Intelligent testing prototype for monitoring thermal variables in a thermal chamber according to optimize an ultrasonic washing machine

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ABSTRACT

The following article shows the mathematical analysis, simulations, design and experimental tests of an intelligent prototype for monitoring the physical variables: temperature, which is measured and recorded from inside a system. It contains a platform in a movement more than 3 degrees of freedom (DOF) that is coupled to 4 springs that allow the mechanical movement of the platform that supports the monitoring system. The recording system has the ability to be inside the thermal system (not outside the data monitoring, which is the usual way) for monitoring the thermal variables regardless of mechanical disturbances of movement that generally physical-chemical processes require it. The complexity of the case is that the monitoring hardware must be inserted into a closed system at the controlled range of work from 25 to 70 degrees Celsius and the composition of 3 DOF adapts the recording system to achieve a robust control for a washing machine that uses ultrasound. Since connection and wiring problems disturb the transfer of information, if the monitoring system is outside the thermal system. For this reason, this designed system has the robustness of hardware to isolate the heat that is produced in the thermal camera with respect to the interior of the recorder. Also the appropriate isolation for the hardware that contains the monitoring system is thermally analyzed, which implies that outside the system the process can be from 25 to 70 degrees Celsius and inside the prototype, where the logger circuitry is located, it is around 25 degrees Celsius. However, the analysis of correct filtering and self-control of the system is also necessary during the processing of the information of registered thermal variables, since a large part of the disturbances for data collection is given by the mechanical movement of two degrees of freedom of the thermal system [1], [2]. Finally, it is suggested for a future improvement of this article, the replacement of traditional (electromechanical) sensors by sensors based on nanostructures, because a large part of solutions and strategies for filtering and control through software can be optimized with robust and fast-response sensors. Moreover, this new sensor can avoid mechanical and electromagnetic disturbances.

Keywords: Simulations, monitoring of thermal variables, identification of systems, filtering, control.

1 INTRODUCTION

Currently, the data captured from thermal systems as furnaces requires external connections, such as for example whether the requirement is to measure the internal temperature of an oven, external wiring is a necessity, which leads to miscellaneous cables that make the installation more intricate.

The data collection is quite important due to it contains the dynamic of the system that is the base of the mathematical model for the thermodynamic process description.

If the thermal system is in motion, the data that was captured looks intricate, when recording and control are commanded from the outside. For this reason, there are systems that are better suited for monitoring or control tasks from within the thermal system.

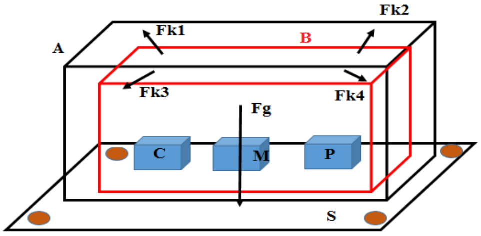
The designed prototype is executed by an intelligent algorithm that was designed from modulating functions techniques and the sensor prototype is based on nanostructures. Furthermore, there were designed new sensors, which can avoid mechanical and electromagnetic disturbances presented in washing process by ultrasound, in which temperature control is a big requirement.

This washing machine (in which was evaluated the algorithm and the sensor that were designed in this article) was provided by the responsible person of the project "Design of a ultrasound washing machine", the engineer Benjamín Barriga, who also is one of co-authors of this article.

2 DYNAMIC SYSTEM

The following system considers the dynamic analysis of the internal recording system “B” of the thermal camera “A”. The movement of the recorder is caused by the resultant force (composition of forces “Fk1”, “Fk2”, “Fk3”, “Fk4” y “Fg”), which is represented by 4 elastic forces vectors. The figure 1 shows the recorder temperature system that as suspended by elastic forces vectors, which also is composed of the control “C” and power subsystem “P” of the monitoring “M” (every subsystem composes the main system “S”).

Figure 1. Forces diagram on the temperature recorder system.



