UNIVERSIDAD SAN FRANCISCO DE QUITO USFQ

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An Embedded System Prototype for Non-Intrusive Load Monitoring

Artículo Académico

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Ingeniería Electrónica

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An Embedded System Prototype for Non-Intrusive Load Monitoring

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RESUMEN

El monitoreo de cargas es importante para soluciones de administración de energía eléctrica, permitiendo obtener estadísticas de consumo de energía específicas de un dispositivo que pueden ser usadas para trazar métodos de programación, para el óptimo consumo de la energía. Un Sistema de Monitoreo de Cargas no Intrusivo (NILM) es un proceso de reconocimiento de dispositivos eléctricos y su consumo energético, en base a señales eléctricas domiciliares que se adquieren empleando únicamente un sensor de corriente, desde un punto de medición que se instala en la entrada de la energía de un sistema eléctrico. En este estudio se diseñó un algoritmo capaz de reconocer cargas eléctricas de una zona de una edificación residencial, por medio de un procesamiento de información que proviene del sensor y un entrenamiento que se respalda en una base de datos de un servidor web; métodos que se realizan con el microcontrolador Raspberry Pi 3.
Palabras clave: Aprendizaje supervisado, aprendizaje sin supervisión, algoritmo de aprendizaje automático, medidor inteligente, sistema embebido, Raspberry Pi 3, NILM, ILM

ABSTRACT

Load monitoring is important for electrical power management solutions, allowing for specific energy consumption statistics of a device to trace programming methods, for optimal energy consumption. A Non-Intrusive Loads Monitoring System (NILM) is a process of recognition of electrical devices and their energy consumption, based on household electrical signals that are acquired using only a one current sensor, from a measurement point that is installed in the input of the energy of an electrical system. In this study, an algorithm was designed to recognize electrical charges from an area of a residential building, through information processing that comes from the sensor and a training that is supported by a database of a web server; methods that are carried out with the Raspberry Pi 3 microcontroller.

Key words: supervised learning, unsupervised learning, machine learning algorithms, smart meter, Embedded Systems, Raspberry Pi 3, NILM, ILM.

TABLA DE CONTENIDO

An Embedded System Prototype for Non-Intrusive Load Monitoring

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***Abstract*—Load monitoring is important for electrical power management solutions, allowing for specific energy consumption statistics of a device to trace programming methods, for optimal energy consumption. A Non-Intrusive Loads Monitoring System (NILM) is a process of recognition of electrical devices and their energy consumption, based on household electrical signals that are acquired using only a one current sensor, from a measurement point that is installed in the input of the energy of an electrical system. In this study, an algorithm was designed to recognize electrical charges from an area of a residential building, through information processing that comes from the sensor and a training that is supported by a database of a web server; methods that are carried out with the Raspberry Pi 3 microcontroller.**

***Keywords*—NILM; ILM; supervised learning; unsupervised learning; self-sensing; sensors; machine learning algorithms, smart meter; Raspberry Pi; Embedded Systems**

I. INTRODUCTION

Currently the conservation of energy is a priority and a challenging problem given the exponential increase in energy demand. A reduction in waste of energy can be achieved by means of a detailed control of energy consumption and the communication of this information with consumers [1]. Taking this into account, it is necessary to implement smart meters in a residential environment; however, traditional smart meters only measure energy consumption data with little detail [1]. To implement a precise information functionality, there are two main approaches, which are intrusive load monitoring (ILM) and non-intrusive load monitoring (NILM) [1], the latter being the one chosen for the present study.

The non-intrusive charge monitoring system measures the energy consumption without the need to place an instrument directly to the devices, which means a reduction of costs in sensors and installations. It is possible to realize adequate energy consumption by improving energy management and real-time information on household appliances in buildings [1]. Hart [2] proposed a method to analyze electrical charges by examining only the device’s specific energy consumption signatures, the data being obtained from the main electrical panel of the residence in a non-intrusive manner.

For the acquisition of energy consumption information, a current sensor SCT-013-100 was used, capable of measuring currents up to 100 amperes. This sensor sends the measurements to an Arduino Uno, which in turn allows converting the sensor’s analog signal to a digital signal to be processed by the Raspberry Pi. In this way, after taking a measurement the data will be processed by means of an algorithm in Python, which stores and compares the values of the loads for their subsequent identification and analysis.

II. METHODS

A. Data acquisition

The data acquisition was done using the sensor SCT-013-100, which works as a transformer so that the current that passes through the cable to be measured acts as a primary winding, and internally the sensor has a secondary winding that can have up to more than 2000 turns [3]. This sensor is able to detect a maximum current value of 100 A having 50 mA output, with a $100A/50mA$ ratio [4] and additionally a load resistance can be placed in the output to work with an output of tension. This type of sensors is known as CT Sensors (Current Transformer), since they act as a transformer [3].

