Remote Laboratory System for Automatic Engineering

Omar Mar Cornelio [1,*], Jorge Gulín González [2], Iván Santana Ching [3] and Bárbara Bron Fonseca[4]

[1]University of Computer Sciences, Cuba; omarmar@uci.cu ; https://orcid.org/0000-0002-0689-6341
[2]University of Computer Sciences, Cuba; gulinj@uci.cu; https://orcid.org/0000-0001-7912-2665
[3]"Marta Abreu" Central University of the Villas, Cuba; ching@uclv.cu; https://orcid.org/0000-0001-5089-520X
[4]University of Computer Sciences, Cuba; bbron@uci.cu; https://orcid.org/0000-0001-9463-8408

* Correspondence: omarmar@uci.cu

Abstract

The training of specialists in automation in Cuba is carried out through the career of Automation Engineering that has within its fundamental disciplines, the Control Systems discipline. For the development of laboratory practices, students work on physical or remote devices, in person or remotely, in the latter using Remote Laboratory Systems. The present investigation proposes a Remote Laboratory System for the practice of control of the Automatic Engineering career. A scale thermal process model is designed for experimentation. The main result was the availability of practices for system identification, controller design and controller execution in real processes. In addition, the implemented solution allows students to carry out studies of the behavior of the temperature variable, the controller's response in the designed process, the establishment times, among other variables.

Keywords: automatic control; laboratory practices; Remote Laboratory System.

1.Introduction

In Cuba the Automation Engineering career has the mission of training specialists in the field of automation. The race has the Control Systems discipline. The study plan of the discipline is made up of a group of subjects that make up the basic curriculum such as: Modeling and simulation, Electrical Machinery, Control Engineering I, Control Engineering II, Processes, Process Control I and Electric Drive.

In order to apply the contents of the Control Engineering II course, laboratory practices are carried out as a class typology. In this modality, students express the knowledge acquired in equipped laboratories, in correspondence with the required profile [1, 2]. In this context, the user can carry out the practicals in physical laboratories, with equipment related to the received subject, or carry out remote practices. To do this, they access centralized physical equipment remotely with the use of remote laboratories.

Remote or Remote Laboratories are conventional laboratories with generally sophisticated or exclusive equipment that, through Web interfaces, allow the equipment to be manipulated remotely [1, 2]. This type of access facilitates the sharing of resources between various institutions, in this way the investment for equipment can be shared between several institutions and the number of specialized users increases, thus increasing academic benefits [3-5].

DOI: https://doi.org/10.54216/JCIM.010201

The Remote Laboratories represent a place or environment whose function is to carry out a control over a physical system at a distance, with the aim of teleoperating a real system, carrying out experiments and accessing data through the network to obtain measurements [6, 7].

Among the characteristics that distinguish remote laboratories is the decrease in expenses for maintenance and equipment concepts [8], [9]. This feature is considered to make them attractive for use by institutions and research centers that offer distance learning courses. However, the main remote laboratory platforms constitute proprietary software, which makes technological sovereignty and independence impossible, restricts its acquisition and use by budgeted educational institutions [10].

The objective of this research is to develop a Remote Laboratory System for the practice of Automation Engineering career control. The proposed system integrates a set of processes that guarantee experimentation, for which a scale model of a thermal process is designed.

2. Method

This section describes the fundamental components of the Remote Laboratory System proposal. The proposal has three fundamental activities: design of controllers, identification of systems and execution of practices in physical systems. The generated work environment incorporates a scenario where students can face the development of practices where an environment homologous to reality is recreated. The design of the Remote Laboratory System has been modeled by four fundamental actors that group the main Use Cases of the System. Fig. 1 shows the Use Case Diagram of the proposed system.

