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A CASE-STUDY VISION

Temperature measuring instrument with piezoelectric sensor

Instrumento de medición de temperatura con sensor piezoeléctrico

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ABSTRACT

The construction of an instrument for the measurement of temperature based on the type of piezoelectric was carried out. The purpose of this instrument was to contribute to the metrology research line of the Integra research group. In the development of this project, a study was carried out on the method of sensing by the medium of these materials where the most appropriate sensor was determined and thanks to it was developed the conditioning of signal from the sensor, subsequently developed a digital processing system that was achieved thanks to a mathematical model generated by a prior identification of the system. The calibration adjustments were also made in order to improve its metrological characteristics. In addition, the temperature measurement was applied to the plant of the Integra research group.

RESUMEN

Se realizó la construcción de un instrumento para la medición de temperatura basado en el tipo de piezoeléctrico. El propósito de este instrumento fue contribuir a la línea de investigación en metrología del grupo de investigación Integra. En el desarrollo de este proyecto se realizó un estudio del método de sensado por medio de estos materiales donde se determinó el sensor más adecuado y gracias a ello se desarrolló el acondicionamiento de señal del sensor, posteriormente se desarrolló un sistema de procesamiento digital. eso se logró gracias a un modelo matemático generado por una identificación previa del sistema. También se realizaron los ajustes de calibración para mejorar sus características metrológicas. Además, se aplicó la medición de temperatura a la planta del grupo de investigación Integra.

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1. Introduction

This document discloses the methodology that was carried out to obtain a temperature measurement instrument based on a piezoelectric sensor, starting from the theoretical and experimental study of the sensor that allowed the design of the conditioning system and digital processing, then the calibration process was carried out, by means of reference values, graphs and experimental tables were obtained that determined an estimate of error, accuracy and precision. The document contains the analysis of the results of the instrument when it is implemented in a thermal plant, which allowed to verify its operation.

2. Theoretical Framework

2.1. Measuring Instrument

It is a device whose main function is the quantitative and / or qualitative indication of the value of a quantity in reference to a standard measurement unit. As measurement unit's standards or standards are used and the measurement results in a number that is the relationship between the object of study and the reference unit, that is, the measurement instruments are the means by which this representation is made [1].

2.2. Temperature Sensor

Temperature sensors are devices that transform temperature changes into changes of electrical variables that are processed by electrical or electronic equipment. Industrially and in general terms three types of temperature sensors are recognized: thermocouples, thermistors and RTD (Resistance Temperature Detector).

A temperature sensor is typically formed by the sensing element, the sheath that wraps it and that is filled with a good temperature conductor material, so that the changes are transmitted quickly to the sensor element and the cable to which the electronic equipment will be connected [2].

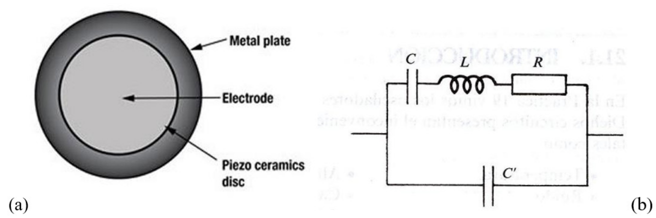
2.3. Piezoelectric Effect

It is the characteristic that some materials have, by which, before a mechanical effort, they respond with an electrical change. It is an effect in which the energy is converted mechanically to electric. It was discovered in 1880 by the Curie brothers. In specific when a pressure (piezo means pressure in Greek) is applied, the mechanical deformation results in an electric charge [3]. These materials have been studied extensively, discovering new variants with different characteristics that make them very useful in many fields of science and technology.

2.4. Piezoelectric Crystals

The quartz crystal is an example of the piezoelectric effect. When the crystal is not under any stress, the charges are uniformly dispersed in the molecules through the crystal, but when the quartz is pressed the order of the atoms changes resulting in that the more the crystal is compressed, the greater will be the potential difference [4].

Figure 1. Quartz crystal: (a) Structure. (b) Electrical equivalent circuit [4].



3. State of the Art

Industrially, three operating principles stand out in terms of temperature sensors: thermocouples, thermistors, and resistance thermometers (RTD). Thermistors are based on the property that semiconductors have in changing their conduction characteristics against temperature changes, but to which is added the possible integration of conditioning circuits to deliver a response with good linearity and accuracy, such as the LM35 integrated circuit used in a mushroom culture [5] or the DS18B20 integrated circuit used in body temperature monitoring [6].

Definitely the industrial sensor most used today to measure temperature is the thermocouple, which is based on the Seebeck principle that shows an electrical potential in the juncture of two different metals which changes with temperature changes, examples of industrial application is like in the case of plastic injection control [7], such as the control case for stamping [8], in the project for controlling environmental variables in the soil [9] or in a thermoelectric test chamber [10].

Resistance Temperature Detectors (RTD) are constructed by means of specific metal wires whose resistivity changes with the change in temperature and can be used in projects of temperature control for sterilization as in the case of the PT10 reference RD250-12- PT-0 / 200C used in [11].

According to the work of Nivia and Jaramillo [12], in the Colombian industry the measurement of temperature is the most required in industrial processes, since the measurement of this variable has proven to be very important in the control and supervision of many processes. However, the use of piezoelectric sensors for temperature measurement is not very common, however, a variety of these have been used with specific qualities that use different types of material or methods for temperature detection, which convert them into the most appropriate for certain applications [13].

3.1. Background of the Investigation

According to the research of V.Gadjanoval, R.Velcheval, L.Spassovl, B.Dulmet from 2006 "Calibration point in thermo-sensitivity investigations, thermal response time and stability of quartz temperature sensors", the quartz resonators are used as high temperature sensors, when making the comparison between two types of response (QTS0I and QTS02) it is obtained that they respond to a short time due to the reduced dimensions of the resonators. The results of this investigation show us that the comparison between the two times shows that for QTS02 it is better due to the smaller dimensions of the resonators, this guarantees the reliable functioning of the sensor [14].

We can also find in the work of Shujun Zhang, Thomas R. Shrout of 2008 which entitled "Piezoelectric single crystal of high temperature ReCa4O for sensors" that talks about the analysis of the results of cultivating crystals by means of attraction Czocharlski, also Investigate electrical properties at high temperature, dielectric permittivity, and piezoelectric tension, the range of devices that use these properties have a difficult space to protect sensitive electronic systems and can withstand temperatures from 500 ˚C to 1000 ˚C with a lifetime of 100,000 hours. In conclusion, crystals of large size and quality can be grown by Czonchralski attraction measure, and show better resistance to high temperatures (theoretically until its fusion of 1500 ˚C) [15].

