



Construcción de un Sistema de dos Tanques Interactuantes para el Laboratorio de Procesos Industriales de la Universidad de las Fuerzas Armadas ESPE Sede Latacunga para la Aplicación de Algoritmos de Control Avanzados

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Virtual Training System for a MIMO Level Control System Focused on the Teaching-Learning Process

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Abstract. The present work is focused on the development of a Virtual Environment to perform the implementation of control algorithms in a MIMO level control learning module. The mathematical model is obtained heuristically and to get the dynamic parameters of the system an identification and optimization algorithm is implemented. The environment has been developed using CAD tools and the UNITY 3D graphic engine, and MATLAB has been used for the control schemes. The purpose of the developed system is to be a functional tool focused on the teaching-learning process in the industrial automation area that is safe and low-cost, especially when access to physical equipment is limited or does not exist.

Keywords: Virtual environment, Learning module, Heuristic model, Process simulate.

1 Introduction

Automation is a process of economic, social, cultural and technological transformations applied to industry, where the production of goods was carried out in a mechanized manner [1], currently represents a great advantage by increasing productivity and reducing labor costs [2]. The industrial revolution played its significant role since the era of industrialization began in the 18th century with mechanical equipment driven by the power of water and steam [3]; the second industrial revolution occurred in 1870, when electric power formed a major system known as mass production [4]; during the 1970s, the third industrial revolution occurred with the rise of electronics [5]. Business development linked to industrial intelligence, robots and virtual environments has driven the emergence of Industry 4.0, known as the fourth industrial revolution, which describes the merger of the factory with the Internet through the design and implementation of intelligent components with the virtualization of systems and processes to achieve greater flexibility and individualization of production processes [6].

As part of Industry 4.0, Virtual Reality (VR), can create and integrate any type of environment, re-design, re-test and refine it in a virtual computer-based

framework [7]. Is the science of how to convert a physical object or resource to an emulated or simulated object in software [11], with technologies that are capable of combining elements of the real world with elements of the virtual world [9]. Virtual training systems are aimed at solving problems in a practical way [10], in which training new personnel is linked to constraints such as high-cost training programs, difficulties in accessing the physical environment, and human error in the development of their activities, among other things. They are a great tool for learning new skills in different areas, such as in [12–14] where robotic assemblies are virtualized in industrial scenarios; training systems for critical procedures that require a lot of knowledge on the part of the operator, such as in [15, 16]; in the area of automation education, [17] develops a virtual system to simulate control algorithms in a wheelchair.

What is sought with the virtualization of a process or scenario is to provide the user with a sense of immersion and interactivity to capture their attention [18], useful features that can be used for training or teaching workers or students. 2020 was a different year, due to the pandemic where isolation and disease brought the world to a virtual standstill [13], the classrooms were emptied, the lockdowns were instated, the educational system quickly changed to emergency distance learning [19], which caused both students and teachers to adapt to new technologies that would allow them to achieve their academic goals. Professionals in the field of education recognize that the teaching-learning process requires the inclusion of information and communication technologies (ICT) [20], is why we must currently prioritize the development of systems that provide teaching tools with appropriate pedagogical criteria for the training of students. As described above, this paper proposes the development of a virtual training system of a level control plant, designed, built and mathematically modeled for the implementation of advanced control algorithms to contribute to the teaching process of advanced control in engineering students.

2 Formulation of the Problem

The virtualized systems in the industry allows users to interact with the processes to learn how they work, devise possible improvements, plan maintenance, and instruct the operator in a safe and realistic environment without physical interaction with the processes. Training and educating personnel is one of the best strategies to control and decrease the accident rate [9], a very critical factor in the industry. Within a massive industry-wide change VR becomes a fundamental pillar because it shows promise in the area of error diagnostics and training [21].

The importance of a quality e-learning plan has recently become evident, especially in areas where it is difficult to replace face-to-face education with virtual education [22], mainly when laboratories are required or interaction with equipment is needed. Is in this area where the virtualization of models becomes a very important tool because visually students can interact with the elements and know how they work. Therefore, we propose the development of a virtual environment oriented to the implementation of MIMO level control algorithms

for the teaching-learning process in the area of industrial automation, the P&ID is shown in Fig.1.

