21 th International Conference on Renewable Energies and Power Quality (ICREPQ'23)
Madrid (Spain), 24 th to 26 th May 2023
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, Volume No.21, July 2023

Modulating Functions Analysis For Wireless Data Transmission Because Of Advanced Sensors In Energy-Saving Process Of Washing

A: J. Alan Calderón Ch.[1,2,3,*], *B:* Julio C. Tafur Sotelo[2], *C:* Benjamín Barriga Gamarra[2], *D:* Jorge Alencastre[2], *E:* Álex Quispe M.[2], *F:* F. Alan Ccarita[2]

[1] Applied Nanophysics, Institute for Physics,
Technical University of Ilmenau, Ilmenau 98693, Germany.
Corresponding and the main author:** ***A: ***alan.calderon@pucp.edu.pe***

[2] Control Engineering and Automation Master Program, Mechatronic Engineering Master Program, Engineering Department, Pontificia Universidad Católica del Perú, Perú.

[3] Aplicaciones Avanzadas en Sistema Mecatrónicos JACH S.A.C.

B: jtafur@pucp.edu.pe, *C:* bbarrig@pucp.edu.pe, *D:* jalenca@pucp.edu.pe, *E:* alex.quispe@unsaac.edu.pe, *F:* alan.ccarita@pucp.edu.pe

Abstract. The vibration measurement of flows in transient or steady-state is a very complicated task. Moreover, to correlate it with a temperature process is quite important according to get information regarding molecular kinetic energy of thermal sources (such as flow measurement used in cleaning tasks) according to achieve heating transfer information of a thermal process. However, there is a trouble concerning the transduction stage in the measurement while it is not a transducer designed algorithm as a consequence of a mathematical model, which correlates the calibration data with the theoretical model of the heating/vibration transfer. For this reason, in this research is proposed intelligent sensors/transducers, which are based on Anodic Aluminium Oxide (AAO) and a mathematical procedure of the measurement instrumentation according to adaptive coefficients in the Modulating Functions strategies analysis and getting optimal measurements. In this research is explained and analysed the temperature measurement process and the transduction process as the strict correlation of the calibration of the temperature/vibration sensor. For this reason, there were evaluated different transducers and the temperature/vibration reference for the calibration. The based on nanostructures temperature sensors are designed by specific and complex procedures according to achieve quite operation range, robustness and precision. Moreover, the transduction can be obtained through different electrical answer variables such as voltage, electrical current or capacitance and possible to send by wireless mechanisms and protocols to the main control system. Therefore, the evaluation of the designed advanced sensor performance was achieved by the vibration and temperature measurement of the water surface of a ultrasound washing machine, for which the designed sensor enhances energy-saving of the washing process.

Key words. Modulating Function, Wireless data transmission, Smart sensors, Energy-saving.

1. Introduction

Peru is a young technological country, in which is developed extractive industrial activities, agriculture and fishing primordially, in spite of Inca empire achieved its own technology to keep the organization among population necessities and strategies solutions to solve tasks, such as agriculture over Andenes. In this research is analysed the problematic of the wireless physical variables measurements according to solve specific engineering task. For example, in plastics productions or alloy, the temperature measurement is quite important due to evaluate the homogeneous heating transmission in the thermal process. Notwithstanding, there are internal sub-process as rotomolding, in which the temperature measurement needs to avoid wire connections. In other side, there are specific cleaning processes, which need to reduce chemical components, as for example, the wool cleaning by ultrasound. Even though it carries over vibrations and excess of sound. Therefore, the wireless measurement of vibration is very important to keep in balance the mechanical energy transmission in machines. Hence, in this research it is explained the strategies to solve the described problematic through advanced sensors based on nanostructures and advanced algorithms to correlate mechanical processes with thermal processes while there are measured the physical variables of the process.