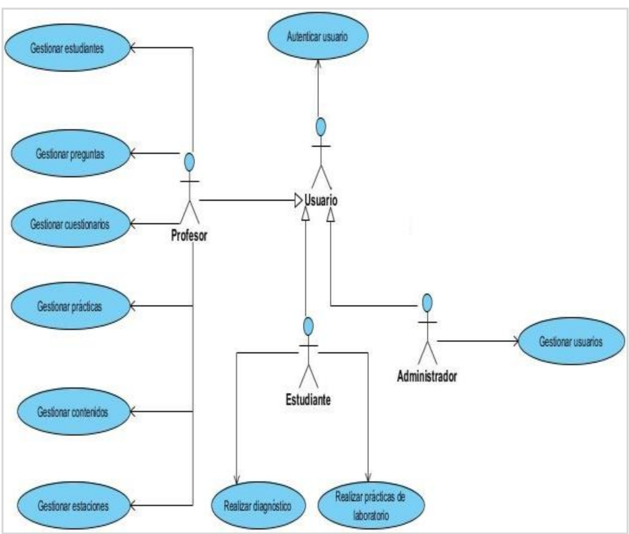

Figure 1. Use Case Diagram of the proposed system.

A. Description of the actors in the Use Case.

The User actor: is a representation of a generic actor that has the role of authenticating in the system. From this actor their permissions are inherited for the rest of the actors in the system.

The Administrator actor: inherits the functionality of the User actor and has the permissions for user management (insert users, modify users and delete users).

The Teacher actor: inherits the functionalities of the User actor and also has the permissions for the management of the workstations to carry out the laboratory practices, manages the laboratory practices that the students will carry out, manages students in the system. It also has other assigned functionalities such as the management of evaluation questions, evaluation questionnaires and study content.

The Student actor: inherits the functionalities of the User actor and can also diagnose his abilities and carry out laboratory practices.

DOI: https://doi.org/10.54216/JCIM.010201

In the literature, the architectures of the Remote Laboratory Systems for teaching Control can be found [6, 11-14]. In them, it was found that each system has a defined architecture and workflow depending on the phenomenon being modelled [15]. Fig. 2 shows the architecture defined for the Remote Laboratory System proposal.

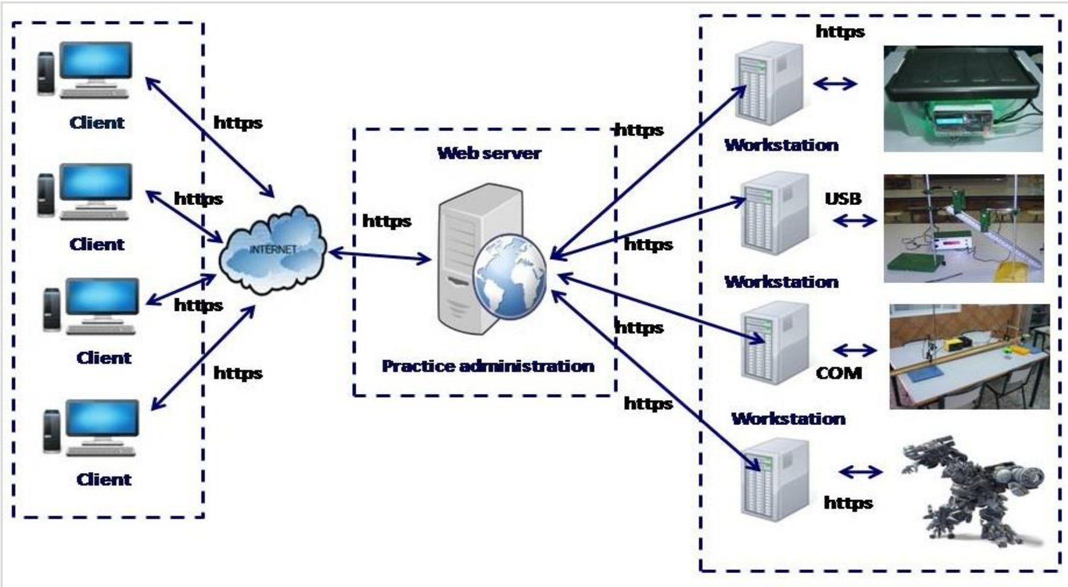

Figure 2. Architecture defined for the proposed Remote Laboratory System.