From figure 1 the following dynamic model is described in equation 1, where "M" is the mass of the recorder system, its acceleration and velocity as the consequence of the second and first derivative respectively to change of position "y", for damping “γ” and deformation coefficient "K" of the 4 elastic forces vectors that hold the recorder system, in addition to the force of gravity "Fg" of this one.

$$\mathrm{M}_2 \frac{d^2y}{dt^2} = \gamma_y \frac{dy}{dt} + K_y y + F_g \qquad (1)$$

It is represented in a matrix to generalize, in which it is necessary to highlight that "y" is the selected coordinate for the trajectory of movement, also each equation is a matrix model that is depending on the dynamic that was provided by the degrees of freedom of the 4 4 elastic forces vectors that are coupled at the recorder system. The matrices must be 4 by 4 (for mxn quoted literally).

$$M = \begin{pmatrix} m & 0 & \dots & 0 \\ 0 & m & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \dots & m \end{pmatrix}_{mxn} \qquad (2)$$

The matrix, that is composed of each stiffness coefficient, is shown through the following equation:

$$k_y = \begin{pmatrix} k_{y_1} & 0 & \dots & 0 \\ 0 & k_{y_2} & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \dots & k_{y_n} \end{pmatrix}_{mxn} \qquad (3)$$

A similar analysis described in the paragraphs above. It is proposed the damping matrix by equation 4.

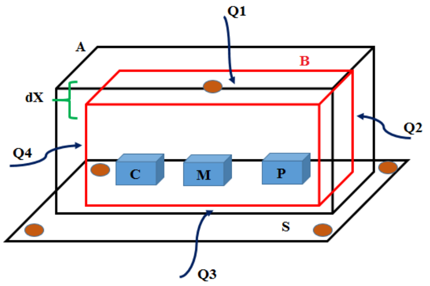
$$\gamma_y = \begin{pmatrix} \gamma_{y_1} & 0 & \dots & 0 \\ 0 & \gamma_{y_2} & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \dots & \gamma_{y_n} \end{pmatrix}_{nxn} \qquad (4)$$

The similar context for the force of gravity that is taken in constant at "g" multiplying the matrix "M".

3 THERMODYNAMIC SYSTEM

The dynamic model that was described in the previous chapter also needs to describe its thermodynamic behaviour due to knowing the theoretical mathematical models that must be contrasted with those that were obtained in experiments according to obtain a better design of the algorithms that allow the tasks to be carried out automatically. Then, in figure 2 the thermodynamic diagram is shown where is the representation of the control subsystem “C”, the monitoring subsystem “m” and the power subsystem “P” are displayed. The transfer of heat "Q" as a result of “Q1”, “Q2”, “Q3”, and “Q4” from the sources of the thermal chamber (furnace) "A" towards the recorder system "B", towards all the transverse surfaces "A" to this heat flow, that was crossing through a differential "dx", which is the thickness of the material that forms the recorder, which is a major computational component for the recorder temperature design.

Figure 2. Thermodynamic diagram of the recorder temperature with the thermal chamber.



Then the equation 5 describes the model of the changing temperature and analyzes as the excitation of an external source to obtain the model on the heating plate, for which "T (S)" is the final temperature in degrees Celsius, "U (S)" is the excitation signal and it can be in Volts or Amps (it depends on the performed analysis), "Kp" is the gain of the transfer function in degrees Celsius by the unit of the electrical excitation signal (Volts or Amps). Also the unit of "τ" is "$\frac{1}{seconds}$", since the Laplace expression "S" is given in seconds.

$$\frac{T(S)}{\Delta U(S)} = \frac{k_p}{\tau S+1} \qquad \textbf{(5)}$$

The solution in steady state is given by equation 6, where "Tf" is the final temperature in degrees Celsius, the result of "ΔUkp" is given also in degrees Celsius according to the previous paragraph, "To" is the initial temperature, "t" is the time that elapses until reaching the stationary, and "τ" is the response time of the system, from where the dimensions of both are given in seconds and it is obtained the dimension in degrees Celsius.

$$T_f = \Delta U K_p \left(1 - e^{\frac{t}{\tau}}\right) + T_0 \qquad (6)$$

However, the theoretical model of heat transfer is also known as the dependence of the geometric path of the heat propagation "r" in meters, which is shown in equation 3, where also "A" is the cross-section to the heat flow in m^2.

$$\frac{dQ(t)}{dt} = KA\frac{dT}{dr} \qquad (7)$$

For which the proposed solution equation is given by:

$$T_f = \frac{QL}{KA} + T_0 \qquad (8)$$

Hence, for a steady-state and analyzing equations 6 and 8, is possible to achieve the thermal conductance value of the corresponding matrix component, which is known as:

$$\frac{QL}{KA} = \Delta U K_p \qquad (9)$$

It is necessary to highlight the focus on various points of the heat transfer, the heat matrix "Q" is proposed for "n" equal to 6, as an analysis of the heat influences that tends to cross the register thermal subsystem.