Since the sensor has an output of $50mA\ to\ +50mA$, it is necessary to rectify the input to work with the positive part, assuming that the signal is symmetric; for this purpose, diodes cannot be used in rectification because the voltage drop is greater in relation to the voltage of the signal. Therefore, an operational LM358 is used in the configuration of voltage follower, in this way it works with positive polarity eliminating the negative part of the signal. Although it is not a full wave rectifier, it is possible to work with a half wave rectification. As indicated above, to obtain a voltage output it is necessary to place a load resistance to achieve a range of 1V, so that $50mA \times 20\Omega = 1V$. The design of the sensor conditioning configuration is shown in the figure 1 and the wiring schema in the figure 2.

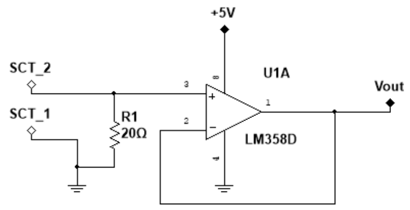

Fig. 1. Schematic of SCT sensor conditioning circuit

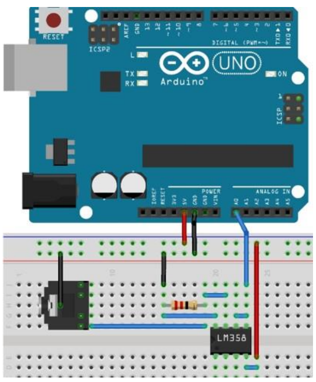

Fig. 2. Wiring Schema

The sensor readings are made with the analog input of Arduino, to then scale the values to voltage and then obtain the current with the *current/voltage ratio*. The LM358 device is saturated with approximately $3.5V$ if it is powered with $5V$, so the $1.1V$ Arduino internal reference was used.

Then, to calculate the RMS is used the formula 1.

$$i = \sqrt{\frac{1}{T}\int_0^T i^2 dt} \quad (1)$$

And in discrete time it would be:

$$i = \sqrt{\frac{1}{N}\sum_{n=0}^{N} i_n^2} \quad (2)$$

Where N is the number of samples in a period.

Therefore, the resulting code is:

```
void setup()
{
  Serial.begin(9600);
  analogReference(INTERNAL);
}

void loop()
{
  float Irms=get_corriente(); //Corriente eficaz (A)
  Serial.println(Irms,4);
  delay(100);
}

float get_corriente()
{
  float voltajeSensor;
  float corriente=0;
  float Sumatoria=0;
  long tiempo=millis();
  int N=0;
  while(millis()-tiempo<500)//Duración 0.5 segundos(Aprox. 30 ciclos de 60Hz)
  {
    voltajeSensor = analogRead(A0) * (0.0510 / 1023.0);////voltaje del sensor
    corriente=voltajeSensor*100/0.05; //corriente=VoltajeSensor*(100A/5mA)
    Sumatoria=Sumatoria+sq(corriente);//Sumatoria de Cuadrados
    N=N+1;
    delay(1);
  }
  Sumatoria=Sumatoria*2;//Para compensar los cuadrados de los semiciclos negativos.
  corriente=sqrt((Sumatoria)/N); //ecuación del RMS
  return(corriente);
}
```

Fig. 3. Data Acquisition Algorithm of SCT Sensor in Arduino

Finally, the value of the sum is doubled to compensate for the negative half cycle that was canceled in the half-wave rectification. The sampling time for the calculation of the RMS must be a multiple of the period, so it took 500*ms* representing 30 cycles of a 60 Hz signal. After reading the current, this value is transmitted by the Serial port to the Raspberry for analysis.

B. Data processing

1) Create Web Server: To create a database to store the current values recognized by the developed algorithm, a web server must first be created with a static IP assigned to the microcontroller. Next, the server that is going to be used is called LAMP, acronym of the tools to be used: Linux, Apache, MySQL and PHP [5]. Since the operating system in which Raspberry operates is Raspbian Linux, you must update the repositories and programs, such as Apache.

2) Non-Intrusive System Program: The main method of the algorithm is represented in the following block diagram:

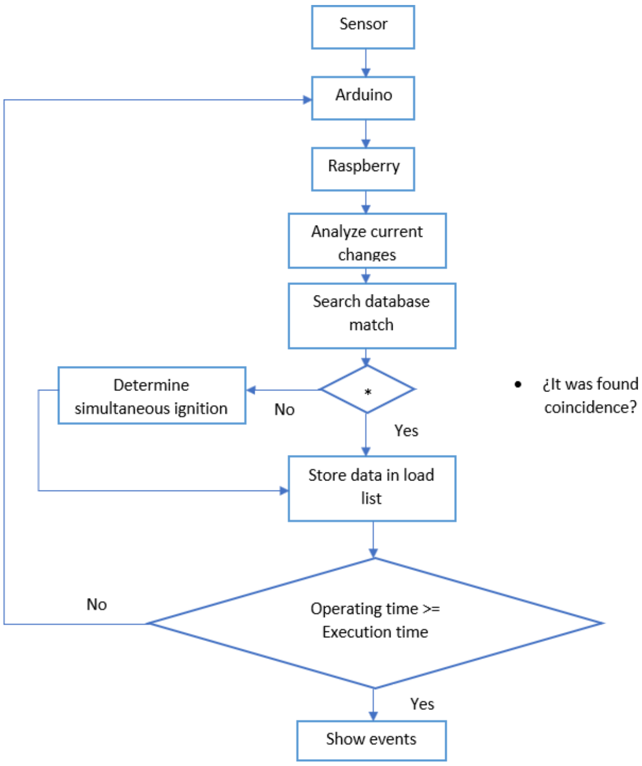

Fig. 4. Block diagram

Initially, measurements are acquired with the sensor and the RMS current is obtained in Arduino. Then the data is sent to Raspberry to analyze the current changes. Then, we search for matches in the database, if we obtain a match, these values are stored in the load list, if a match is not obtained, we proceed to determine the simultaneous ignition and in the same way, to store this data in the loading list. Subsequently, it is checked if the operating time is greater than or equal to the execution time, if it is affirmative it shows the recorded events; otherwise, the process is repeated taking data from the sensor.

Therefore, the operation of the program is as follows:

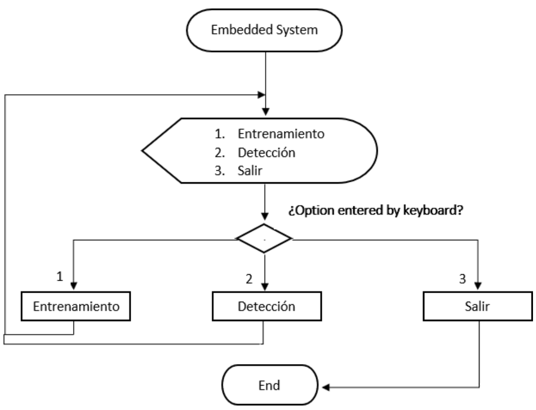

Fig. 5. System flow diagram

As can be seen in Figure 5, 3 options are displayed on the screen for the user to choose, with these options being the training and detection mode. The training mode, in the same way, shows the user 4 options to choose from such as Agregar, Eliminar, Ver and Medir. The Agregar option allows you to add data to the database by entering the value and name of the device to be added. The Eliminar option displays the elements in the database and then asks the user to enter the device number to be deleted. The option Ver shows the user the screen elements on the database. This process is observed in figure 6.

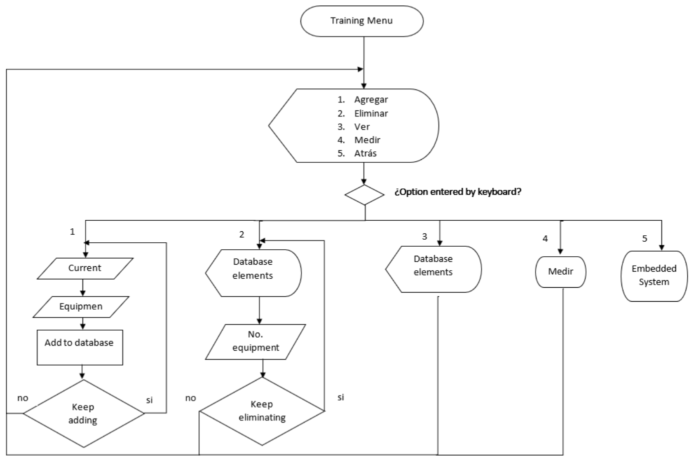

Fig. 6. Training menu flow diagram

The option to measure initially connects with Arduino, then the user is asked to enter the operating time of the program. Then, an Arduino reading is made to record the measured value, then another Arduino reading is made, and the registered value and the measured value are compared. If a current increase or decrease is not determined, we proceed to determine if the operating time is greater than or equal to the execution time to show the recorded events or again perform the described process from performing the Arduino readings. If a current increase or decrease determines a match search in the database, if there is a match, the data is recorded in the list of loads on or off; Otherwise it is determined if it was a simultaneous ignition of two or more charges, if a negative response is obtained, this information is registered in the list of new devices. Afterwards, it is determined if it was a power on or off, if it was turned on, the data is registered in the corresponding load list or if a shutdown is determined it is identified that the load was turned off. After this, the operating time is compared with the execution time to show the recorded events or again to repeat the process of analyzing the data obtained. This described process is shown in the flow diagram of Figure 7.