The proposed architecture has three fundamental components: clients, practice administration and workstation. The clients represent the end users who carry out the experiments available in the Remote Laboratory System. The practice administration groups all the management carried out by the application servers for the proposed laboratory system. Workstations and labs are managed on the application server. For their part, workstations represent the real processes on which students carry out the proposed experimentations.

For the development of this research work, a set of technologies and tools were used to guarantee the solution construction process. The principle was that the technologies and tools should be entirely free software with the aim of guaranteeing technological sovereignty and independence. PostgreSQL was used in its version 9.6 as a database management system, Hibernate as a working environment, Python in its version 3.0 as a programming language.

For the implementation of the remote practices, a model was designed that manages the control of the process using an Arduino microcontroller [16], [17], [18] as a development platform open hardware [19, 20], [21] Fig. 3 shows the designed model.

Figure 3. Scale model of a thermal process.

DOI: https://doi.org/10.54216/JCIM.010201

The model represents a thermal process at scale. It is designed for students to experiment on it where they can identify the system, tune the controller, and test the controller on the physical system.

The model is made up of polyethylene armor; it uses an LM35 temperature sensor, an Arduino one microcontroller card with an Ethernet interface to guarantee communication with the Remote Laboratory System. It also incorporates a resistor inside responsible for dissipating thermal energy which is re-circulated through an internal ventilation system.

From the general conception of the model, a PID controller was programmed on the Arduino microcontroller card that receives its adjustment parameters from the Remote Laboratory System. The student can analyze the behavior of the temperature variable, the controller's response in the designed process, the establishment times, among other variables of interest.

From the three fundamental activities proposed for the Remote Laboratory System (design of controllers, identification of systems and execution of practices in physical systems). Fig 4. Shows the three fundamental activities of the Laboratory System.

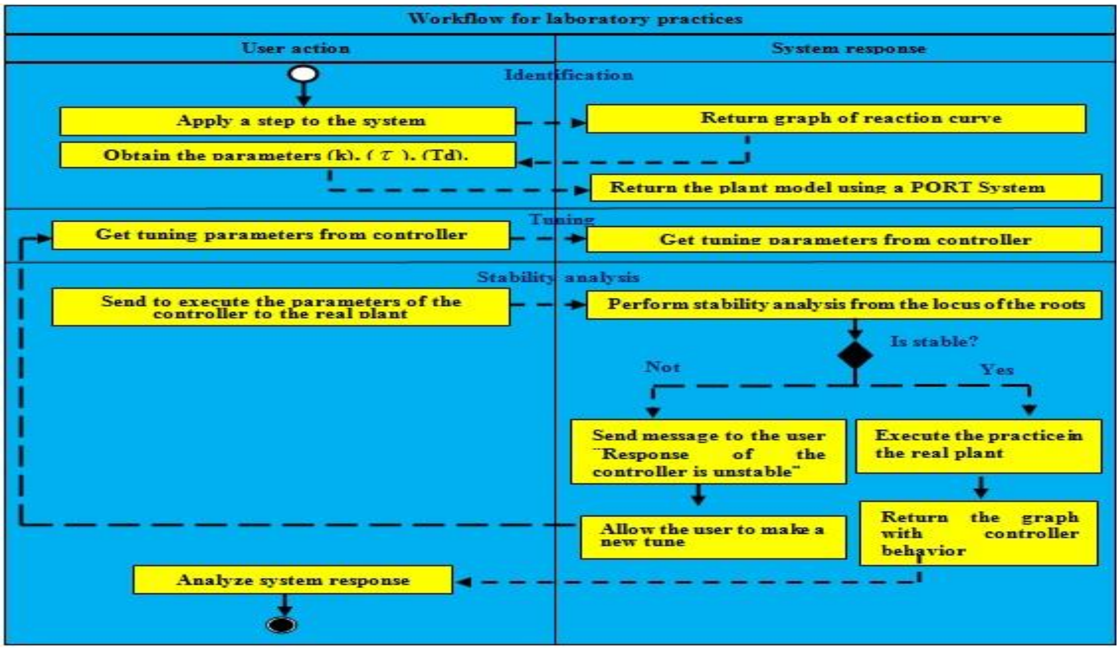

Figure 4. Workflow of the proposed activities for the Remote Laboratory System.