$$Q = (Q_1, Q_2, Q_3, \dots, Q_n)^T \qquad (10)$$

Summarizing, the matrix analysis of the previous equations is:

$$G = \begin{pmatrix} \frac{\alpha A_{1X1}}{L_{1X1}} & 0 & \dots & 0 \\ 0 & \frac{\alpha A_{2X1}}{L_{2X1}} & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \dots & \frac{\alpha A_{nXn}}{L_{nXn}} \end{pmatrix}_{nxn} \qquad (11)$$

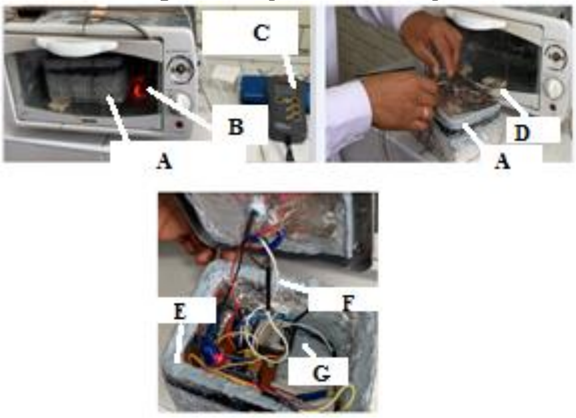
Therefore, the temperature matrix is:

$$Q = (T_1, T_2, T_3, \dots, T_n)^T \qquad (12)$$

4 SETUP FOR THE EXPERIMENTS

After analyzing the mathematical models of the dynamics and thermodynamics of the temperature recorder subsystem and its environment, it was proceeded to design and select the necessary devices with instrumentation, in order to have the entire setup ready for the experimental verifications. The figure 3 shows the temperature chamber that is indicated by “A”, which was adapted to the control temperature [1] between values ranges from 25 to 70 degrees Celsius. This adapted temperature chamber has two parallel electrical resistors of 50 Ohms and 64 Ohms respectively and they are indicated by “B” and “D” in figure 3.

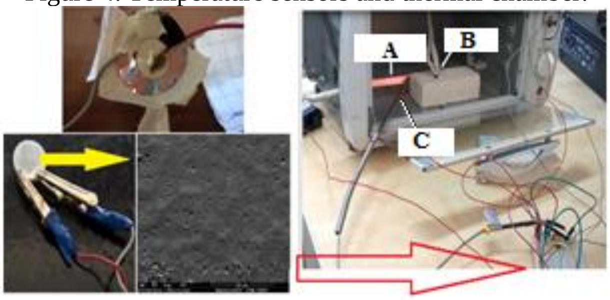
Figure 3. Experimental setup



The recorder has dimensions 10 cm by 20 cm, which is also shown as the base for small walls of the height of 10 cm and they are indicated by “E”, “F” and “G” in figure 3, whose thickness and obtained material were based on the equations of the previous chapter. It was necessary to cover aluminum sheets for the Faraday effect, which means this helped that some external electromagnetic signals do not generate interference at the time of storing the thermodynamic data in the temperature recorder subsystem and this was measured by a multimeter temperature and it is indicated by “C” in figure 3. In addition, this subsystem has its own energy source from a DC 9 Volt battery that provides power to the internal devices of the temperature recorder subsystem.

The figure 4 shows the designed prototype temperature sensor that was based on "Anodic Aluminum Oxide (AAO)" [2] [3] that has pores at the nanoscale due to the performance of being robust, fast response time and good stability in the capture of physical variables, such as the temperature, but transduced to an electrical value as it is shown in "C" of figure 4. The objective of the designing temperature sensors to replace the Lm35 or thermocouples (as it is shown in “A” and “B” of the figure 4) is to monitor the surface temperature, which is useful for optimal temperature control and to analyze the effect of ultrasound cleaning in washing machines, which is used in washing machines for cleaning vicuña wool (for the model of the washing machine that was designed by the engineer Benjamín Barriga).

Figure 4. Temperature sensors and thermal chamber.

