are key actions for reducing dependence on energy purchases, building large and expensive production, transmission and distribution systems, reducing pressure on natural resources and, why not, making savings on consumers' pockets. In other words, responsible practices contribute to the reduction of greenhouse gases, which in the end is profitable and healthy.

The work carried out in this article makes extensive use of the so-called chatbots. Chat-bots or messenger bots are computer programs that process natural language as input and generate a response back to the user [11]. There are currently two kinds of bots: those that are operated by rule-driven engines or by artificial intelligence (AI). The difference is that the first responds to specific commands and the second uses machine learning to provide indicated answers and not pre-planned commands by the creator. In 2015 Telegram opened its bot API for developers to create their own bots offering a number of services. Shortly after, other big ones like Facebook followed, and since then the use of bots in messaging applications has grown exponentially.

The interaction between user and bot is mainly done through a text interface. It is well known that there are bots that recognize spoken language such as Siri, Alexa, and Google Home among others. These types of bots are based on technologies similar to that of voice assistants, which transform the voice into text so that the program can work with it. The advantage of using a text-based interface is that the user can express his intention using natural language. However, for the developer to transform the natural language into a code that the program can understand, it is very difficult, considering the countless possibilities that exist. This brings the difficulty for the user that not all their queries can be answered. For this reason, elements such as buttons, quick-replies, carousels, web-views, among others were introduced, so that the bot could show certain types of data to the user and the user could reply to the bot with just one touch [10]. The bot turns out to be, in simple words, the interface between the user and the hardware as shown in Fig. 1.



Fig. 1. Interaction between users – hardware through bot.

2 Related Works

It is essential to promote processes educational practices that allow the implementation of responsible consumption practices, such as: washing clothes with full charge and with cold water, disconnecting electrical appliances that are not operational; being perhaps at night the most critical hours; plan-char minimally, changing habits when selecting devices with category A or B, are basic practices that transform the place where they are implemented into sustainable areas. There is a wide variety of instruments for measuring electricity consumption, but some innovative applications and systems propose models that integrate measurement, control application, use of industrial communication networks, cost projections and integration into robust data transmission systems, among others [3].

These processes have as a fundamental parameter or main variable the energy consumption of households and buildings in general, and are projected as a tool for optimizing energy consumption [4]. Before the widespread diffusion of the IoT, monitoring systems were carried out that were directly connected to a PC to which the measured data was directly projected, using protocols such as USB, although the acquisition and deployment devices were connected via Wi-Fi [3]. With the advent of IoT and cloud computing-based applications, energy monitoring systems migrated to this field [5]. In [6] an energy monitoring system is presented with a similar objective to that developed in this article, in which the energy consumption of the users is calculated and the tariff that they would have to pay during the month consumed is presented to them. For this purpose, they make use of the current sensor ASC712 that works with Hall effect, the microcontroller Atmega328, and develop a mobile application that must be installed on the smartphone to be able to visualize the information that is received via Bluetooth. Thus, the user must first pair his mobile phone with the monitoring device in order to have access to the energy consumption data. The calculation of the consumption and the tariff is made by the implementation of algorithms that are programmed in the microcontroller. The mobile application is for visualization purposes only.

In [7] a system is exposed which seeks to encourage good practices of energy consumption in households by monitoring this. For this purpose, the main wiring of the home is divided into three zones which are individually monitored using two sensors, the SCT-013–000 for currents between 1 - 100A and the ACS712-20A for currents below 20A. This system does not consider the variations of the supply voltage, considering it constant, just as it only allows the local visualization of the information. In [8] the aim is to implement a monitoring system of energy consumption for households and at the same time to promote good consumption practices that allow people to know the negative effects on the environment. This process is carried out through simulations where are indicated what are the benefits that are obtained by controlling the consumption of

energy. This system is able to send information such as: voltage, current, power, and additionally the values of temperature and humidity that could serve for control of heaters or air conditioners based on the area of influence, however, does not provide information on the monetary value of energy consumption. On the other hand [9] implements a load control system through Telegram for the control of different devices in a dwelling.