Another study conducted by Pioneer Petrotech "Oscillating Electronic Sensor," 2010, which we can find are oscillating quartz crystals for use in optical fiber that is exposed in a temperature conduction system based on fiber optic coupling of oscillating quartz crystal, The results of the sensor show that it can withstand high voltage, improves the anti-interference capacity that allows it to withstand a strong voltage in a magnetic field and temperature control, [16].

3.2. Quartz Sensor Applications

Of the applications with temperature and pressure quartz sensors is in oil and gas wells. Pressure measurements help to optimize oil and gas wells, fast response sensors made of crystalline quartz give stability in pressure cycles, this applied externally are dependent on its crystalline orientation. Only pressure compensation after temperature equilibrium is possible, using the berry estimate to merge the data and calculate the exact temperature [17].

Another application are the quartz temperature sensors, tuning fork. The principle of this temperature sensor as a quartz adjustment retainer is to detect the displacement of the resonance frequency by an external temperature. This material is selected for high sensitivity, high precision and good long-term stability [18].

In biomedical these sensors are used for their high sensitivity, one of the important application is the SAW resonator sensors [19], an element is needed, and this element is a reference to reduce the margin of error related to the propagation of waves electromagnetic, has been studied to find the material with good properties, the most indicated and promising candidate is the quartz crystal since in a temperature range of (30˚C and 45˚C), the bandwidth is not affected of the frequencies required in this area [13].

With the piezoelectric SAW sensors, we can find two applications. In the first Saw temperature sensors, used for optimal energy performance, in this the choice of substrates of the resonator saw provides high sensitivity of resonance frequency at high temperature. The analysis of the relationship between re-radiation efficiency and electromagnetic coupling. Quartz is selected because it provides optimal solutions between sensitivity and efficiency of re-radiation energy [15]. The second application is in surface of acoustic waves saw, the piezoelectric microphones are a good example of this phenomenon. Alternatively, an electric charge is applied to a polarized crystal, the crystal passes through a mechanical deformation that can create an acoustic pressure. An example of this are piezoelectric horns [20].

For the measurement of small dynamic deformations in the structure can provide useful information on the state of a machine, although research has been done on the use of piezoelectric materials attached to the surface for the measurement of dynamic strains, little interest has been paid by the use of piezoelectric materials as an element of displacement sensors and deformation transducers. Zirconium titanium lead (PZT), this piezoelectric ceramic has a higher electrical output and low noise levels [21].

3.3. Applications of temperature measurement instruments.

In the automotive industry since it covers several manufacturing processes in which different materials are processed. The processes can be monitored and optimized by thermometers and infrared cameras to ensure excellent product quality [22]. In Health Sciences there are different processes that can be monitored and optimized through non-contact temperature measurement, such as the manufacture of dental products and monitoring in cryogenics [23].

In the metal industry, non-contact temperature meters are a very important part in metal production and processing. Through the use of measuring devices, high quality products can be achieved, they are used for shrinkage process, melting temperature measurement [24].

In the glass industry, this depends on the control of temperature, due to the complex use of energy in its production. Temperature measurement instruments are used for temperature monitoring of products and devices, control of glass melting furnaces, production of glass containers and manufacture of flat glass [25].

4. Methodology

4.1. Sensor study

Considering the principle of the piezoelectric effect, tests were carried out on different crystals with piezoelectric properties (Table 1), in such a way that when subjected to different temperatures a mechanical force was generated on the crystals and thus deforming them until a response was obtained. that the most suitable crystal is the medium size piezoelectric sensor with characteristics shown in (Table 2) and given this a favorable result, an A / D converter is designed with the FRDM-KL25Z microcontroller and thus collect data in real time . Temperature samples were taken with a K-type thermocouple coupled to the reference multimeter (UNI-T, UT39C) used as reference instrument, this has a temperature measurement range of 10ºC to 400ºC, with a resolution of 0.1ºC and an accuracy of ± (1.0% + 0.8 ° C).

Table 1. Study piezoelectric crystals.

Piezoelectric Material	Reference	Observations
	Quartz Oscillator (32.768Khz 3x8mm)	Response given in frequency. Range (250 to 300 ºC) Noise in the signal to be measured Low Sensitivity
	Quartz Oscillator (10 Mhz)	Response given in frequency. Noise in the signal to be measured Range (250 to 300 ºC) Low Sensitivity
	Quartz Oscillator (3.68 Mhz)	Response given in frequency. Range (250 to 350 ºC) Low Sensitivity Noise in the signal to be measured

Piezoelectric Material	Reference	Observations
	Large piezoelectric Sensor (35mm)	Response given in voltage. Range (20 to 100 ºC) High Change in potential difference High sensitivity to vibrations
	Medium Piezoelectric Sensor (27mm)	Response given in voltage. Range (20 to 130 ºC) Low Change in potential difference High sensitivity to vibrations
	Small Piezoelectric sensor (15mm)	Voltage response Range (20 to 130 ºC). Very low change in potential difference. High sensitivity to vibrations

Source: own.

Table 2. Characteristics piezoelectric sensor medium (27mm).

ESPECIFICATIONS		
PARAMETERS	VALUES	UNITS
VOLTAGE	10	Vp-p
OPERATING VOLTAGE RANGE	1~30	VP-^{P}
CURRENT (MAX)	9	mA
CAPACITANCE	11,000±30 %	Pf
MINIUM SPL @ 10 CM	80	dBA
RESONANT FREQUENCY	5,000±500	Hz
OPERATING TEMPERATURE	-30 ~125	°C
STORAGE TEMPERATURE	-40~135	°C
HOUSING MATERIAL	ABS	-
TERMINAL MATERIAL	LEAD WIRE	-
WEIGHT	1	Grams

Source: own.

The selected sensor was coupled in such a way that it remained internally in an aluminum capsule and given this changed some characteristics (Table 3) that were considered for the measuring instrument, determining a relationship between internal and external temperature (Table 4).

Table 3. Coupled sensor characteristic.

Temp-int	Temp-Ext
28	40
32	44
34	46
35	47
38	49
40	51
42	55
45	60
48	64
50	66
53	69
54	70
55	72
57	76
61	82
69	92
72	96
75	99
79	103
85	109
90	113
92	114
95	117
97	118
100	120

Source: own.