2. Methodology

Optimization is a methodology or mathematical procedure, in which is compared the requirement of a task with a measured or estimated variable. The best comparison is achieved, when the error tends to be null. There are methods by simple statistical contexts, adaptive matrix, predictive values and complex neural models, in which *"y"* is the output matrix according to store the transduction result in the time domain *"t"*, the derivative

"$\frac{d^n}{dt^n}$" in the order *"n"*, the coefficients *"a"* and *"b"* for every component of the output matrix *"y"* and input matrix *"u"* achieved by the auxiliary variable *"i"*. The polynomial expansion of the dynamic over the variable *"y"* is obtained with the error "*e(t)"* that helps to enhance the estimated model of the transduced result, as it is described in the equation (1).

$$\frac{d^n}{dt^n}y(t) + \sum_{i=1}^{n} a_i \frac{d^{n-i}}{dt^n}y(t) = \sum_{i=1}^{n} b_i \frac{d^{n-i}}{dt^n}u(t) + e(t) \qquad (1)$$

The costing function *"J"* depends on the physical parameters "θ", the connector auxiliary *"r"* correlates the generalized input variable "g_i" with the generalized output variable "g_k", as it is showed by the equation (2)

$$J(\theta) = \sum_{i=0}^{n_1}\sum_{k=0}^{n_1} r_{ik} g_i(\theta) g_k(\theta) \qquad (2)$$

The previous equation lets to work in nonlinear domain, even though for linear models the equation (3) is the reduction of the equation (2) and the derivative of the costing function that is proposed by the equation (3) looks for the optimal parameters "θ" in the corrected minimal square, because of the weight matrix "W", in which "Γ" is the total input matrix that was achieved before the transduction result.

$$\frac{\partial J}{\partial \theta} = (\Upsilon - \Gamma\theta)^T W^{-1}(\Upsilon - \Gamma\theta) \qquad (3)$$

Therefore, it is obtained the physical parameters matrix that is given by the equation (4).

$$\theta = (\Gamma^T W^{-1}\Gamma)^{-1}\,\Gamma^T W^{-1}\Upsilon \qquad (\mathbf{4})$$

Furthermore, every input variable is prone to be disturbed by electromagnetic noise, because of the measurement process. Therefore, it was analyzed by Least Mean Square (LMS) algorithm an adaptive filter in order to achieve a previous filtered signal before to get the final transduced matrix. It means, the equation (5) is the LMS that is used to achieve the adaptive filtering for previous transduced signal that is adapted by the coefficient "α".

$$\alpha_{n+1}(m) = \alpha_n(m) + \mu e(m) X(m) \qquad (5)$$

Finally, the measured matrix of the physical variables of the surface *"C1"* can achieve an optimal surface *"C2"*, because of the mathematical analysis that is described in paragraphs above and helped to design the optimization algorithm for the transduction task of the smart designed sensor. Moreover, the estimated matrix that is depicted by the surface *"C3"* also can get the optimal result *"C2"* to support tasks of predictive models, which is showed by the figure 1.

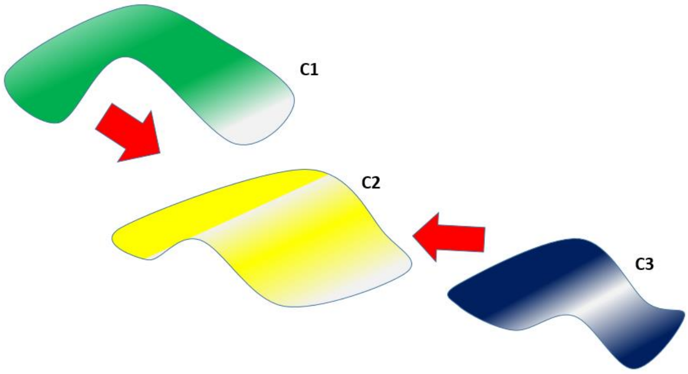

Fig. 1. Optimization analysis by surfaces.

In order to obtain the mathematical model of the transduction dynamics, it was studied two simple processes that are given by the heating transmission and second order system based in mass, damping, spring system, as a consequence of the experimental data that can be correlated by the theoretical models and the advanced estimated algorithm, which can enhance the final transductions of the designed sensor.

In figure 2, it is depicted the heat transmission from a warm temperature surface at temperature *"HT"* irradiating heating through infrared (IR) to the surface of the smart designed sensor. Moreover, it is depicted the vibration of the fluid surface as a consequence of the parameters deformation coefficient "K" and the damping coefficient "β".