The project uses an ESP8266 NodeMCU, an ACS712 current sensor and three relays as actuators. This work performs control functions through a messenger bot and uses an ACS712 current sensor to confirm the current flow to the device to which it is connected, but not with the intention of monitoring the energy consumption. In [10] we present the development of a residential energy monitoring system based also on the ACS712 current sensor, which, by means of an ESP8266 NodeMCU and an Arduino Uno module, sends the data to a Web server using the HTTP protocol and to a mobile application developed to be installed on the user's smartphone. It is an IoT solution supported by the technology of Google Cloud and Database whose communication is supported by the IoT Gateway Thingspeak. The mobile application of the user not only allows the monitoring and monitoring of energy consumption, but also has the possibility of carrying out load control.

3 Design of the System

The overall design of the system is dealt with in three stages, which are described below.

3.1 Stage 1. Design of Basic Functions

In this stage the structure of the NodeMCU programming was carried out, besides the connections in the physical part of the prototype were established. It was possible to establish the implementation of basic functions of the project, including communication with the Pzem-004t analyzer, the parameters for calculating the energy values, communication with the NTP and protection of sensitive information in the EEPROM. In the physical part, the connections of the module PZEM-004t, current sensor PCZT-02 and NodeMCU were realized, as well as the installation of the assembly of these to the home electrical network. At this stage only one sensor operated in the prototype, the collected and processed data were transmitted via serial communication and could be analyzed with the help of Arduino IDE software, where the first quality estimates of the measurements were analyzed and established. The architecture of stage 1 can be seen in Fig. 2.

3.2 Stage 2. Design of the Monitoring System

In stage 2 it was possible to implement messaging bots that allowed to perform different processes among them to establish the connection with the NodeMCU. This action makes it easier to send a data or signal to the microcontroller, which receives, processes and implements an action according to the instruction, and additionally stores the data in the EEPROM to preserve the established configuration. Another of the characteristics of stage 2 is the implementation of alerts (exceeding the established threshold), the sending

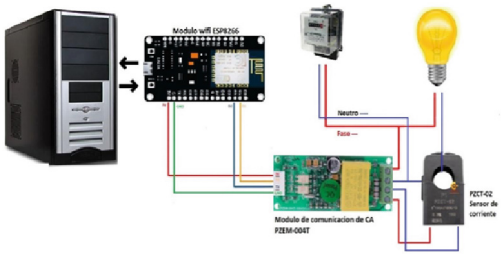

Fig. 2. Architecture of the basic functions stage.

of daily messages with the value for consumption of the last 24 h, as well as the ability of the bot to identify the types of characters received (text or number) and answer if the type of character is valid or invalid.

It was possible to structure the state machine that would allow access to the different instruction blocks or options of the prototype, among the most important are: States, Monitoring and Configuration. The structure of the status machine allows to see the information in an orderly way and to access the options via direct commands or routes established in the options tree, as can be seen in Fig. 3.

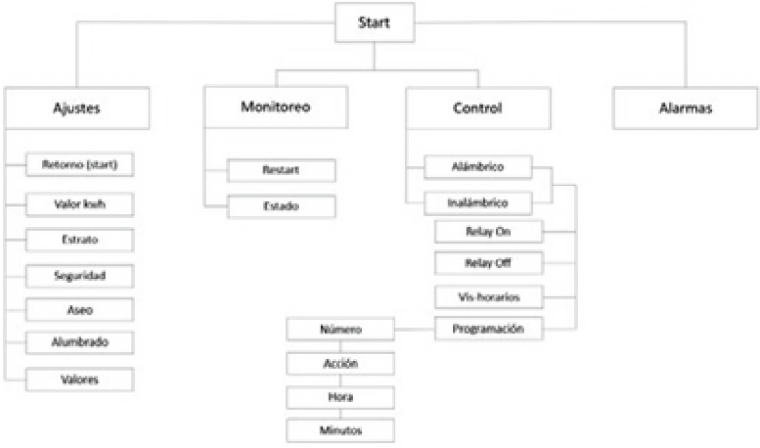

Fig. 3. Tree of options.

When one of the commands is selected, the parameters of the measurement delivered by the current sensor are displayed and it is possible to set configurations through messages containing the novelties or values processed by the microcontroller. Figure 4 shows the architecture of the monitoring stage.