Table 4. Temperature relationship.

Characteristics Piezoelectric Sensor Coupled	
Operating Temperature	20~130 °C
Response time	RTP
Siza	4,6 cm
Terminal Material	2-wire shielded cable
Encapsulation material	aluminum
Thermal transfer coefficient	209,3 w/mK
Weight	10g
Piezoelectric sensor material	Quarts
Piezoelectric expansion coefficient	0,4
Coefficient of thermal expansion Aluminum	2,4 mm a 100

Source: own.

The equation of the relation of temperature that was obtained experimentally was considered at the time of carrying out the identification of the system, the aluminum is a material that for this case suffers a deformation of 2.4mm at 100°C which allows us to take as insignificant this data.

$$y=1{,}0059+13{,}654 \quad (1)$$

Equation 1: Equation of the temperature ratio.
Source: author

Figure 2. Sensor response to temperature over time.

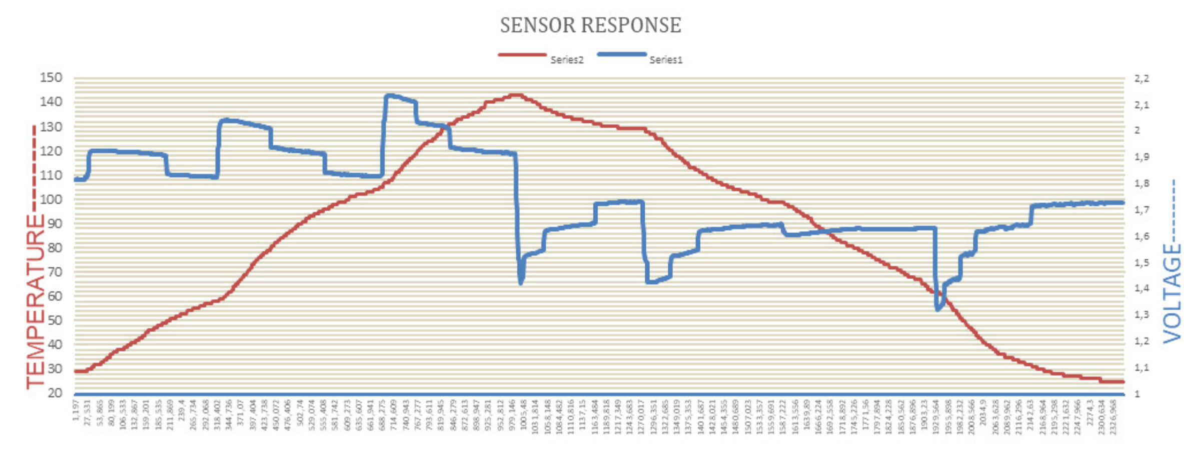


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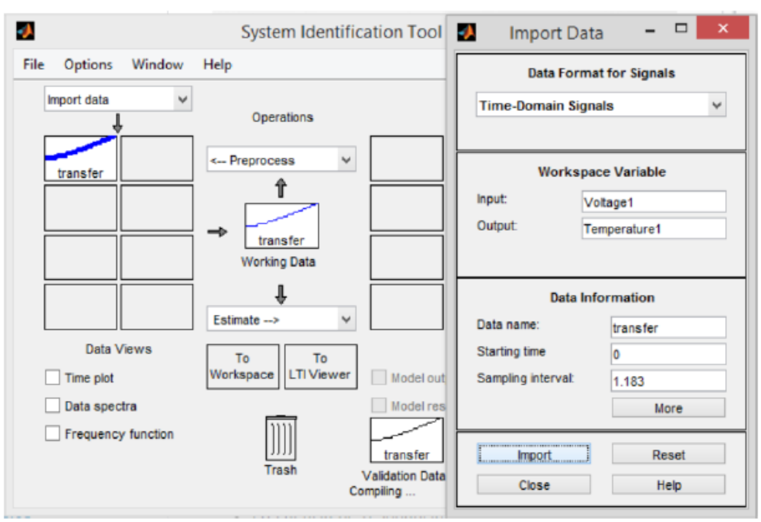
Figure 3. System Identification Toolbox interface.



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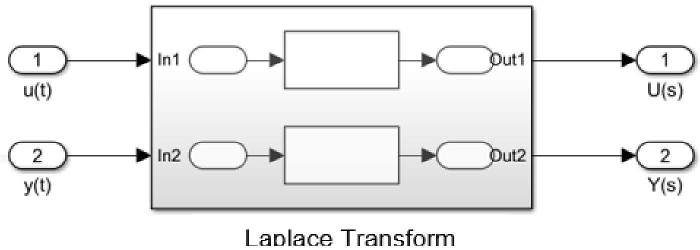
With the analysis of a set of tests the response of the selected and coupled sensor was observed when subjected to a temperature sweep (Figure 2). For the identification of the resulting signal, the Matlab software was used as it has a system identification application, this application is called System Identification Toolbox and uses statistical methods that build mathematical models of dynamic systems (Figure 3) once the output and input data to the **System identification**, application is entered, the application internally performs the Laplace transform calculations of these two signals since initially the input data $u(t)$ (Voltage) and output $y(t)$ (Temperature) are in the domain of time (Figure 4), to obtain as a result $G(s)$ that is the transfer function, where it is in the domain of the complex variable "s".

Figure 4. Transformation of the signals u(t) and y(t).



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The transfer function (Figure 5). It is defined as the quotient of the Laplace transform of the output signals and the input, where $G(s)$ is the transfer function, $U(s)$ the Laplace transform of the voltage input signal and $Y(s)$ is the Laplace transform of the temperature output signal (2).

Figure 5. Transfer function G(s).

Source: own.

$$G(s) = \frac{Y(s)}{U(s)} \quad (2)$$

The identification of the system allowed obtaining the first-order transfer function $G(s)$ with a pole and zero zeros (3).

$$G(s) = \frac{0{,}593}{s + 0.0009761} \quad (3)$$

The transfer function $G(s)$ was considered as the response of the system initially inherent to an input signal stimulus $u(t)$ and it is necessary to make the inverse transform of Laplace (4) to the transfer function (3) to pass from the complex domain "s" to the domain of "t", therefore, the response or output of the system $y(t)$ is given in the time domain (5).