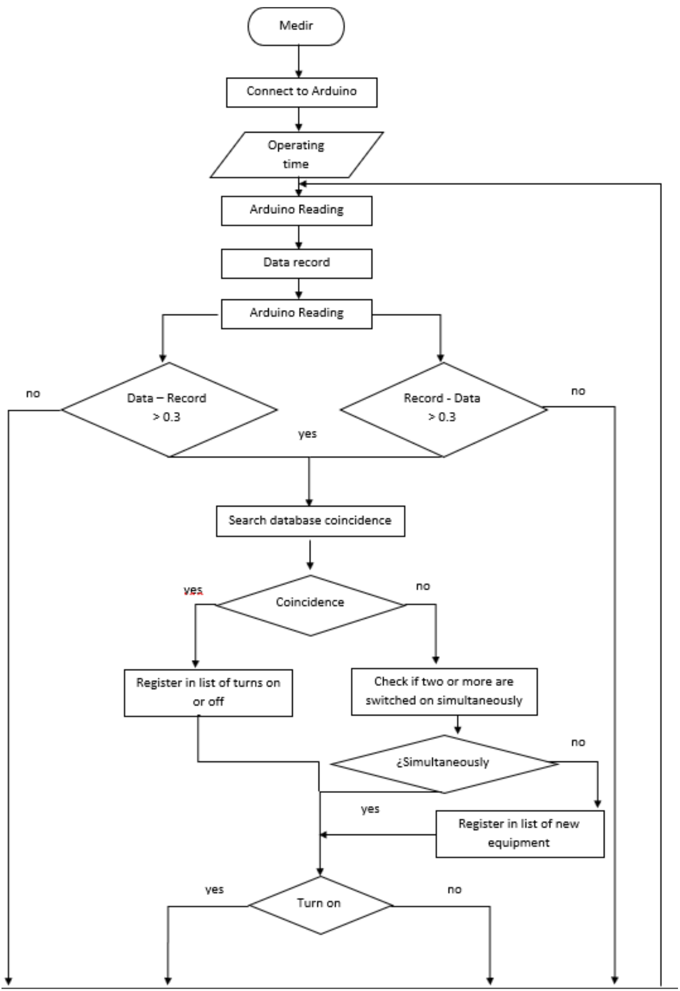

Fig. 7. Training menu flow diagram

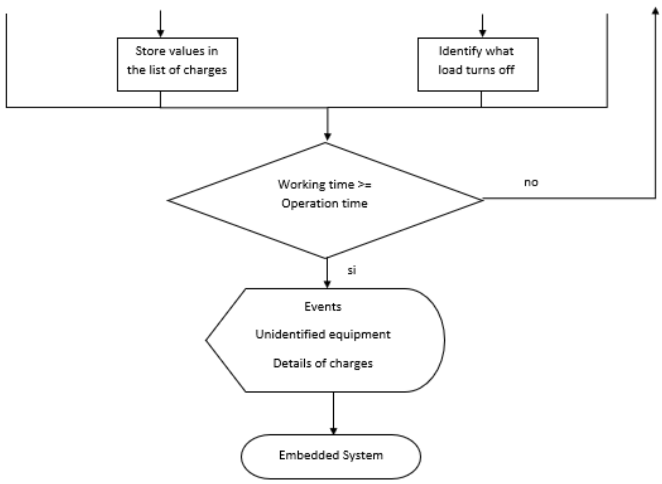

Fig. 8. Training menu flow diagram

The Detectar option is similar to the option to measure, it only changes that the execution time is defined by placing a time of 86400 seconds, corresponding to 24 hours.