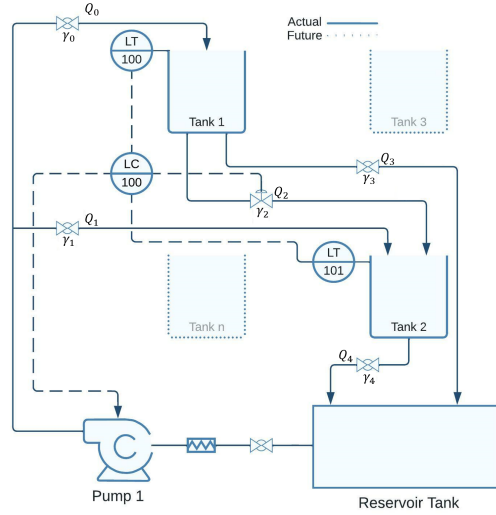


Fig. 1. MIMO Level Control Process P&ID

For the formulation of the mathematical model that describes the dynamic behavior of the system, it is taken into account that the volume of the liquid in the plant undergoes variation in time due to the inflow and outflow, as expressed in (1).

$$\frac{dV(t)}{dt} = Q_{in} - Q_{out} = A_i \frac{dh_i(t)}{dt} \quad (1)$$

where, V represents the tank volume; Q_{in} and Q_{out} represent the inlet and outlet flow rates respectively; A_i when $i = 1, 2$ represent the cross-sectional area of the tanks; h_i when $i = 1, 2$ represent the height of the tanks. Tanks 1 (T1) and 2 (T2) are considered to have a constant cross-sectional area and the height of the liquid inside them is considered to vary over time. Based on (1) it is possible to determine the behavior of the level of T1 according to the mass balance expressions represented in Fig.1.

$$A_1 \frac{dh_1(t)}{dt} = Q_0 - Q_2 - Q_3 \quad (2)$$

$$\frac{dh_1(t)}{dt} = \frac{\gamma_0 (1 - \gamma_1) k_1 v(t) - (k_2 \gamma_2(t) + k_3 \gamma_3) \sqrt{2gh_1(t)}}{A_1} \quad (3)$$

where, Q_0 represents the inlet flow rate; Q_2 and Q_3 represent the outlet flow rates of T1; γ_i when $i = 0, 1, 2, 3, 4$ represent the setting values of the valves (0

is completely closed, 1 is completely open); k_i when $i = 1, 2, 3, 4$ represent the gains of the pump and valves respectively; $v(t)$ represents the voltage applied to the pump; g represents the gravity. Similarly for T2, Q_1 and Q_2 represent the inlet flow rates and Q_4 the outlet flow rate. The behavior of the T2 level is represented by:

$$A_2 \frac{dh_2(t)}{dt} = Q_1 + Q_2 - Q_4 \quad (4)$$

$$\frac{dh_2(t)}{dt} = \frac{\gamma_1 k_1 v(t) + k_2 \gamma_2(t) \sqrt{2gh_1(t)} - k_4 \gamma_4 \sqrt{2gh_2(t)}}{A_2} \quad (5)$$

3 Methodology

The methodology used for the development of the system can be seen in Fig.2, which shows the stages for the implementation and development of the virtual MIMO level control environment. The proposed scheme consists of three main stages: (i) Conceptualization, in this stage, the design is carried out, which consists of interconnected tanks, loading valves, a motorized valve and a pump to fill the tanks. With the arrangement of the elements, the mathematical modeling that simulates the dynamic behavior of the system is obtained as shown in the expressions (3 and 5) it is necessary to consider the inlet and outlet flow rates of each of the tanks T1 and T2. Is important to note that, by changing the opening value of the valve γ_0 , the operation of the process can be made independent in case a system with one inlet and one outlet is required to test SISO control algorithms. Additionally, identification and validation algorithms are implemented to obtain the dynamic parameters of the system, this process is performed through experimental tests. (ii) Scheme Controls, the system allows the implementation of control algorithms focused on the learning process, in this paper it is proposed to control the level of the interconnected tanks T1 and T2 via control signals for the activation of the pump and the motorized valve. (iii) Virtualization, the physical elements of the module are designed with CAD tools; additional functionality of the load valves is included to add disturbances to the system; after the design, Solidworks Visualize software is used (Dassault Systèmes SolidWorks Corporation) to render the model, add textures, lighting, color and export it to a file compatible with Unity 3D software; the communication between the PC with the controller and the virtual environment is done through MODBUS TCP/IP. Finally the tests are developed between the learning module and the virtual environment, which allows to check and compare the operation of the control algorithms in the physical system as well as in the virtual one; with the purpose of validating the operation of the virtual environment.