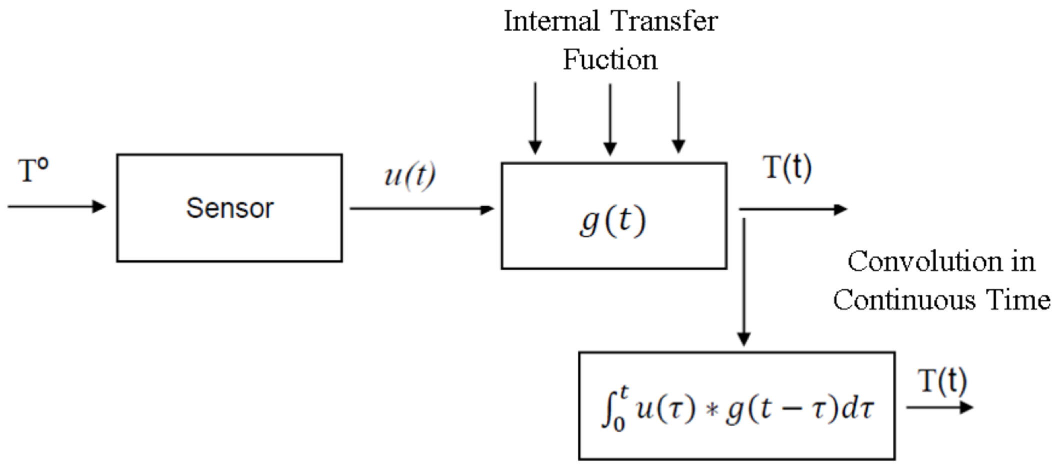
$$g(t) = \mathcal{L}^{-1}\{G(s)\} \quad (4)$$

$$y(t) = u(t) * g(t) \quad (5)$$

Once the Laplace inverse transform of the transfer function (6) is done, all the terms in equation (5) will be in the time domain, where it will later be applied in the algorithm for temperature detection.

$$g(t) = 0.593e^{-0.000976t} \quad (6)$$

Figure 6. Flow diagram of the mathematical processing of the signal.



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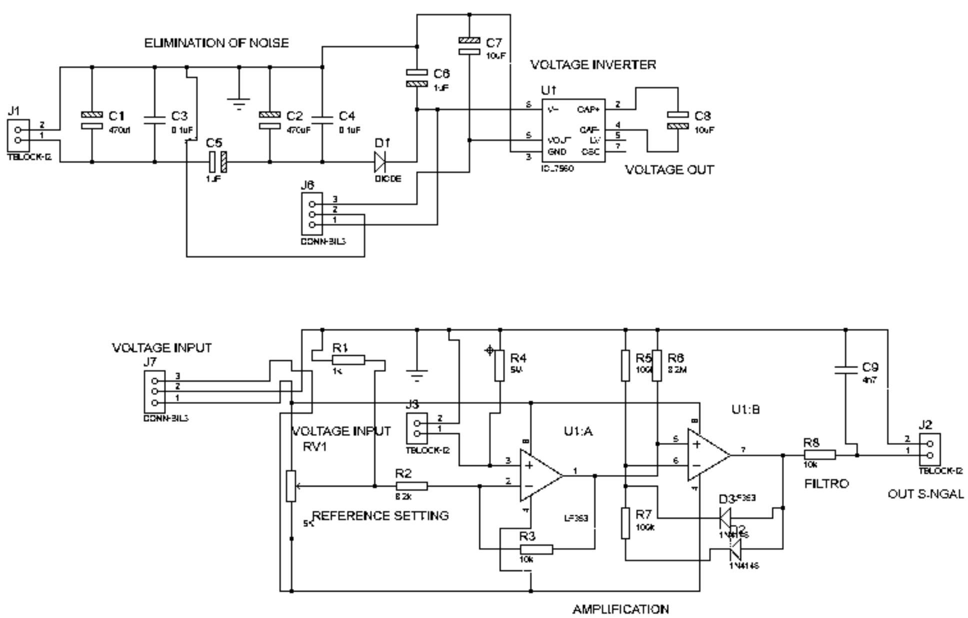
The diagram of figure 6 represents the mathematical treatment that was performed for the detection of the temperature signal.

4.2. Design Measuring Instrument.

4.2.1. Signal Conditioning.

Several stages were implemented for the conditioning of the signal (Figure 7), the first of which is the noise elimination stage, fulfilling the objective of eliminating unwanted frequencies by means of a circuit, the second stage is responsible for the amplification , since the voltage levels delivered by the sensor when subjected to different temperatures are relatively low, this has a gain of 1.5 times the input voltage, this stage also has a voltage reference adjustment, in such a way that When the sensor registers a negative potential differential it prevents the output voltage of the amplifier from going below 0 volts causing damage to the micro controller. The third and last stage is responsible for filtering the signal through a low pass filter that is then sent to the micro controller (Mbed).

Figure 7. Stages signal conditioning.



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4.2.2. Digital Processing.

The prototype FRDM-KL25Z (Figure 8), is the micro controller used for digital processing, the development of the algorithm was performed by means of the mbed platform. This has 48MHz, 16KB RAM, 128KB FLASH, ADC (16 bit) and 5V USB.

Figure 8. Mbed microcontroller (FRDM-KL25Z).