3. Results

The development of the laboratory practices generates a set of events that are managed and stored in the system database. From the storage of the operations carried out, reports are generated on the actions carried out by the students and the operation history is controlled.

Web clients are the end users of the tool. In the same proposal, the students carry out the Control Laboratory practices. They access the application server through a connection to the university network or the Internet.

The web application server is in charge of communication between web clients and workstations; from this, the administration of the practices is carried out and the proposed workflow is managed. The web application server allows the exchange of information through web services with workstations. The workstations are physically connected to the plants that function as a model in the system.

The system supports the management of Control laboratory practices through a workflow. The flow represents an effective solution based on a sequence for the proposed activities. Fig. 5 represents the proposed workflow.

DOI: https://doi.org/10.54216/JCIM.010201

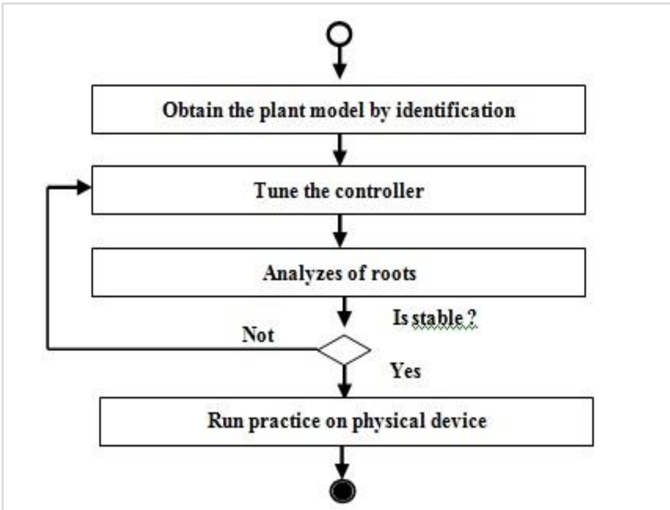

Figure 5. Proposed workflow.

The Fig. 6 shows the system interface to perform the system identification activity. The system identification activity allows you to carry out system identification practices to be controlled. The student performs an approach using a First Order System with Transportation Delay (PORT).

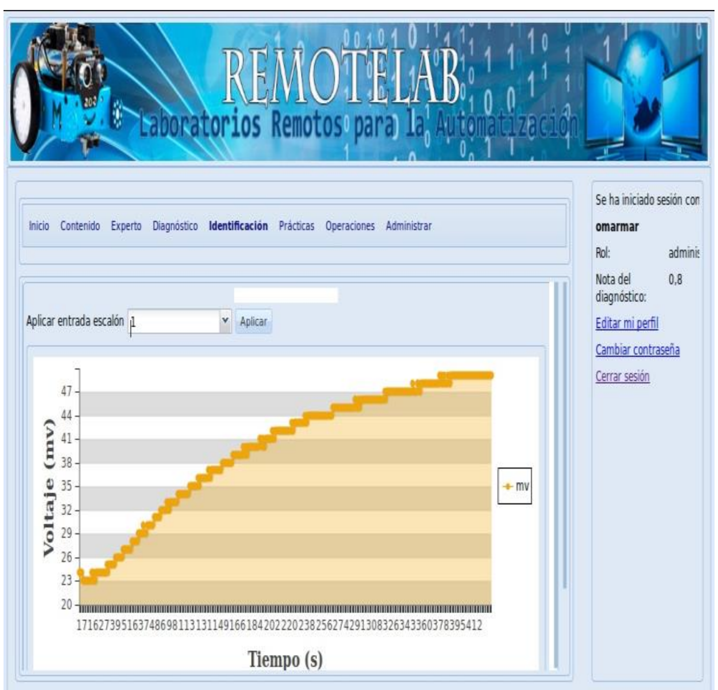

Figure 6. System identification interface from the reaction curve.