3.1 Virtualization

The virtual environment developed is focused on the teaching-learning process, so it must have elements that allow the student to interact, realistic scenarios of

an engineering laboratory, and sounds that increase the level of realism to motivate the student to perform their tasks of implementation of control algorithms. The process for the realization of the virtualized environment of the learning module is shown in Fig.3.

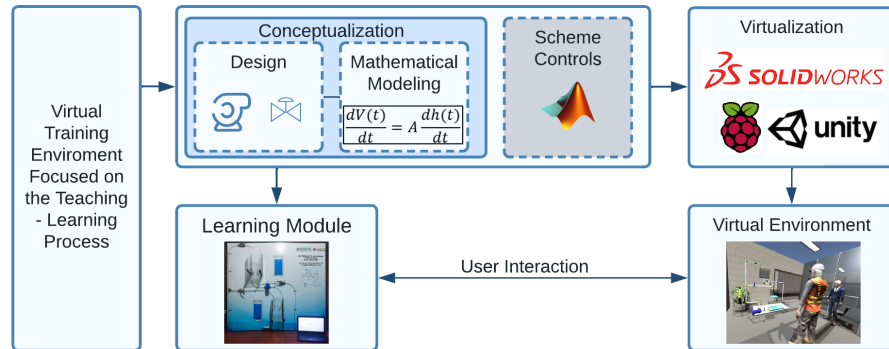


Fig. 2. Methodology for Implementation of Control Algorithms using Virtual Environments

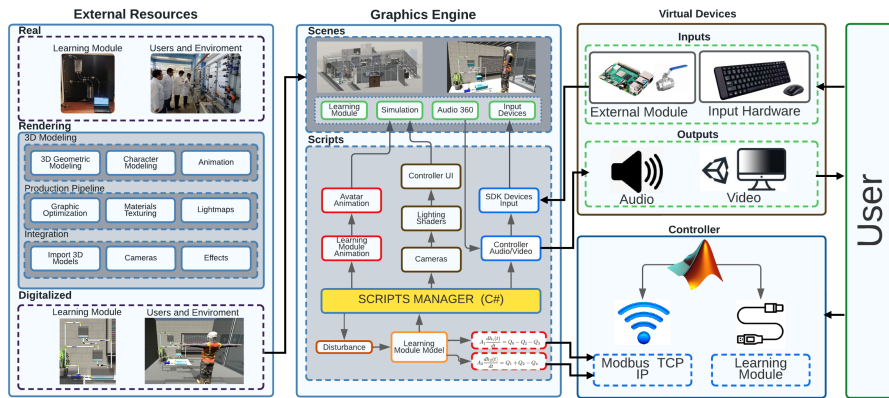


Fig. 3. Proposed Outline of the Virtual Environment

Four main stages are established for the development of the virtual environment: (i) External Resources, here are included all the related elements that will be found within the virtual environment, these elements can be organized into two groups: (a) Learning Module, within this are located the elements with which you can interact, in this case, the tanks, valves and pump, it is here where you

can visually identify the control algorithms that will be implemented. (b) Users and Environments, it is here where the space where the student and the teacher will navigate is designed, it is set in a laboratory where industrial automation practices are performed within an educational institute. The design of the virtual environment is carried out in a CAD tool with many capabilities such as 3D Solidworks [23], the geometries of the system are modeled and the movements of the animations are restricted. Solidworks Visualize is used for rendering, adding textures, materials, graphic optimization and for exporting to a Unity 3D compatible file. (ii) Graphics Engine, here is developed all the emulation of the real learning module process, it can be divided into two groups: (a) Scenes, it is conformed by everything designed in stage (i), audio of pump ignition, valve opening, environmental noise and all the elements that allow the user to have an interactive experience, so typical elements to be found in a real learning laboratory are added, simulations of the visual change of the level of the tanks are included with which the operation of the control algorithms to be implemented can be reviewed; a real-time trend graph is included in which the heights of T1 and T2 and the control actions of the motorized valve and the pump are monitored. (b) Scripts, these are developed in C Sharp (C#) and must be added to a scene object so that they can be called by Unity [8], these can be used to emulate the system compartment, movements, and the change of tank level variables; additionally, there is a script that allows interaction with an external module that was built to allow the opening and closing of the valves, this action is represented visually within the virtual environment, they are used to add disturbances to the mathematical model of the plant, in addition to increasing the user interaction with the environment. The rest of the scripts manage the interface, cameras, alarms and sounds of the elements of the virtual learning module. (iii) Controllers, are the control algorithms that are implemented in the real and virtual learning module, the desired values are the heights of T1 and T2 modifying the control actions that directly affect the motorized valve and the pump, within Matlab will be the design of the controllers, they will communicate via MODBUS TCP IP to a Raspberry Pi 4 card in which is the mathematical model of the system in Phyton, this, in turn, sends the variables of the variables to be affected in the simulation to Unity. For the physical learning module, Matlab sends the control actions via serial communication to an Arduino Uno R3 board. (iv) Users, who are in charge of interacting directly with the modules, implementing the control algorithms, selecting the Set Point (SP) values, adding disturbances to the system and verifying its operation.