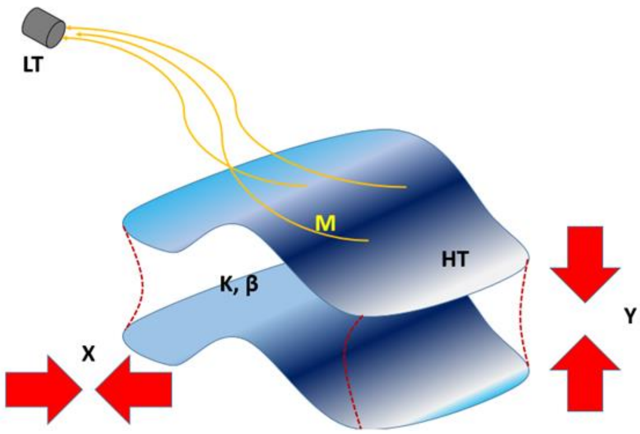

Fig. 2. Thermal and vibration scheme for the theoretical modelling of the designed sensor.

Hence, from the figure 2 that is showed above, it was possible to identify the heat transmission that is interpreted by the equation (6), in which "$\Theta(t)$" is the final temperature in the time domain "t", the temperature from the source after time of the thermal equilibrium is given by "Θ_f" and the thermal coefficients "*R*" and "*C*" that are showed by the equation (6).

$$\Theta(t) = \Theta_f \left(1 - e^{-\frac{t}{RC}}\right) \quad (6)$$

The equation (7) is obtained after the Laplace transformation in equation (6), in which "K_p" is the proportional gain, "L" is the sensor delay in temperature measurement, "τ" is the sensor response time for the temperature measurement.

$$\frac{T^{\circ}}{U(S)} = \frac{K_p e^{LS}}{\tau S + 1} \quad (7)$$

Thus, the equations (6) and (7) are the time domain and Laplace domain models, respectively, according to summarize theoretical models for the heat transmission and consequentially the temperature measurement. Moreover, by the equation (8) it is possible to model a second order system according to understand its dynamic in time domain, such as also it is represented by the equation (8). The deformation and damping coefficients "*K*" and "*β*" are parameters of the fluid vibration as it was depicted in the figure 2.

$$M\left(\frac{d^2X_1}{dt^2} - \frac{d^2X_0}{dt^2}\right) = KX_0 + \beta\frac{dX_0}{dt} \quad (8)$$

By Laplace domain in the equation (8), it is obtained the following model due to interpret the experimental data as the second order response, which is given by the equation (9).

$$MS^2X_1(S) = X_0(S)[K + \beta S + MS^2] \quad (9)$$

Thereby, the equation (9) summarizes the parameters for a vibration sensor in Laplace domain. The equation (8) and equation (9) give information of the dynamic characteristics of the mechanical movement effects that were measured by the smart sensor. However, these equations in complement with the equations (6) and (7) are the theoretical model for the temperature and vibration measurement, which proportionate a referential criterion for the designed adaptive algorithm. This algorithm correlates the experimental information by multiple estimation variable, modulating functions and least mean square in order to give to the user the transduction result of the physical variables that were measured: temperature and vibration of the fluid surface.

There are simple mathematical models for sensors, which give a first order response. There are explained two model equations for sensors, such as in figure 3, in which is represented heat transmission from thermal focus to the sensor.

As a consequence of the equations analyzed in paragraphs above, the first order response is associated with slowly system, such as thermal process. Nevertheless, there are processes, which are under overshoots, such as starting from second order systems (air pressure changes processes, high ultrasound systems, and magnetic bearing systems), but it does not mean that a thermal system could not be under overshoots during calibration of the thermal sensor, which is analyzed in following chapters.

The figure 3 shows the fluid vibration sensor scheme, in which is depicted the vibration source "*A*" and the medium transmission fluids "*B*" and "*C*". The designed sensor/transducer has an emitter and receiver owing to send the infrared emitter signal and by the reflection and refraction of the infrared wave according to capture the temperature/vibration measurement. Furthermore, it is depicted the adaptive algorithm scheme by the input signal. "*Yi*", the output signal "*Yo*", the disturbance "*W*" and the matrix adaptive coefficients "*G*".