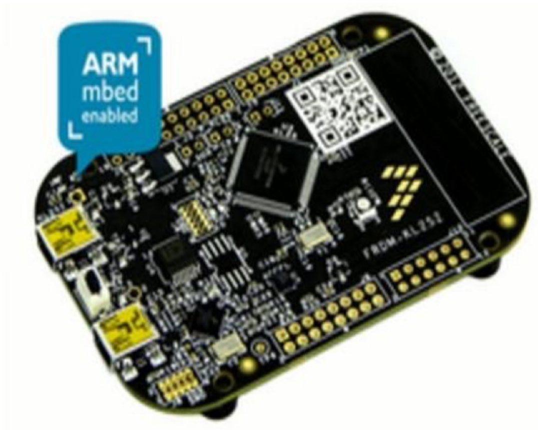

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Figure 9. Fragment of the Programming Code.

```
while(acum1==1) {
t.start();
c=(b-a)/n;
 for(f=1;f<=4;f++){
   for (i=0;i<64505;i++){
     z=ain2.read()*3.3;
     T=T+z;
       if(i==64504){
           P=T/64505; //PROMEDIO
           if(P<=1.551 || P>=1.716){ V=P-1.630;}
           else if(P>=1.7085 & P<1.71){V=0.050;}
           else{  V=0; }
           ec1=c*V*((multiplicador*exp(-exponente*(b-(a+(c*f)))))); // CONVOLUCIÓN
           temperatura+=ec1;        // SUMATORIA AREA BAJO LA CURVA
           if(f==4){
               a+=4.732;
               b+=4.732;                }
               T=0;   }    //if}   //for  }//for
              if(bluetooth.read()==0) { //envio de datos por bluetooth de temperatura o voltaje
               device.printf("%3.1f %cC \n\r",temperatura,248);        }
              else {
               device.printf("%3.2f% V\n\r",V);  }
               if(V>1.66  || temperatura>130){ //si se excede los 130°C visualiza adevertencia
               wait(0.1);
               lcd.cls();
               lcd.locate(2, 0);
               lcd.printf("TEMP FUERA");
               lcd.locate(1, 1);
               lcd.printf("DEL RANGO");}
               else{
               wait(0.1);
               lcd.cls();
               lcd.locate(2, 0);
               lcd.printf("TEMPERATURA");
               lcd.locate(6, 1);
               lcd.printf("%3.1f %cC",temperatura,167); //visualizacion temperatura}
```

Source: own.

The main objective of the algorithm is to perform an integral (7) where the equation (6) obtained previously applies convolution with the impulse of the voltage signal $u(t)$ coming from the sensor, these correspond to the internal factors of said integral.

$$y(t) = \int_0^t u(\tau)\, g(t - \tau)\, d\tau \qquad (7)$$

In this way the area under the curve is found and we can know the response to the impulse in real time, the convolution in continuous time is performed every 4.7s, a voltage value is received that is replaced in the equation of the integral already defined in the algorithm and in parallel a summation is made where it will accumulate (area under the curve) since it represents the value of the temperature, (Figure 9). To define the integral in the algorithm the trapezoid method was used.

5. Communication

For the display of the temperature, the instrument has a bluetooth module with the identification name (HC-05) that can be connected to the cell phone by means of the application (Multi FREE terminal), to the computer with the help of LabVIEW software, or can directly be viewed on an LCD display located on the top of the instrument.

6. Operation

Before carrying out any measurement, some initial conditions must be taken into account, one of them is to know the ambient temperature at which the instrument is at that moment, the second one is to enter said temperature directly in the instrument, with the button (ok) the temperature will be saved and after this process the instrument will start its measurement.

7. Calibration

The calibration of the instrument is based on the comparison of values delivered by the standard instrument Vs the values delivered by the instrument to be calibrated under the same conditions and adjusted in such a way that the difference between these data is minimal. For this, the characteristics of the standard instrument were considered (Table 5).

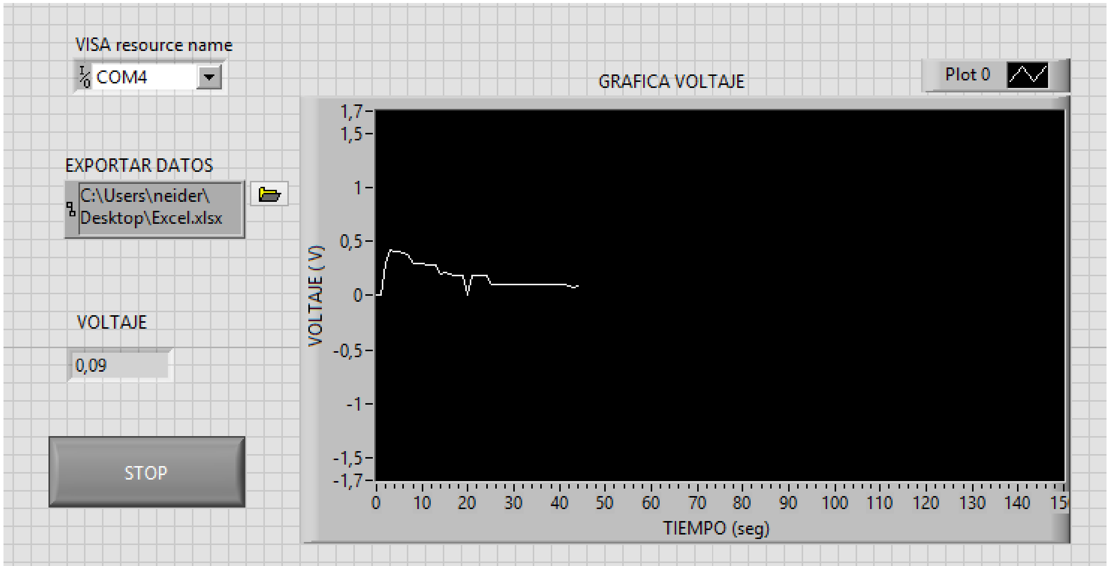
Table 5. Characteristic instrument features.

Specifications			
MULTIMETER DT-51			
Function	Range Max	Resolution Max.	Basic precisión
Light	20,000 Lux	0,1 Lux	± 5%10d
Humidity	95%RH	0,1%RH	± 3.5%RH
Temperature	-20~750 °C	0,1° Hasta 400° Sobre 400°	±3%± 3°C
	-4~1400 °F	0,1° Hasta 400°, 1° sobre 400°	±3%±5 °F
Voltage DC	600V	0,1 mV	± 0,5%2d
Voltage AC	600V	0,1 mV	± 1,2%10d
Intensity DC	10A	0,1 uA	± 1,0%2d
Intensity AC	10A	0,1 uA	± 1,0%2d
THERMOCOUPLE UT-T10K			
Temperature Range		-40~260 °C	
Accuracy		± 0,75%	

Source: own.

To adjust the values of the designed instrument it is necessary to modify the internal equation and to do this it must be recalculated, in this case the sensor is subjected to a temperature sweep, to take voltage data. The instrument is equipped in such a way that at the moment of the calibration it sends voltage data via bluetooth and for this it has a switch located in the upper part with the bluetooth symbol which must be kept OFF to receive said voltage data to an interface designed in the Labview software (Figure 10), the data is subsequently exported to be identified in the Matlab System Identification Toolbox application to perform the transfer function and thus obtain a new equation. The temperature data should be taken with the reference instrument.

Figure 10. Labview interface (Voltage data).