For the system identification process, the student must select a step that will be applied to the floor to obtain the reaction curve. From the reaction curve the student must be able to obtain the values (k), (τ), (Td). In the activity the student obtained as a result the approximation of the plant model identified by PORT in the continuous domain.

DOI: https://doi.org/10.54216/JCIM.010201

Once the system has been identified, the controller is tuned and the plant and controller model is obtained before running on the physical systems. Figure 7 shows the data entry interface for the designed controller. Students from the application of a design method must obtain the tuning parameters of the controller to be used in real practice.

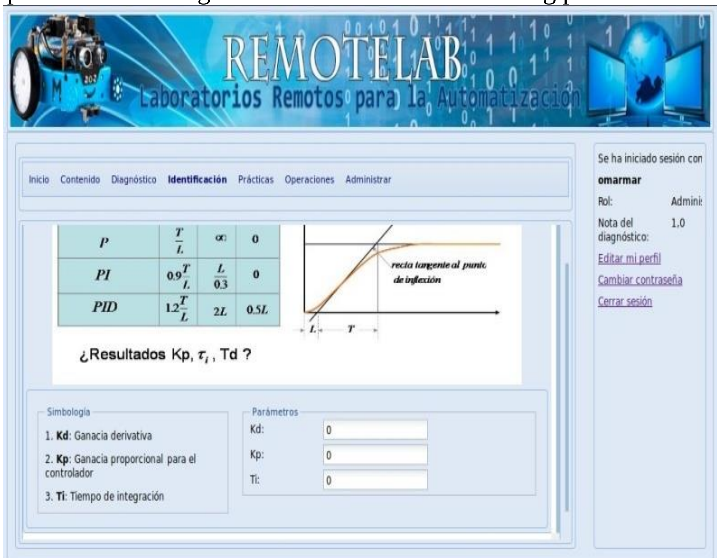

Figure 7. Interface in which the controller is tuned.

For the tuning of the controller it is important to know the rules of the design, for example:

If a steady state error equal to zero is desired, a rule that introduces the integrating component.

If the establishment time should be as short as possible, a rule that introduces the derivative component.

From the design rules it is decided if the controller is P, PI or PID so that the type of the system is one. For Ziegler-Nichols the controller parameters are calculated as expressed in Table 1 [22].

Table I. Values of the controller parameters according to Ziegler-Nichols.

Controller type	K_p	τ_i	τ_d
P	$\frac{T}{L}$	∞	0
PI	$0.9\frac{T}{L}$	$\frac{L}{0.3}$	0
PID	1.2	2L	0.5L

To obtain L and T, a tangent line is drawn to the inflection point of the response, the intersection with the time axis and with the final value of the amplitude form the distances L and T.

With L and T, the parameters of the PID controller are obtained obtaining the controller model as shown by equation 1 in the continuous domain.

$$G_c(s) = K_p\left(1 + \frac{1}{\tau_i s} + \tau_d s\right) \quad (1)$$

The stability analysis allows to identify the malfunction in the stations available for the Remote Laboratory System [23], [24], [25].

DOI: https://doi.org/10.54216/JCIM.010201

The authors implemented an algorithm to perform stability analysis from root locus analysis using Matlab functions. Fig. 8 describes the proposed algorithm.

The authors implemented an algorithm to perform stability analysis from root locus analysis using Matlab functions [26]. Fig. 8 describes the proposed algorithm.

```
Name: Algorithm to perform stability analysis.
Input: Identified plant model Controller model
designed

Output: System stability analysis

        The execution in the actual plant of the
requested practice

Home

P1

    1.  Enter the plant model
    2.   Enter the controller model
P2

    3.  Get controller transfer function
    4.   Analyse locus of roots
    THEN
```

Figure 8. Algorithm to perform stability analysis.