3.3 Stage 3. Implementation of Load Control

For stage 3, load control was implemented. Two alternatives were implemented for this control. The first consists of a relay connected to the NodeMCU through one of the output

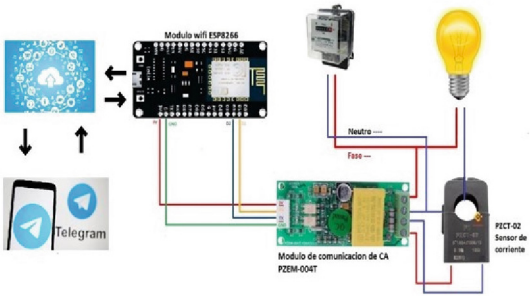

Fig. 4. Architecture of the monitoring stage.

pins and the second system through the ESP8266 Relay. The control of both systems is done through Telegram by commands to the messenger bot. The commands allow switching on/off the relay and setting of On-Off activation times for the relay. Figure 5 shows the overall system architecture. For stage 3, load control was implemented. Two alternatives were implemented for this control. The first consists of a relay connected to the NodeMCU through one of the output pins and the second system through the ESP8266 Relay. The control of both systems is done through Telegram by commands to the messenger bot. The commands allow switching on/off the relay and setting of On-Off activation times for the relay. Figure 5 shows the overall system architecture.

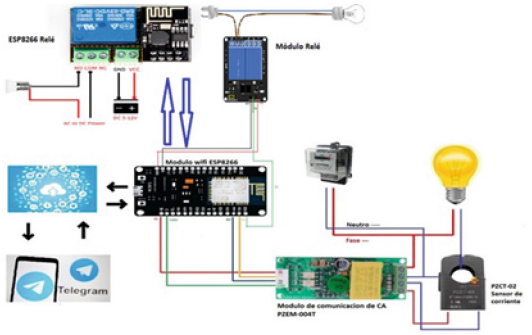

Fig. 5. General architecture of the system.

4 Implementation of the System

4.1 Calculation of the Value of Energy Consumption

In Colombia, payment for the consumption of residential public services, such as energy, is based on a system of charges for differential rates. These rates are associated to the socioeconomic stratum to which the residential property belongs. In this way, housing belonging to socio-economic strata, considered to be of lower resources, may receive

subsidies and other assistance from the state. The tariffs of the domestic public service of electric energy in Colombia are established through Resolution CREG 079 of 1997, in Table 1 of tariff charges, it is possible to appreciate the system of calculation to be considered by the CREG (Commission of Regulation of Energy and Gas of Colombia) to establish the invoicing values. For its part, Table 2 shows the socioeconomic strata in Colombia and the subsidies corresponding to each of them.

Table 1. Tariff charges of the energy service in Colombia.

Tariff	=	Value
Tariff strata 1, 2 and 3	=	CU – Subsidy Tariff
Strata 4 and Officer	=	CU
Tariff strata 5, 6 and industrial	=	CU + Contribution

Table 2. Strata and subsidies for the charging of the energy service in Colombia.

Strata	Subsidies
1	50%
2	40%
3	15%
4	0%
5,6	Industry, 20% contribution

Figure 6 shows the flow diagram for the calculation of the estimation of the value of the energy bill. The values of Toilet, Lighting and Security are fixed values charged by the company that supplies the energy service.

4.2 Assembly

The functioning of the developed system was checked and validated, installing it in the main connection of electric power supply of a residence in the city of Barranquilla, stratum 5. Figure 7 shows the picture of the installed system and the names of its listed parts:

1. Current sensor PCZT-002.
2. Main impact (neutral).
3. Main task (1st phase).
4. Main task (2nd phase).
5. Multifunction meter PZEM-004T.
6. Microcontroller Node MCU ESP8266.

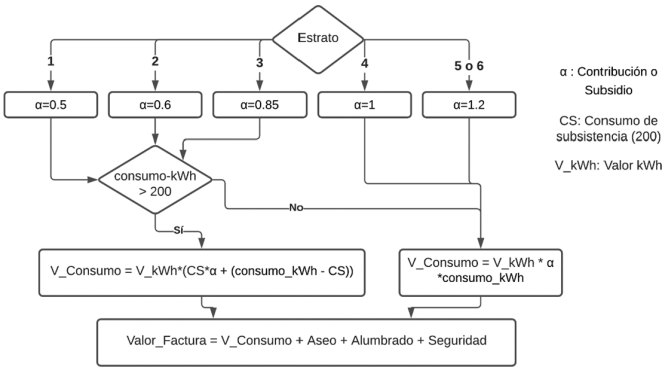

Fig. 6. Flow diagram for the calculation of the estimation of the value of the energy bill.