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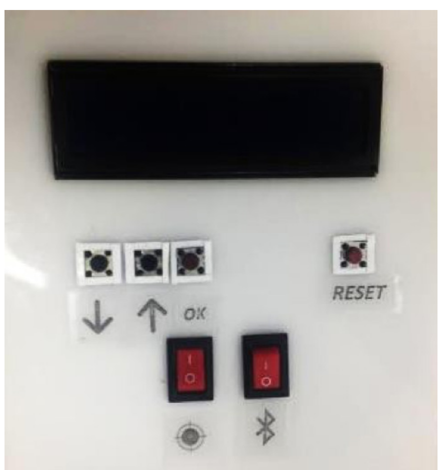
The instrument has a switch located in the upper part with calibration symbol, it must be kept in one to enter the obtained equation, it will ask for the value of both the multiplicative and the exponent, by means of buttons it will be able to decrease or increase the value according to the case in such a way that modifies the previous equation, with the (ok) button can be selected and the equation will be modified, finally the switch must be turned off. The button (Reset) fulfills the function of restarting a new measurement, (Figure 11).

Figure 11. Switches and buttons on the top of the instrument.



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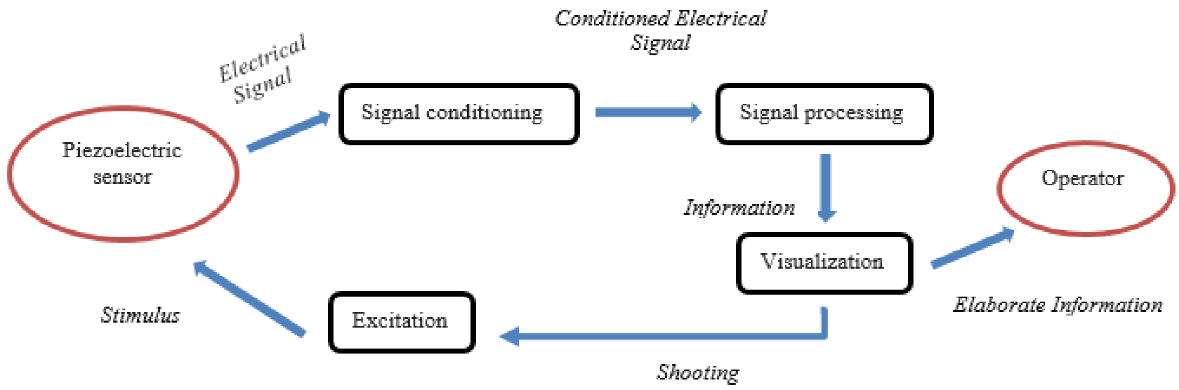
8. Instrumentation System

Figure 12 shows the scheme of the instrumentation system obtained.

Figure 12. Instrumentation System.



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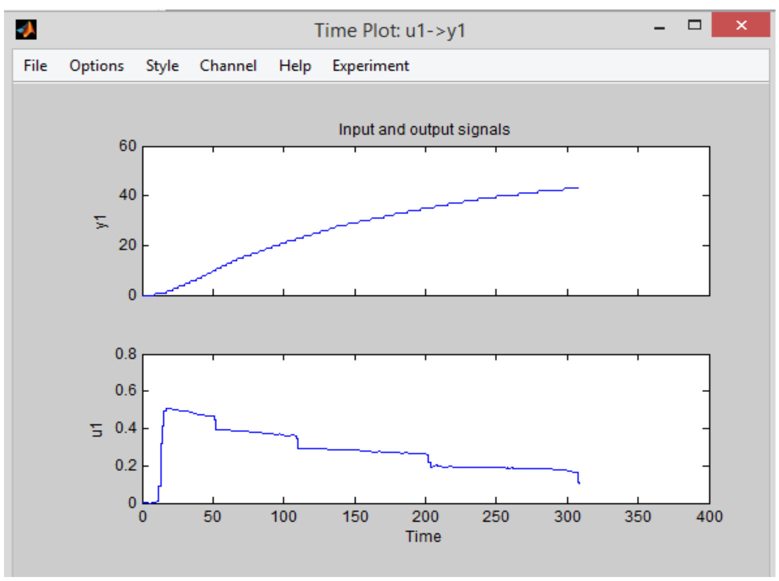
9. Results

a. Sensor Study

The tests carried out on the sensor by subjecting it to a temperature sweep at the time of studying it correspond to the voltage vs. temperature levels that are brought to Matlab (figure 13), allow to establish a temperature range between (20° C to 130°C) which, the sensor responds correctly and does not suffer physical damage.

Figure 13. Sensor response: voltage vs. temperature in Matlab.



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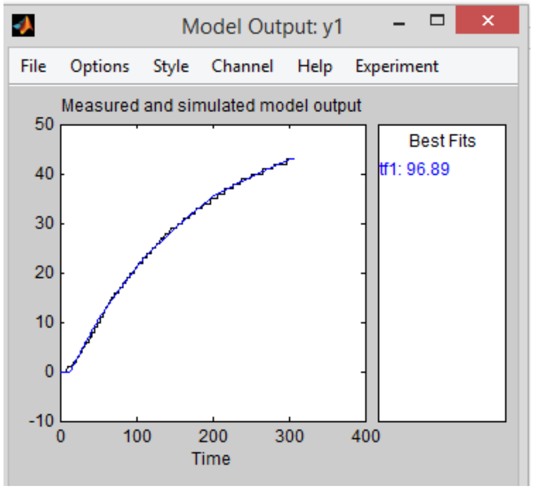
b. Identificación del sistema

The transfer function obtained in the identification of the system by means of the Matlab software (Figure 14), gave an approximation of 96.89% accuracy.

Figure 14. Transfer function obtained from the simulation.



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The resulting transfer function is precisely equation (3).

c. Calibration

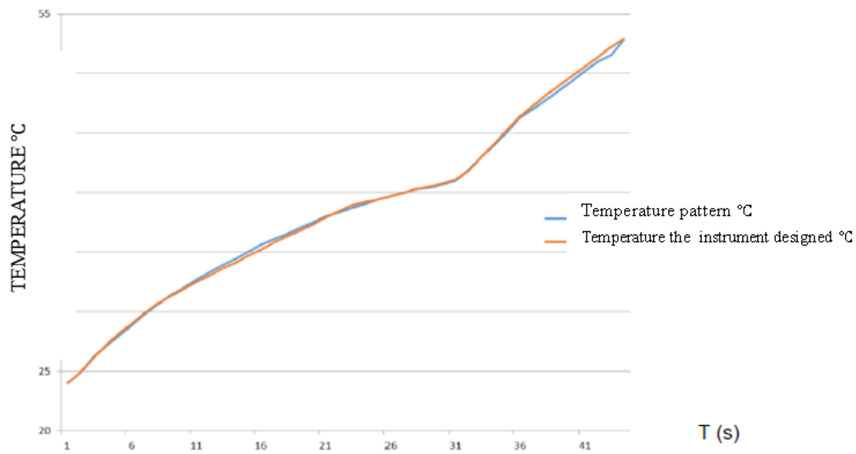
Equation (8) is the result of the new equation when performing the calibration process described in item 6.

$$g(t) = 0.580e^{-0.0009761t} \tag{8}$$

d. Verification of the Instrument.