Flow of activities to perform the stability analysis:

- Obtain the plant model: from the plant identification process an approximate model of the process was obtained in the previous activity and is taken as input for the stability analysis of the system.
- Obtain the controller model: the controller model was obtained from the controller tuning process, which represents an input for the stability analysis of the system.
- Root analysis: a system is stable if it responds with finite variation to finite variations of its input signals. If a linear and time-invariant system is considered, the instability of the system will suppose a response that increases or decreases exponentially, or an oscillation whose amplitude increases exponentially (Ogata, 2010). For the stability analysis, the root locus (LGR) was applied and an instance of MATLAB was used to obtain results.
- Execute practice: from the determination that the controller tuned by the student is stable according to the LGR, the information is sent to the real plant to carry out the laboratory practice on the physical device.

After obtaining the controller parameters, the actual practices were carried out.

The execution of the real practices allows, starting from the tuning of the controller parameters, to execute the practice in the physical device. For this, the stability of the previously proposed controller is determined. Fig. 9 shows the interface used to carry out the actual practices.

DOI: https://doi.org/10.54216/JCIM.010201

Figure. 9. Interface to run a lab on the physical device.

The interface shows a view to enter the tuned parameters of the controller. The system returns the response of the control action behavior on the process. Once the controller parameters have been entered, the stability analysis is performed.

4. Conclusions

The proposal presented is based on the need to implement a Remote Laboratory System supported on technology and free software tools.

The proposed Remote Laboratory System establishes three fundamental activities: identification of the system, design of controllers and execution of practices in real processes, facilitated the remote work of the students of Automatic Engineering.

From the experiments carried out in the Remote Laboratory System, it was possible for the students to analyze the behavior of the temperature variable, the controller's response in the designed process, the establishment times, among other variables of interest that facilitate obtaining an overview of the contents received in the subject.

The proposed Remote Laboratory System implements an architecture that allows the incorporation of new processes to carry out experiments. On this basis, future research will focus on creating new processes that nurture the functioning of the proposed system.

Funding: "This research received no external funding"

Conflicts of Interest: "The authors declare no conflict of interest."

References

[1] J. Saenz, J. Chacon, L. De La Torre, A. Visioli, and S. Dormido, "Open and Low-Cost Virtual and Remote Labs on Control Engineering," *Access, IEEE,* vol. 3, pp. 805-814, 2015.

[2] D. Samuelsen, and O. H. Graven, "Remote laboratories in engineering education - an overview of implementation and feasability."

[3] C. A. Cáceres, and D. Amaya, "Desarrollo e interacción de un laboratorio virtual asistido y controlado por PLC," *Entre Ciencia e Ingeniería,* vol. 10, pp. 9-15, 2016.

[4] W. Jin-Hsien, and H. Jongyun, "An Approach to Computing With Words Based on Canonical Characteristic Values of Linguistic Labels," *Fuzzy Systems, IEEE Transactions on,* vol. 15, no. 4, pp. 593-604, 2007.

[5] I. Santana, M. Ferre, E. Izaguirre, R. Aracil, and L. Hernandez, "Remote Laboratories for Education and Research Purposes in Automatic Control Systems," *Industrial Informatics, IEEE Transactions on,* vol. 9, no. 1, pp. 547-556, 2013.

[6] J. T. Buitrago-Molina, J. S. Carvajal-Guerrero, and C. A. Zapata-Castillo, "Plataforma virtual para el mando local y remoto de un brazo robótico de apoyo para la educación en ingeniería," *Tecno Lógicas,* vol. 17, pp. 67-74, 2014.

DOI: https://doi.org/10.54216/JCIM.010201

[7] D. A. Milner, and E. B. Holladay, “Laboratories as the Core for Health Systems Building,” *Clinics in Laboratory Medicine*, vol. 38, no. 1, pp. 1-9, 2018/03/01/, 2018.

[8] M. Zabaljauregui, O. Rodríguez, H. Mazzeo, and J. Rapallini, "Diseño de una plataforma remota para desarrollo de prácticas de laboratorio."