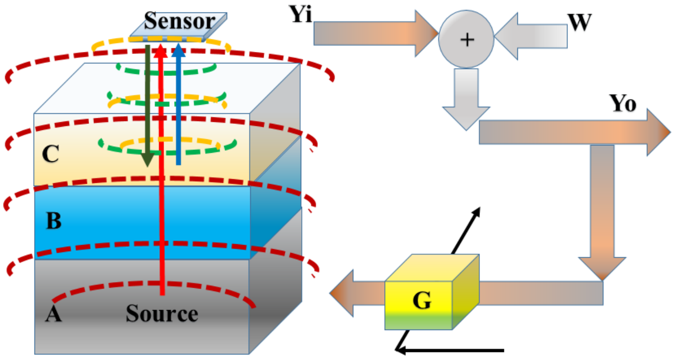

Fig. 3. Fluid vibration ultrasound sensor scheme.

3. Results

The sensor design process depends on the steps sequence made according to obtain the nanoholes in which are stored atoms under specific geometries, such as dots, wires and tubes or configuration of them. In spite of the robustness and short response time, which are characteristics and properties that can not be achieved only fixing the nanostructures geometry of the designed sensor. Hence, the material properties are quite important in the sensors designed task, such as for example, it is given titanium dioxide that has good performance.

Nevertheless, to elaborate the transducers samples, it is necessary a selection of the main component of the sample, as it is showed in the subfigure A of the figure 4, and the required material is Aluminum, because of more simple and cleaning process after the geometrical structure achieved consequently the anodization. In the subfigure B is showed the previous step that was given by the electropolishing. In the subfigure C is showed the chemical components that were used for the electrochemical deposition over the anodize samples. And finally in the subfigure D is showed the electrochemical deposition to obtain the transducer samples by nanodots or amorphous nanostructures that are presented in this research.

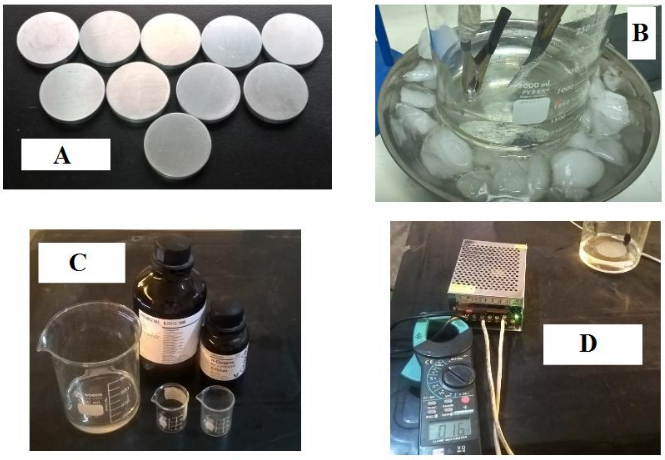

Fig. 4. Setup for the transducer samples design.

The designed transducer samples were evaluated by different methodologies according to verify their performance. Also, it was possible to see some nanodots by an optical microscope due to the size of the showed samples were around 1 um or 1000 nm (the minimal size to watch by optical microscopes).

Moreover, there are showed two samples of the designed sensors based in the elaborated samples transducers, which are the support of the temperature measurement and vibration measurement. These samples are showed by the figure 5.

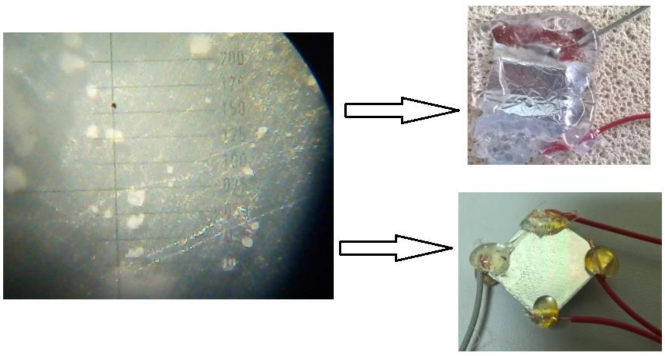

Fig. 5. Setup of the designed transducer and sensor samples.