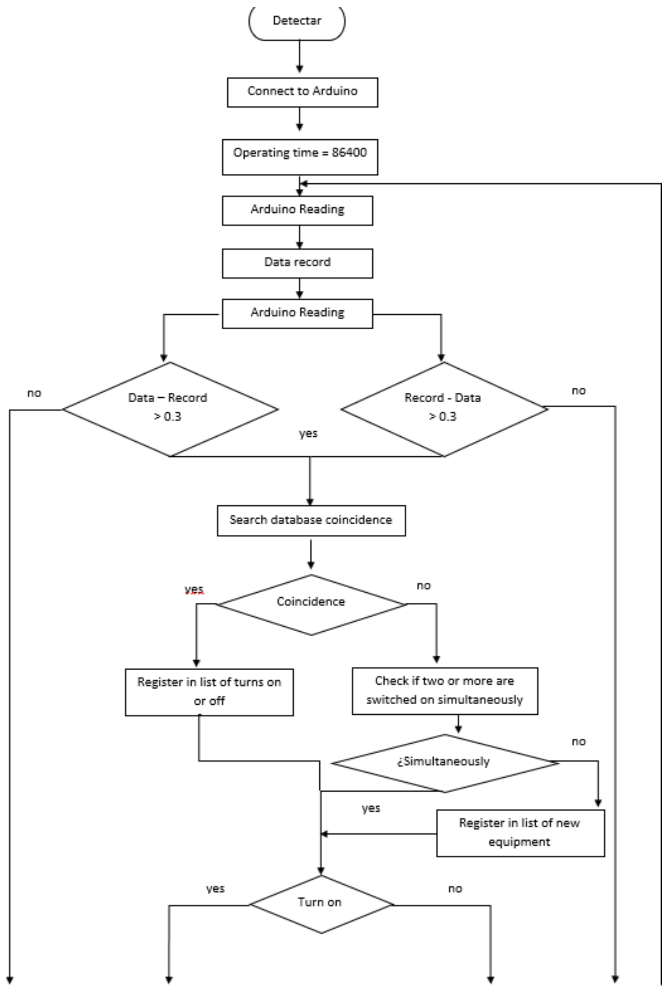

Fig. 9. Training menu flow diagram

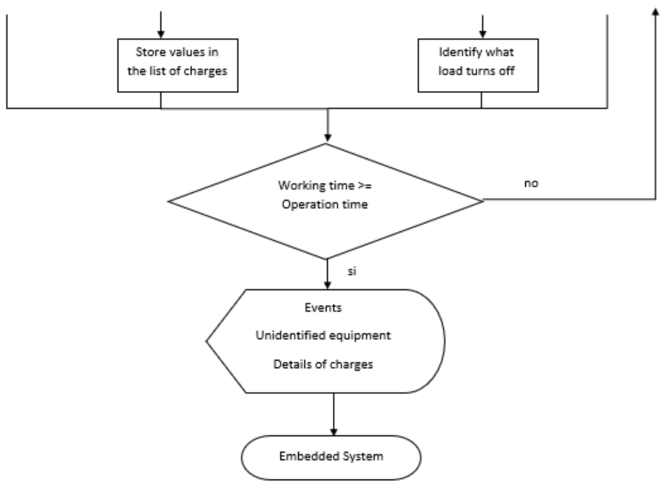

Fig. 10. Training menu flow diagram

C. Results

The armed prototype can be seen in figure 11, connecting the conditioning circuit to Arduino and in turn connected to

Raspberry, additionally a screen was placed to Raspberry to be able to visualize the interface and data of the program.

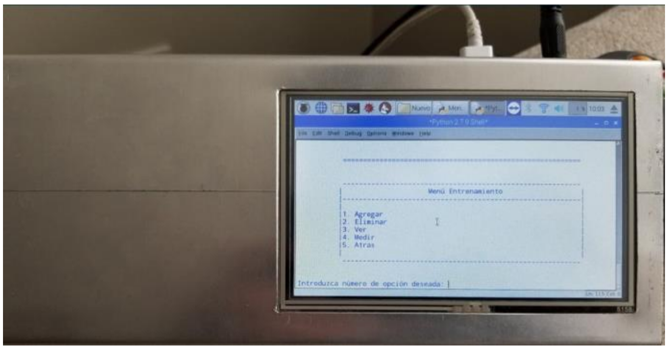

Fig. 11. Prototype

For the tests, the following equipment was used:

- Calefactor Sutex.
- Licuadora Osterizer.
- Televisor Digital Sony Bravia.
- Plancha de vapor para ropa.
- Extractor de frutas Homissi

The detection of these devices is reflected in the following figures, where a device is identified with the current change, whether it is turned on or off.