To verify the operation, the values delivered by the designed instrument are compared with the values of a reference instrument by means of a temperature sweep (Figure 15). The test was carried out with a conditioned system that dissipates heat by means of a light bulb and maintains the temperature with a fan (Figure 16).

Figure 15. Temperatures taken by the instrument designed Vs reference instrument.



Source: own.

Figure 16. Conditioning system for temperature.

Source: own.

Figure 17 shows some evidence during the measurement process.

Figure 17. Instrument designed Vs instrument pattern.

Source: own.

e. Error, Precision and Accuracy.

Table 6 represent the data taken for error calculation and accuracy. The actual temperature that the instrument should measure is 42.1ºC.

Table 6. Temperature samples.

Sample Number	Temperature (ºC)
1	42,2
2	42,5
3	42,2
4	42,2
5	42,5
6	41,5
7	41,5
8	41,5
9	42,1
10	41,8
Average $\bar{x}$	42,0

Source: own.

9.1. Accuracy

Equation (9) represents the formula for the precision calculation.

$$s = \sqrt{\frac{1}{n-1}\sum_{0}^{n}(x-\bar{x})^2} \quad (9)$$

Where:

n = Total number of samples
x = Temperature data
$\bar{x}$= Arithmetic average of the temperature data

Table 7 contains the data according to the procedure performed to find the accuracy.

Table 7. Precision calculations.

$x - \bar{x}$	$(x - \bar{x})^2$
0,2	0,04
0,5	0,25
0,2	0,04
0,2	0,04
0,5	0,25
-0,5	0,25
-0,5	0,25
-0,5	0,25
0,1	0,01
-0,2	0,04
Total Sum	1,42

Source: own.

Using equation (9), and the data in Table 7, we obtain the result of the precision according to equation (10):

$$s = \sqrt{\frac{1}{10-1}\sum_{0}^{10}(x-\bar{x})^2} = \pm 0.39 \quad (10)$$

With equation (11) the average deviation is calculated.

$$sp = (Tst)(vS) \quad (11)$$

For $v = 9$, we have that $Tst = 2,262$

(v) Represent the degrees of freedom that are associated with the standard deviation, 10 samples were taken, but only n-1 is needed.

Then the result of the average deviation is:

$$sp = (2.262)(0.39) = \pm 0.88\% \quad (12)$$

9.2. Systematic Error

Equation (13) shows the calculation of systematic error.

$$Error = \frac{42.0 - 42.1}{42.1} * 100 = -0.23\% \quad (13)$$

In equation (14) the correction factor for the systematic error is performed.

$$FB = \frac{1}{1 - Error} = 1.0023 \quad (14)$$

With equation (15) the systematic error range is calculated:

$$\pm Error = \frac{0.88}{\sqrt{10}} = \pm 0.27\% \quad (15)$$

9.3. Accuracy

With the equation (16) the accuracy is calculated

$$ACC = Error \pm \sqrt{sp^2 + \frac{sp^2}{n}} \quad (16)$$

With the obtained data, it is calculated:

$$ACC = -0.23 \pm \sqrt{0.88^2 + \frac{0.88^2}{10}} = -1.152\% \ a \ 0.692\% \quad (17)$$

In equation (18) the correction factor for accuracy is obtained.

$$ACC = \sqrt{1 + \frac{0.88^2}{10}} \quad (18)$$

10. Electrical and Dimensional Characteristics

Table (8) specifies all electrical characteristics and in (table 9) the dimensional characteristics obtained by the temperature measurement instrument with piezoelectric sensor.

Table 8. Electrical characteristics of the instrument.

	TECHNICAL DATA SHEET OF THE MEASUREMENT INSTRUMENT
INFORMATION	
INSTRUMENT / EQUIPMENT	Temperature meter
RANGE	20°C to 130°C
MINIMUM READING	20°C
SCREEN SIZE	Digital 7,1 X 2,4 Cm
SCREEN	updated every 1.10s
SENSOR	Piezoelectric
MEASUREMENT AREA	environment, materials with thermal transfer
POWER	9v-220mA
RESOLUTION	0,1 °C
PRECISIÓN	±0,39
SPAN	110°C
ERROR	0,27%
ACCURACY	±0,85%

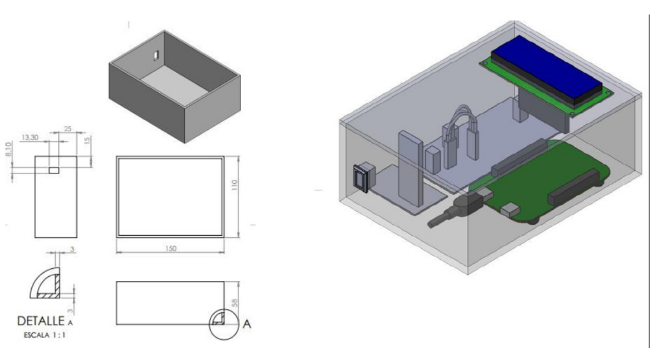
Source: own.

Table 9. Dimensional characteristics.

Dimentional Characteristics	
Size	15x11x5.8 cm
Weight	510g

Source: own.

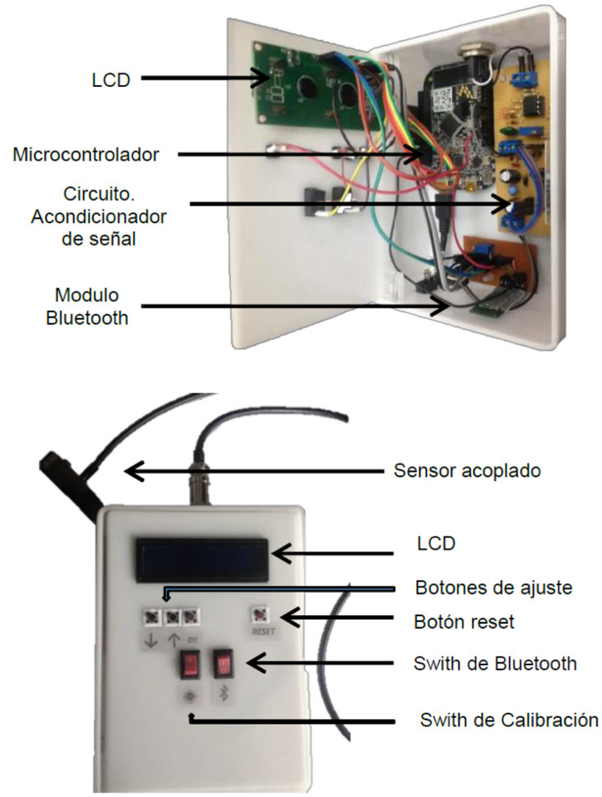
Figure 18. Modeled Instrument in SolidWorks.