The following figure 6 shows one of the ultrasound actuator that produced ultrasound over the water of the washing machine in order to achieve the vicuña wool cleaning.

The designed smart sensor that is presented in this research evaluated the temperature and vibration surface of the water for the cleaning process performance. The washing machine was designed and elaborated by engineers: Benjamín Barriga, Jorge Alencastre, Alan Ccarita and Álex Quispe because to clean vicuña wool in the Andes mountains. And this machine needed the evaluation of its performance by the intelligent sensor that was designed and presented in this research.

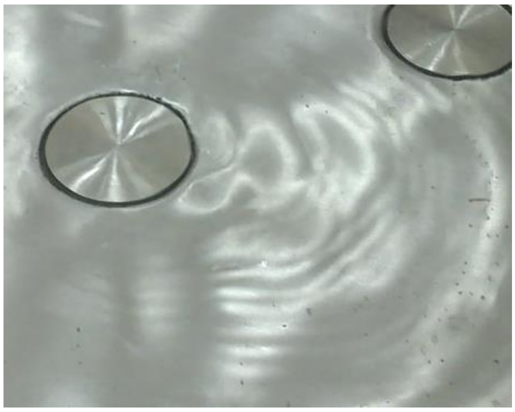

Fig. 6. Ultrasound actuator.

In the figure 7 is showed the setup of the designed sensor for the vibration signal measurement. It is showed the vibration source, the fixation of the sensor over the vibrator box actuator and it is showed the multimeter to verify the electrical value of the transduction measurement. This multimeter helps to correlate with the decibels of the vibration signal correlation.

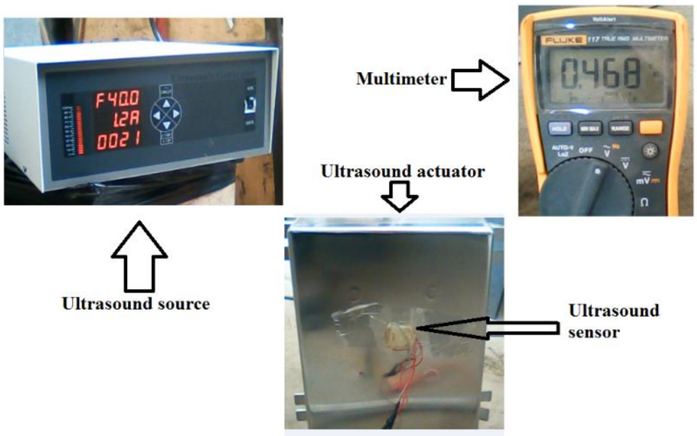

Fig. 7. Setup vibration sensor.

It was necessary to design an algorithm to study the registered temperature, to estimate, to adapt and to predict them in order to organize the measurement information in comparison with every desired signal from the calibration information by an optimal analysis.

The performance of the designed transducer helped to understand the dynamic of the temperature in the range of 19 Celsius degrees to 300 Celsius degrees.

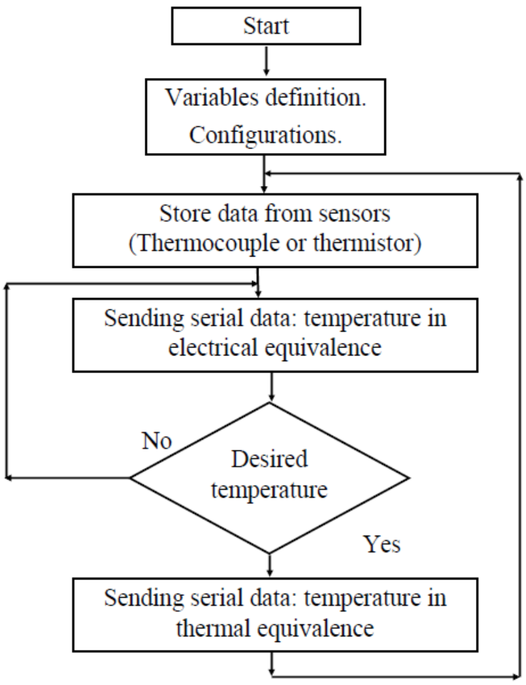

Fig. 8. Algorithm scheme for the temperature transduction.