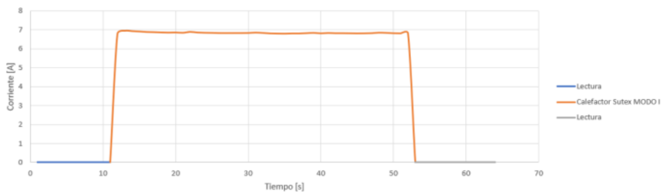

Fig. 12. Waveform Calefactor Sutex MODO I

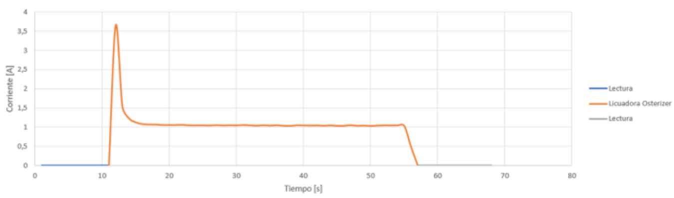

Fig. 13. Waveform Licuadora Osterizer

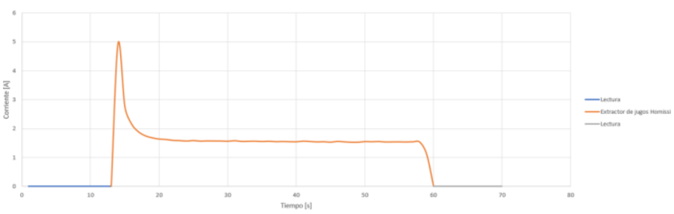

Fig. 14. Waveform Extractor de Jugos Homissi

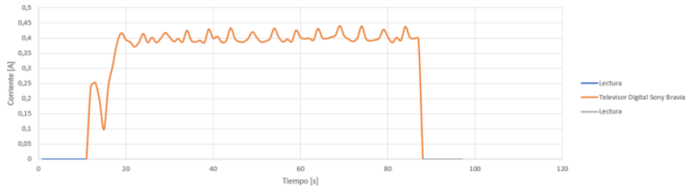

Fig. 15. Waveform Televisor Digital Sony Bravia

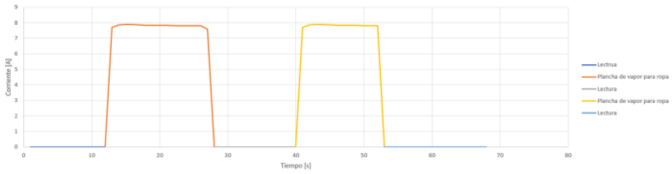

Fig. 16. Waveform Plancha de vapor para ropa

Next, the ignition recognition of two loads is detected sequentially, and the shutdown of these:

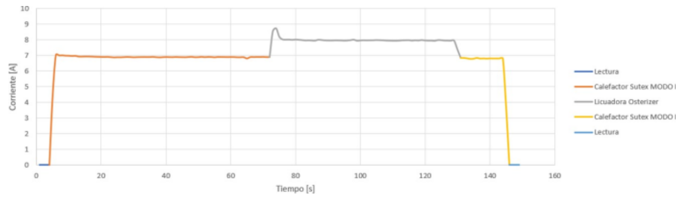

Fig. 17. Waveform two equipments

As shown in the previous figure, the recognition happens when there is a change of current, either an increase to determine the ignition of a device or decrease to determine the shutdown of a device. For the storage of these values, the data is saved from the moment in which the device is in a stable state until another device is switched on, since the average of the data stored is calculated and this value is saved in order to register the value of the new device, so that the obtained data subtracts the average of the load that was previously turned on and the current value of the new device is obtained.

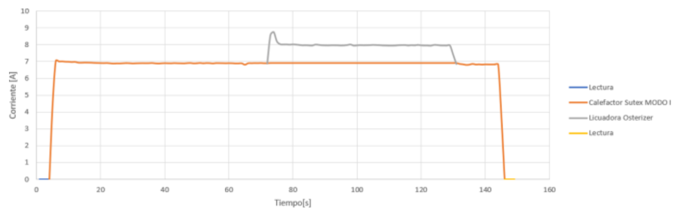

Fig. 18. Data storage waveform of two devices

The same happens in the case that three or more equipment are lit sequentially, where the on and off of these is determined based on the current changes. In the same way, to store the data we obtain the average of the stored values to obtain the value of the last device that is turned on. This can be seen in figures 19 and 20.

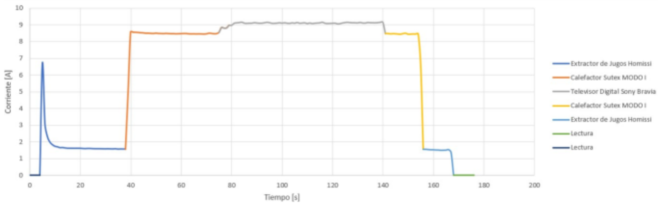

Fig. 19. Waveform three equipments

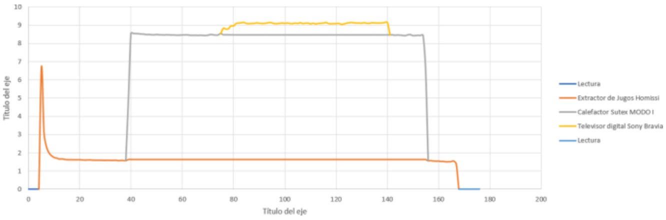

Fig. 20. Data storage waveform of three devices

Finally, the confusion matrix was used to determine the accuracy and error rate of the developed algorithm.

		Mediciones									
		Calefactor Sutex MODO I ON	Calefactor Sutex MODO I OFF	Licuadora Osterizer ON	Licuadora Osterizer OFF	Extractor de Jugos Homisster ON	Extractor de Jugos Homisster OFF	Televisor digital Sony Bravia ON	Televisor digital Sony Bravia OFF	Plancha de vapor para ropa ON	Plancha de vapor para ropa OFF
Observación	Calefactor Sutex MODO I ON	10	0								
	Calefactor Sutex MODO I OFF	0	10								
	Licuadora Osterizer ON			7	2						
	Licuadora Osterizer OFF			1	7						
	Extractor de Jugos Homisster ON					8	1				
	Extractor de Jugos Homisster OFF					1	7				
	Televisor digital Sony Bravia ON							10	0		
	Televisor digital Sony Bravia OFF							3	6		
	Plancha de vapor para ropa ON									10	0
	Plancha de vapor para ropa OFF									1	9