Source: own.

Thanks to the SolidWorks software, the physical schema was modeled (Figure 18) where the appropriate dimensional measurements for the manufacture of the external case of the instrument were determined (Figure 19).

Figure 19. Parts of the Designed Instrument.



Source: own.

11. Comparison of Metro Logical Characteristics

The comparison of the metro logical characteristics of the designed instrument and the reference instrument available in the faculty was carried out (10).

Table 10. Comparison of metrological characteristics.

Characteristic	Designed Instrument	Reference Instrument
Error	0,27%	---------------
Accuracy	± 0,85%	± 0,75%
Precision	± 0,39%	± 0,3%
Resolution	0,1 °C	0,1 °C
Range	20~130 °C	-40~260 °C

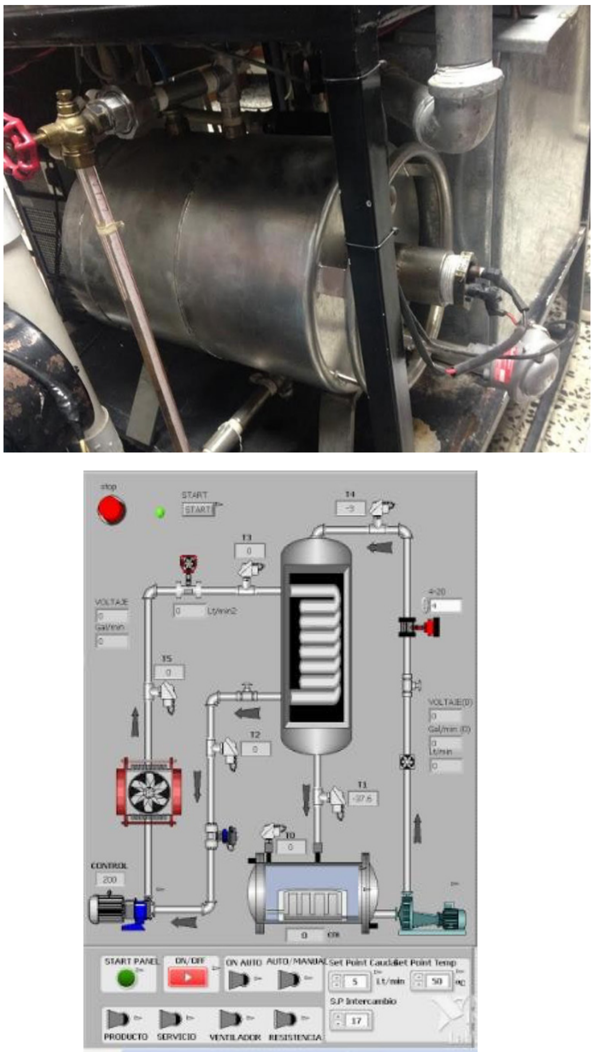
Source: own.

Thanks to the comparison of the metrological characteristics, it is possible to affirm that the designed instrument presents a low difference with respect to the reference instrument.

12. Thermal Plant Operation

To measure the temperature in the thermal plant of the INTEGRA research group, the sensor was coupled to the water tank externally, which has an electrical resistance to heat said water. For the control of this, there is a graphical interface in LabVIEW (Figure 20) that allows visualizing the temperature at which the water is internally and entering a set point to reach the desired temperature.

Figure 20. Graphical interface for thermal plant control.



Source: own.

A temperature sweep was performed in a range of 23 to 54 ° C. Table 11 shows the data taken by the designed instrument and the reference instrument.

Table 11. Data obtained in the thermal plant application.

Temperatures	
Reference	Designed
24,7	25
27,3	27,1
30,6	30,2
35,3	35,1
38,4	38,4
41,9	41,6
44,1	43,9
46,7	46,6
49,6	49,7
52,3	52,2

Source: own.

The average error of the data delivered by the instrument designed with the reference instrument (Table 12) is obtained.

Table 12. Calculation of internal and external temperature ratio.

Designed	Reference	Difference
25	24,7	0,3
27,1	27,3	0,2
30,2	30,6	0,4
35,1	35,3	0,2
38,4	38,4	0,0
41,6	41,9	0,3
43,9	44,1	0,2
46,6	46,7	0,1
49,7	49,6	0,1
52,2	52,3	0,1
	Average	0,19

Source: own.

The average percentage error obtained is 0.19%

Figure 21 shows the data taken by the instruments and the interface at the time of the measurement.

Figure 21. Measurements in the thermal plant.

13. Conclusions

The verification of the metrological characteristics required by the National Institute of Metrology proposed in the general objective was changed by comparisons with faculty teams.

The construction of the temperature measurement instrument with piezoelectric sensor is an important advance for the INTEGRA research group's metrological research line, which contributed to the development of new alternatives when performing temperature detection.

Thanks to the selected sensor study, it was determined that the sensor is not designed to measure temperature, so the instrument manages to measure said variable under initial conditions.

The developed instrument can be improved in several aspects such as accuracy, lower error range and accuracy by making calibration adjustments.

The designed instrument was implemented in the thermal plant of the INTEGRA research group obtaining accurate and accurate results, but this can also be applied in different temperature control processes where required.

Thanks to the international metrology vocabulary (VIM), basic concepts were contextualized and subsequently used appropriately.

Calibration of the instrument was achieved after a previous study of the behavior of the sensor and multiple tests, comparing it with values of the reference standard, which allowed to approach a value very close to it.

The communication and he sent instrument data to the computer and / or cell phone through Bluetooth was successful, this with the objective of displaying temperature in real time or for data acquisition for a next calibration.

Other elements of application and innovation can be considered as research perspectives: [26-33].

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