In figure 9 is showed fluid surface vibration simulation, by the designed transducer simulation, it was possible to identify the amplitude of every 3D wave over the fluid surface, besides the frequency changes as a consequence of the temperature/vibration correlation of the designed intelligent transducer based in nanostructures of AAO.

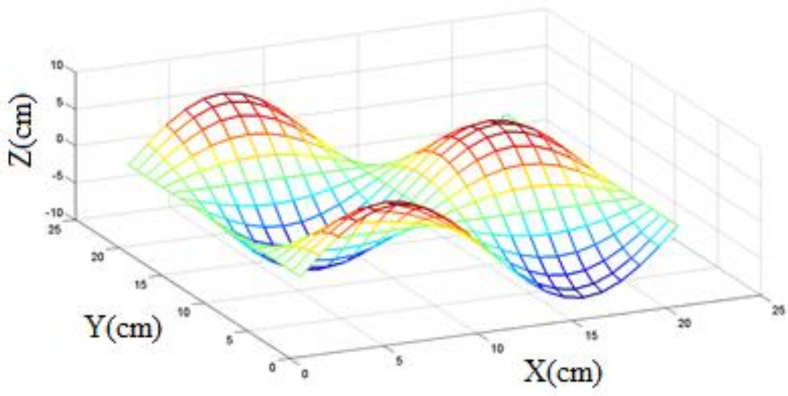

Fig. 9. Fluid surface vibration simulation by the transducer designed measurement.

It is showed in the following figure 10 the theoretical vibration surface of the measured fluid, this analysis is depicted by the surface that is located at the top of the figure 10, in which it is possible to identify the theoretical decibels that are caused by the ultrasound actuators (Z axis) and their theoretical length waves (X and Y axis). Moreover, in the surface that is located at the bottom of the figure 10 is showed the vibrating analysis result from the designed smart sensor, from which it was identified that the measured vibration surface had 2 percent of steady state error and the temperature surface achieved 1.6 percent of error in the steady state too. The figure 10 also shows the temperature behavior over the vibrating surface of the fluid by red color in maximal values for the theoretical model (the surface that is located at the top of the figure 10) and the experimental result measured by the designed smart sensor (the surface that is located at the bottom of the figure 10).

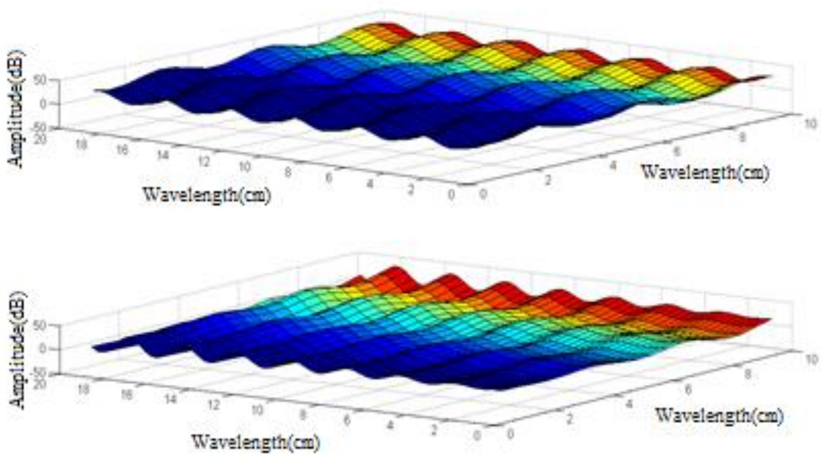

Fig. 10. Fluid surface vibration by the designed transducer measurement.