Fig. 21. Confusion matrix

With this, you get a value of 45 positive True, 39 true negative, 6 false positive and 3 false negative, giving a total of 93. To calculate the accuracy, the formula was used:

$$\frac{TP + TF}{TOTAL} = 0.903 \tag{3}$$

To calculate the error rate, the following formula was used:

$$\frac{FP + FF}{TOTAL} = 0.0968 \tag{4}$$

III. CONCLUSIONS

The developed system shows results that are promising in terms of load detection and monitoring of an area of a residence. This while maintaining a low cost and simplicity in the installation of the system, given the non-intrusive mechanism that was used allowing protection for the system and for the user. Therefore, the Non-Intrusive System for Monitoring Loads Using Embedded Systems provides information on the operation of electrical devices in an area of a residence, detecting in real time the device that was turned on or off by means of the current changes analyzed, showing a history of events and the energy consumption of the detected events, all from a single point of measurement.

The tests carried out demonstrated the effectiveness of the developed algorithm, by correctly identifying the devices that were used, individually, sequentially and simultaneously; however, it was determined that the simultaneous detection of loads is only achieved with two loads, with more than two the system fails to identify the devices that make up the current that is generated. Additionally, this software is not capable of differentiating devices or charges that consume the same or similar current; the algorithm will work with support in the database taking the most similar values of devices, for the identification of loads.

This system lends itself to a non-intrusive electrical monitoring and automation system, combining with control signals beneficial information for the administration and correct management of electrical energy, and determination of faults.