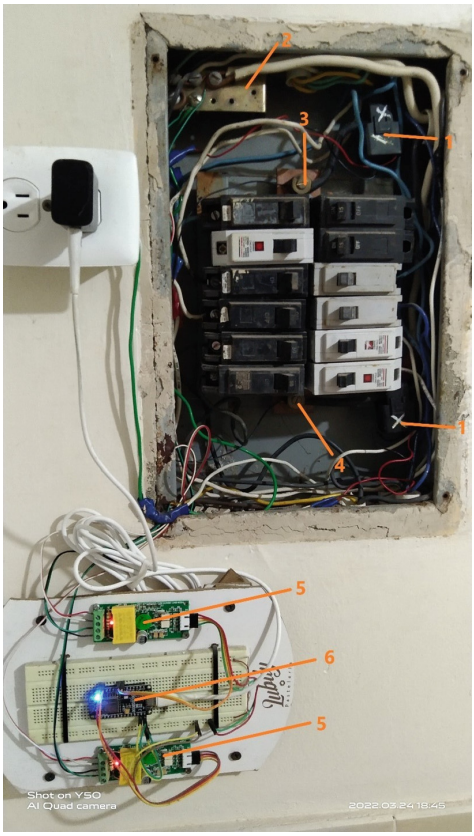

Fig. 7. Installed system and its parts listed.

5 Results

Before exposing the results obtained, we show the answers associated with the implementation of the parameters, technical specifications, operating characteristics and control processes from a computer with internet access, through the Telegram bot and directed to the NodeMCU. Next, in Fig. 8 (Selection Start, Access to the bot) it is observed how it is possible to access the initial menu of the options tree and the submenus that are in it.

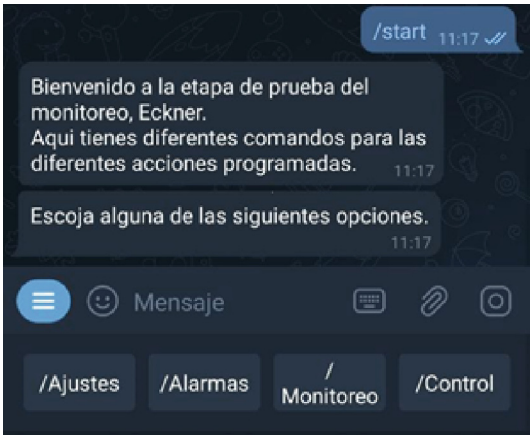

Fig. 8. Access to Telegram bot with/Start.

One of the sub-menus is that of Settings through which you can access the tab of attributes or configuration values, where it is possible to enter the values of stratum, toilet, security, illumination and value of Kwh. This can be seen in Fig. 9. It is noteworthy that the values obtained for the different results were collected during the months in which this project was developed, and therefore the value per kWh used by the prototype to calculate the estimation of the cost of energy consumption may vary between the different results, since this value changes month to month.

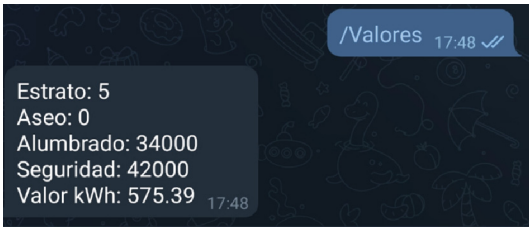

Fig. 9. Values required to calculate the energy bill.

The implementation of the Telegram App allowed, through the bot, to weave the bridge between the user and the prototype, and thus, in a simple way to access the

features of programming, data request and control of the associated devices. Later it will be appreciated how the final implementation of the prototype allowed the day-to-day verifications of the costs per consumption, i.e. the total invoiced at the date of consultation. Another function of the prototype is to alert when the consumption in weights exceeds a threshold programmed by the user. To set this threshold, the user sends the command /Alarms, to which the bot responds and the user enters the desired threshold, as shown in Fig. 10 and Fig. 11.