[9] O. Mar-Cornelio, I. Santana-Ching, and J. González-Gulín, “Sistema de Laboratorios Remotos para la práctica de Ingeniería de Control,” *Revista científica*, no. 36, pp. 356-366, 2019.

[10] O. Mar, and J. Gulín, “Model for the evaluation of professional skills in a remote laboratory system,” *Revista científica*, vol. 3, no. 33, pp. 332-343, 2018.

[11] A. R. Sartorius C., L. Hernández S., and R. A. Santonja, “Laboratorio a distancia para la prueba y evaluación de controladores a través de Internet,” *Sba: Controle & Automação Sociedade Brasileira de Automatica*, vol. 16, pp. 84-92, 2005.

[12] E. Rubio, I. Santana, V. Esparza, and J. Rohten, "Remote laboratories for control education: Experience at the universidad del Bío Bío." pp. 1-6.

[13] I. Aguilar Juárez, and J. R. Heredia Alonso, “Simuladores y laboratorios virtuales para Ingeniería en Computación,” *Revista Iberoamericana para la Investigación y el Desarrollo Educativo*, vol. 10, no. 1, pp. 1-19, 2013.

[14] O. Mar, J. Gulín, and S. I, “Sistema de Laboratorios a Distancia para la práctica de Control Automático,” *Revista Cubana de Ciencias Informáticas*, vol. 10, no. 4, pp. 171-183, 2016.

[15] O. Mar, L. Argota, and I. Santana, “Módulo para la evaluación de competencias a través de un Sistema de Laboratorios a Distancias,” *RCCI*, vol. 10, no. 2, pp. 132-147, 2016.

[16] Y. A. Badamasi. pp. 1-4.

[17] J. Blum, *Exploring Arduino: tools and techniques for engineering wizardry*: John Wiley & Sons, 2019.

[18] M. Malhotra, I. K. Aulakh, N. Kaur, and N. S. Aulakh, "Air Pollution Monitoring Through Arduino Uno," *ICT Systems and Sustainability*, pp. 235-243: Springer, 2020.

[19] A. A. Murthy, N. Rao, Y. R. Beemaiah, S. D. Shandilya, and R. B. Siddegowda, “Design and Construction of Arduino-Hacked Variable Gating Distortion Pedal,” *IEEE Access*, vol. 2, pp. 1409-1417, 2014.

[20] M. Matijevic, and V. Cvjetkovic, "Overview of architectures with Arduino boards as building blocks for data acquisition and control systems." pp. 56-63.

[21] J. A. Contreras-Mendieta, C. P. Sarango-Lapo, D. I. Jara-Roa, and M. V. Agila-Palacios, “Implementación de un Laboratorio Remoto (LR), como recurso de apoyo en un sistema de Educación a Distancia,” *Revista Ibérica de Sistemas e Tecnologias de Informação*, no. E17, pp. 923-935, 2019.

[22] J. G. Ziegler, and Nichols, “Optimum Settings for Automatic Controllers,” *Americana de Ingenieros Mecánicos (ASMET) Transactions*, vol. 64, no. 11, pp. 1-10, 1942.

[23] J. Arántegui. "Control de procesos," http://web.udl.es/usuaris/w3511782/Control_de_procesos/Unidades_files/apuntes_10-11.pdf.

[24] L. J. RAMIRO, and S. M. Cuzange, “SEPNATC Controladores basados en predictor dinámico: análisis de estabilidad en el dominio del tiempo,” *IEEE Latin America Transactions*, vol. 17, no. 7, pp. 1207-1213, 2019.

[25] J. P. Ramírez, R. Terán, J. Beristáin, and V. Cárdenas, “Sintonización del controlador en cascada PI-STA para aplicaciones de filtros activos de potencia,” *Revista Iberoamericana de Automática e Informática industrial*, 2020.

[26] J. González, and O. Mar, “Algoritmo de clasificación genética para la generación de reglas de clasificación,” *Serie Científica de la Universidad de las Ciencias Informáticas*, vol. 8, no. 1, pp. 1-14, 2015.

DOI: https://doi.org/10.54216/JCIM.010201