IV. ACKNOWLEDGMENT

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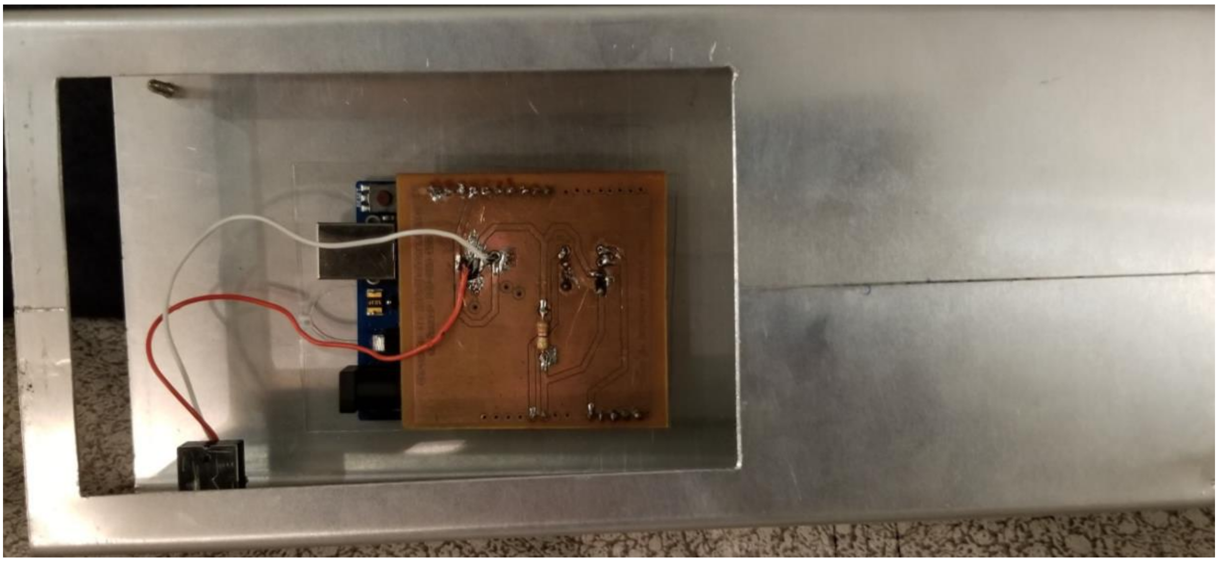
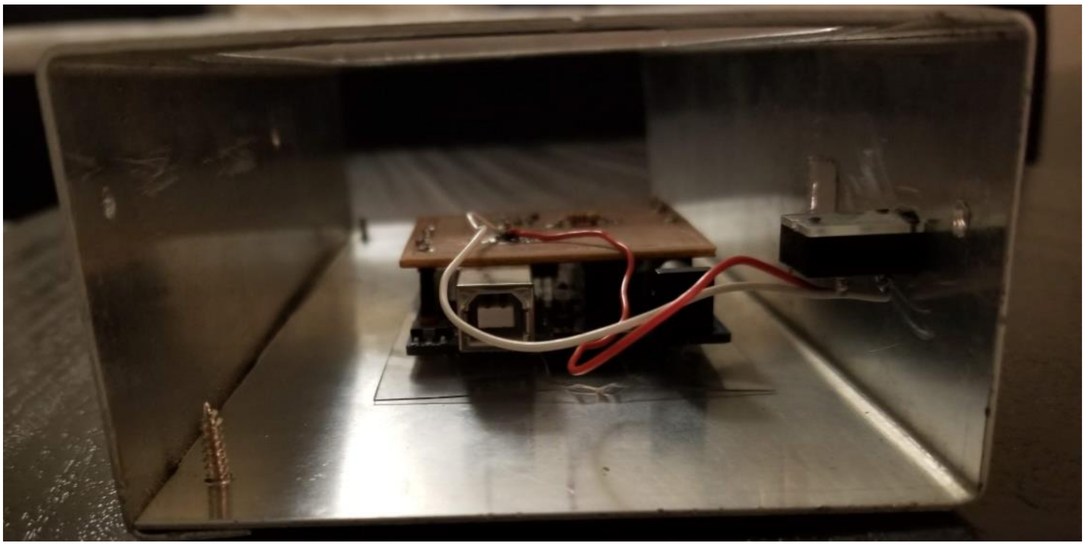
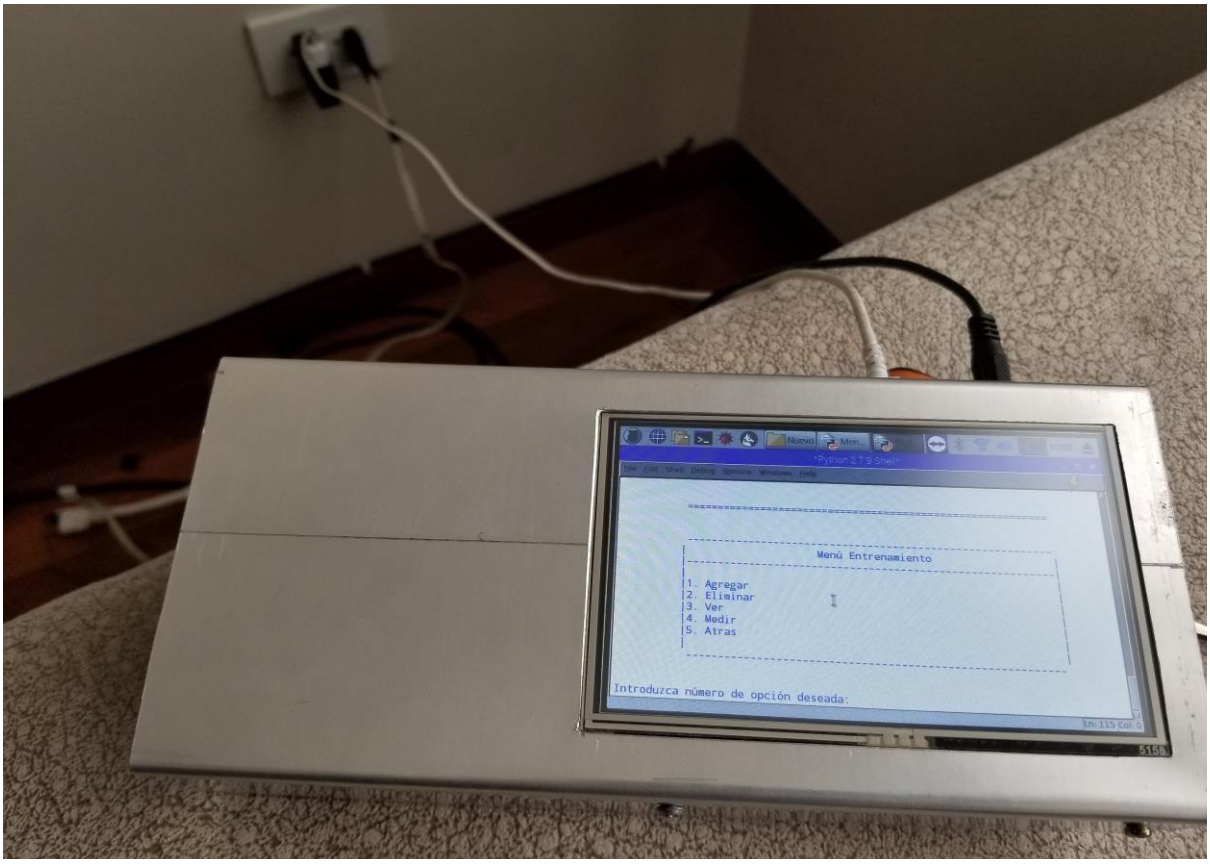
ANEXOS



Anexo 1: Ubicación de circuito de acondicionamiento de sensor SCT en case del prototipo



Anexo 2: Armado de circuito de acondicionamento de sensor SCT em case de protótipo



Anexo 3: Prototipo funcionando

Anexo 4: Planta de prueba de prototipo