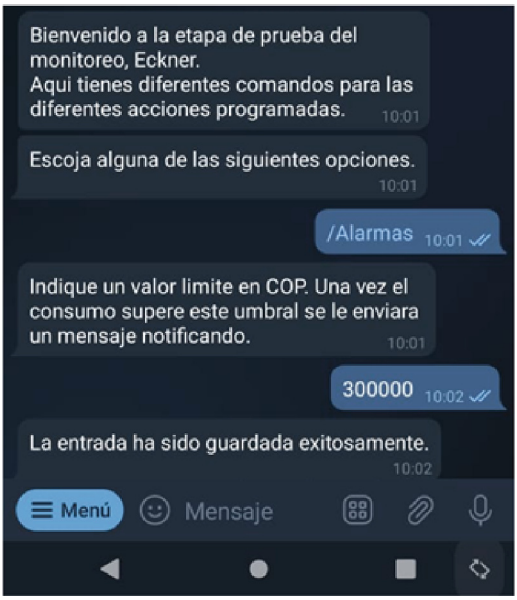

Fig. 10. Threshold programming.

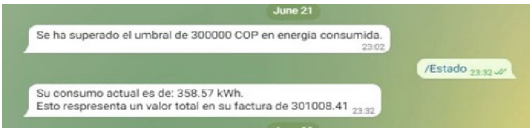

Fig. 11. Threshold crossing message.

By means of the command /Status located in the submenu´ Monitoring, as can be seen in Fig. 12, the consumption and an approximation of the invoiced value are evidenced, based on what was measured by the prototype. This value will be contrasted with that invoiced by the company providing the service in Barranquilla (Colombia) to calculate the variation or deviation of the measurements of the equipment under test.

The prototype sends a daily message with the measured consumption and its approximate value every 24 hours, as shown in Fig. 13.

Figure 14 shows the values collected during 8 days, the days the measurements were made and the differences in consumption of one day with respect to the previous one.

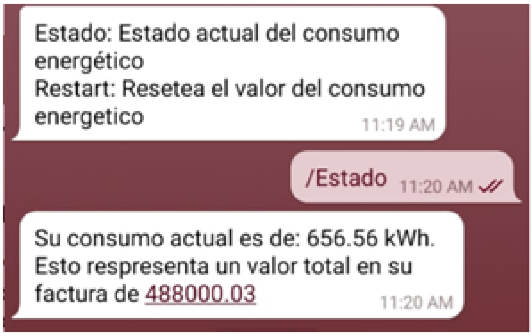

Fig. 12. Request of State (Partial Invoiced Value).

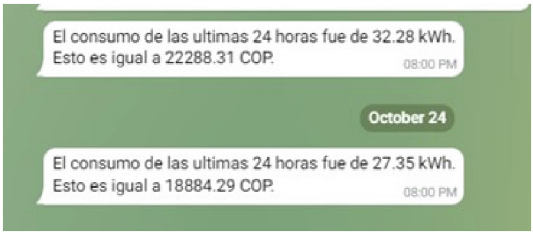

Fig. 13. Daily message of measured consumption.

The collected values were saved in a photographic record for later comparison with the measurement delivered by the prototype. It should be noted that the meter readings were taken visually on an analogue device and rounded to the most visible unit, so that errors of a few tenths of kWh will occur. The time difference between the respective measurements and photos is only a few minutes and does not significantly affect the result. The figure checks the precision of the prototype.

Subtracting the value of day 10 with that of day 17 of the results obtained through Telegram, we get 258.98 kWh. This gives a difference from the total measured by the meter of -3.02 kWh, which represents deviation from -1.15 % with respect to the accumulated household meter. It is clarified that the dates of the measurements are known, but the exact time of the measurements is not known; it is to be expected that there will be a variation in the final result, which will be taken into account when evaluating all the data collected.