4. Conclusion

It was designed an intelligent temperature/vibration sensor/transducer with the capacity to measure the temperature/vibration of liquids (fluids) in high frequency, hence, this sensor sent infrared signal and ultrasound signal over the surface of the liquid according to receive the refraction of the ultrasound signal and the absorbance of the infrared signal. Both of them received signal that helped to measure the frequency of the liquid vibration surface and to know the frequency of the vibration, moreover, the temperature of the liquid surface by infrared analysis. Therefore, keeping the right temperature measurement helps to enhance an optimal energy consumes of the ultrasound washing machine.

The measurement of the ultrasound refraction also helped to validate the frequency of the liquid vibration. Also, it was possible to enhance the noise cancellation of the system owing to the ultrasound measured signal is the anti-noise signal of the main system.

The sensor design system can enhance the control of the temperature and vibration over the fluid surface.

It is expected that proposed wireless intelligent designed sensor/transducer could be evaluated in more applications to control more physical variables such as pressure, distance, level, temperature or flow of different fluids. In addition, it is expected to evaluate the Modulating Functions algorithm through adaptive coefficients due to increase the range operating work in spite of nonlinearities in the measurements.

Furthermore, this new proposed sensor looks for optimization in energy consumes for systems that use it due to this proposed sensor reduces the possibility of mechanical disturbance in the main control system.

Therefore, the distributed control gets that the system, which has multivariable, could organize and distribute the measurement of the data and the control answer variables can achieve faster answer with the capability that the hardware of the system is reduced in quantity of wires then as a consequence of this, it is suggested to evaluate the performance of the proposed sensor in more applications.

Acknowledgement

It is expressed deep warm gratefulness to Aleksandra Ulianova de Calderón due to her total support for the development of this research during experiments and format of the proposed article, moreover, the analysis to understand the importance of caring for the environment conditions.

It is expressed thankful to Carlos Luis Calderón Soria, because of his continuous support in experimental analysis results for this research.

There is expressed special thankful to the Master Degree Mechatronic Program PUCP and DGI (Dirección de Gestión de la Investigación) researching office from PUCP (Pontificia Universidad Católica del Perú), because of its financial support in this research.

References

[1] Joaquim Carneiro. Development of capacitive-type sensors by electrochemical anodization: humidity and touch sensing applications. Sensors MDPI (2021).

[2] Domagalski, Jakub. Recent Advances in Nanoporous Anodic Alumina: Principles, Engineering, and Applications. MDPI, nanomaterials (2021).

[3] Endress Hauser GmbH Co. Portable Ultrasonic Flow Measuring System prosonic flow 92.

[4] Martin Kraft. VIBRATIONAL SPECTROSCOPIC SENSORS. Fundamentals, Instrumentation and Applications. CTR - Carinthian Tech Research AG, A-9524 Villach/St. Magdalen, Austria (2006).

[5] Ian F. Ayldiz. Electromagnetic wireless nanosensor networks. Nano Communication Networks, Science Direct (2010).

[6] Landau L. D., Lifshitz E. M. Theory of elasticity, course of theoretical physics, volume 7. Institute of physical problems, USSR academy of science (1959).

[7] Feynman Richard, Leighton Robert, Sands Matthew. The Feynman lectures on physics, volume I. New millennium editors (1962).

[8] A. E. Person, Aerodynamic parameter estimation via Fourier modulating function techniques, Brown University , NASA Contractor Report 4654, (1995).

[9] Faye Zhang, Mingshun Jiang, Lei Zhang, Shaobo Ji, Qingmei Sui, Chenhui Su, Shanshan Lv. Internal Combustion Engine Fault Identification Based on FBG Vibration Sensor and Support Vector Machines Algorithm. Hindawi, Mathematical Problems in Engineering, https://doi.org/10.1155/2019/8469868 (2019).

[10] B. Christiana, J. Volkb, I. E. Lukàcsb, E. Sautieffc, C. Sturmd, A. Graillote, R. Daukseviciusf, E. O´Reillyg, O. Ambachera,h, V. Lebedeva. Piezo-force and vibration analysis of ZnO nanowire arrays for sensor application. Procedia Engineering (2016).

[11] Optimal Analysis for the Correlation between Vibration and Temperature through an Intelligent Sensor/Transducer Based in Amorphous Nanostructures to Measure Vibrating Surfaces Temperature. (2022).