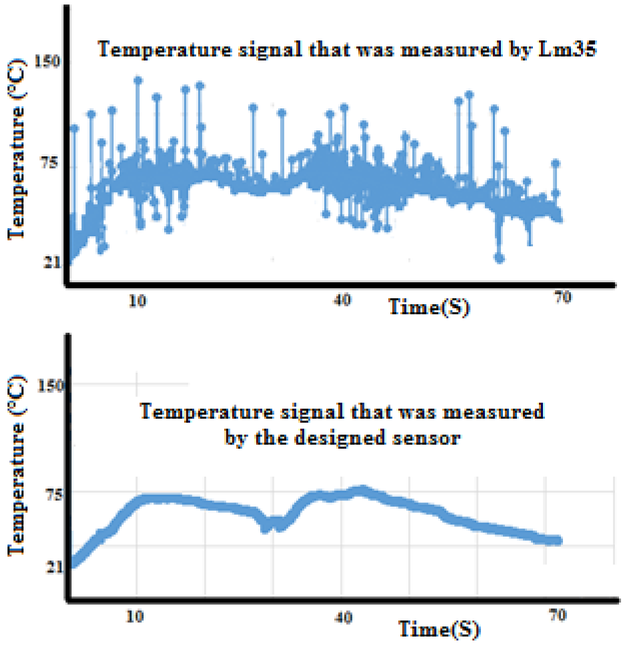


5 EXPERIMENTAL ANALYSIS

For the experimental evaluation, the thermal chamber that was described in the previous chapter that was used by inserting the temperature recorder at values from 25 to 70 degrees Celsius. The thermal behavior of the temperature recorder was analyzed first, which geometric parameters were calculated and based on the models of the equations that were cited in previous chapters, from which the type of material was known as "ceramic mixture of thermal conductivity 0.8W", in addition to the thickness of the walls is around 1.8 cm.

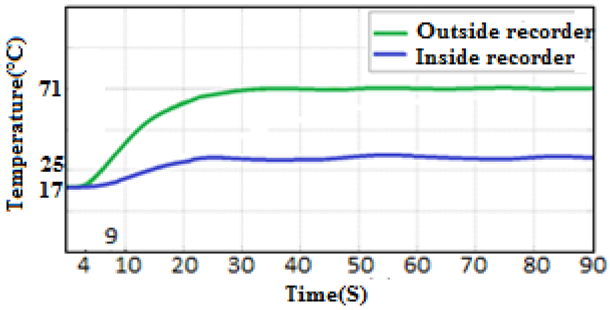
With such information that already designed in the recorder and test on the thermal chamber, a comparison was made of the prototype sensor based on nanostructures [4] [5] AAO versus an integrated temperature sensor the LM35, which comparison curves are shown in the figure 5. From where it can be seen that it is necessary to have a filter for the case of the registration with LM35, but not for the prototype sensor, since the tests were carried out for a temperature increases from 21 to 75 degrees Celsius and then from the latter to 50 degrees Celsius and increases again until 75 degrees Celsius and finally returns to 21 degrees Celsius. This thermal trend behavior is maintained by the prototype sensor, which is finally chosen for internal monitoring of the internal temperature of the recorder, since for external temperatures it was decided to work with a K-type thermocouple [6] that was linearized and compensated by the AD595 integrated circuit. Monitor external temperatures of the recorder is around to 70 degrees Celsius, despite the fact that it is in motion due to external force that is applied in opposition to the elastic vector forces and achieving forced oscillation, because of testing the temperature control in oscillation tasks, such as it was given by washing machine that is using ultrasound.

Figure 5. Temperature curves analysis.



The figure 6 shows the experimental tests curves, where the temperature data was stored in the designed recorder, the total monitoring time was 1 hour. However, there are shown for about 90 seconds of which the temperature outside of the temperature recorder (green color curve) is compared versus the temperature inside the recorder (blue color curve). Then the recorder has the ability to save thermal variables in memory of the system despite the fact that it is in motion and at 70 degrees Celsius externally.

Figure 6. Final tests results curves.



6 CONCLUSIONS

It was measured the temperature data inside the thermal system (temperature recorder) around 70 degrees Celsius outside of this and the system is under 4 degrees of freedom (DOF) to achieve a surface control that was emulated in washing machine that uses ultrasound conditions.

It was possible to compare the performance of sensors based on nanostructures with traditional sensors, because of verifying the consequence of using them in thermo-mechatronic systems. Hence, it is possible to take the advantage of the robustness and short response time of this new kind of sensor.

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