The estimated value on December 9, 2021 obtained by the prototype reaches a value of $655,523.63 (six hundred and fifty-five thousand five hundred and twenty-three pesos with 63 cents), i.e. a consumption of 839.32 kWh; while the value invoiced by the provider reaches a value of $681350.0 (six hundred and eighty-one thousand three hundred and fifty pesos), the value payable, month of consumption November for a consumption of 851 kWh. Consumption in kilowatts obtaining a difference of -11.68kWh with that of the prototype. For a greater fidelity of the estimation made by the prototype, an attempt was made to restart the accumulated and take the consumption

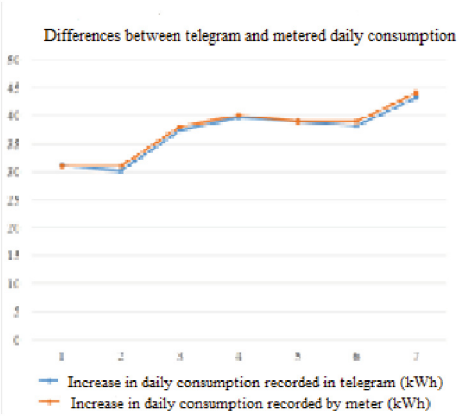

Fig. 14. Request of State (total value invoiced November).

measure at the same time as the service provider carried out the readings. In the first case the difference was a couple of hours and in the second case the proposed was achieved.

Finally, Table 3 invoicing and difference shows the value of the invoice, the value accumulated by the analyzer, the costs invoiced by the service provider and by the meter, as well as the final difference of both measurements.

Table 3. Invoicing by energetic meter and difference with measure of the prototype.

Billed accountant	851.00 kWh	$681,350.00
Prototype measurement	839.32 kWh	$655,523.63
Difference	11.68 kWh	$25,826.37

The difference could well be associated with the time difference of the reset time of the sensor PZEM-004T and the time of the reading of the service provider, as well as with the associated losses in the measurement systems, which could be the object of study later. The deviation between the measurement of the prototype with respect to that of the counter is -1.37 %, which is consistent with the interpretation made of the values in Table 3. The main reason for the difference between the calculated values and the actual value is the change in cost per kWh. The reference value taken is 575.39 COPs and between November and December the value increased to 592.79 COPs. The incremental difference of the reference kWh values is multiplied by 1.2 because the residence where the device is installed belongs to stratum 5.

$$1{,}2 \times (592{,}79 - 575{,}39) \times 839{,}32 = 17{,}52 \tag{1}$$

$$655523{,}63 + 17525 = 673048{,}63\,\text{COP} \tag{2}$$

This results in a difference of 8.265.37 COP between the invoice and the prototype estimate.

As for the control part, in order to be able to operate the different commands, first choose the relay with which you want to interact. If a relay is not selected, the bot will respond with an error message.

To program the routines, you must send the command /prog routines to which the BOT will respond asking the routine to modify, the action to perform and the time. To activate the routine, the command /vis times must be sent where the times of the routines will appear and if they are activated (A) or deactivated (D).

6 Conclusions

For The installation of the prototype at the main power outlet of the home for the measurement of energy consumption became successful and quickly. Mainly because the installation of the sensors was made easier, because they are non-invasive sensors. In the same way the creation of the messaging bot in the Telegram application for sending commands and receiving messages from the prototype was done successfully. The results in the monitoring part showed the precision of the prototype to measure energy consumption, having a difference of 11.68 kWh, which represents an error of -1.37%, with respect to the home meter. The difference of 25,826 COP between the estimated cost and the cost on the invoice lies primarily in the difference in the kWh value. Little can be done here, since the estimates are made with the kWh value of the previous invoice and there is no way to check the new kWh value until the new invoice is received. The aim was to show the accumulated energy consumption and the estimation of the value to be paid in real time as well as to send alarm messages through the Telegram application. The control of the status of the wire and wireless relays was achieved using the Telegram application. In addition, it was achieved the establishment of up to three times to automatically put the respective relay in the programmed state. It is noteworthy that the command tree was made with the intention of being intuitive for the user, however, the monitoring commands can be executed in any order, unlike the control part where you must first choose the relay to control before executing the different commands. As aspects to be improved and to extend the functions of this project, it would be interesting to implement a function that allows adding and removing devices in the control part. Also the implementation of routines where the user can add the available devices and program an action, making the project more dynamic and similar to the systems found today on the market. Moreover, as mentioned earlier, this project does not show the history of consumption. One could implement the use of a server where this data is sent, as was done by other projects mentioned in the background section, or establish a range of days that allows the information to be stored in the EEPROM of the microcontroller, or also the use of external memories.

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