4 Control Schemes

This section presents the formulation of the controllers; Fuzzy controller and Model Predictive Control (MPC); their objective is to maintain the tank head at desired values (SP) by manipulating the voltage level applied to the pump and the motorized valve. The control schemes are subject to disturbances that can be added with manual loading valves as shown in Fig.4.

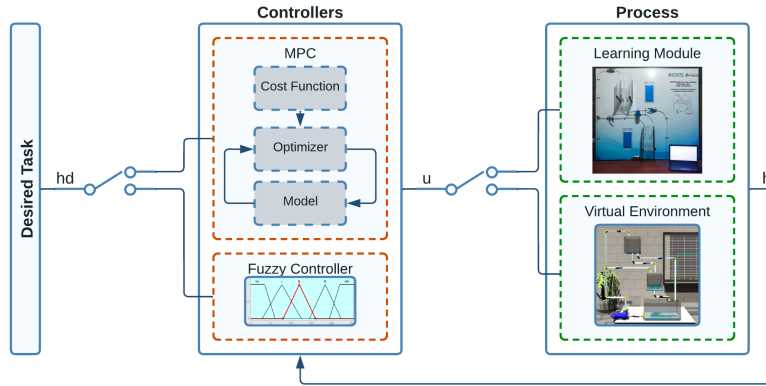


Fig. 4. Proposed controller scheme

4.1 Fuzzy Controller

The fuzzy logic based level control system has two inputs, the voltage applied to the Pump and the opening of the Motorized Valve; and two outputs, height T1 and height T2, for the development of the Outputs Membership Functions (OMF) the operating range is divided into seven, at the ends are placed trapezoids and in the middle triangles, the operating ranges for both OMFs are $[0 - 30]$ centimeters, which is the actual measurement of the tanks of the learning module; each is constituted of the following sets: VVL (very very low), VL(very low), L(low), M (medium), H(high), VH(very high), VVH (very very high). For the Inputs Membership Function (IMF) in a similar way both, the pump and the valve have five operating ranges, at the ends are placed trapezoids and in the middle triangles, the operating range of the pump output is $[0 - 255]$ PWM and it is constituted of the following sets: VS(very slow), S(slow), M(medium), F(fast), VF(very fast); and for the valve its operating range is $[0 - 1]$ and is constituted of the following sets: VC(very close), C(close), M(medium), O(open), VO(very open). In Fig.7 the IMFs and OMFs are shown. Twenty-five rules were established which were developed based on the experience gained when testing was performed.

4.2 Model Predictive Control

Within the present paper a nonlinear MPC control scheme is used, where the system can be expressed as:

$$\dot{h}(t) = f(u(t), h(t)) \quad (6)$$

where, $\dot{h}(t) = [\dot{h}_1 \ \dot{h}_2] \in \mathfrak{R}^2$ represents the vector of the rate of change of the outputs of the process to be controlled; $h(t) = [h_1 \ h_2] \in \mathfrak{R}^2$ representing the

outputs to be controlled and $u(t) = [v \ \gamma] \in \mathfrak{R}^2$ which represents the maneuverability vector of the pump and motorized valve actuators respectively.

When applying the predictive control algorithm, the cost function (J) is defined which depends on the control error and the variations of the control actions, where the control error is defined by:

$$\tilde{h}(k+i|k) = h_d(k+i) - h(k+i|k) \quad (7)$$

Over a prediction horizon N plus the sum of the norm of the predicted increments of the control action over a control horizon N_u :

$$J = \sum_{i=1}^N \delta_i \|hd(k+i|k)\|_Q^2 + \sum_{i=1}^{N_u} \lambda_i \|\Delta u(k+i-1|k)\|_R^2 \quad (8)$$

where, K represents the current time instant; i represents the sampling period to be predicted; hd represents the desired values; δ_i and λ_i are sequences that are usually chosen penalty constant [24]. In this manner J can be expressed as a function dependent only on future control actions.

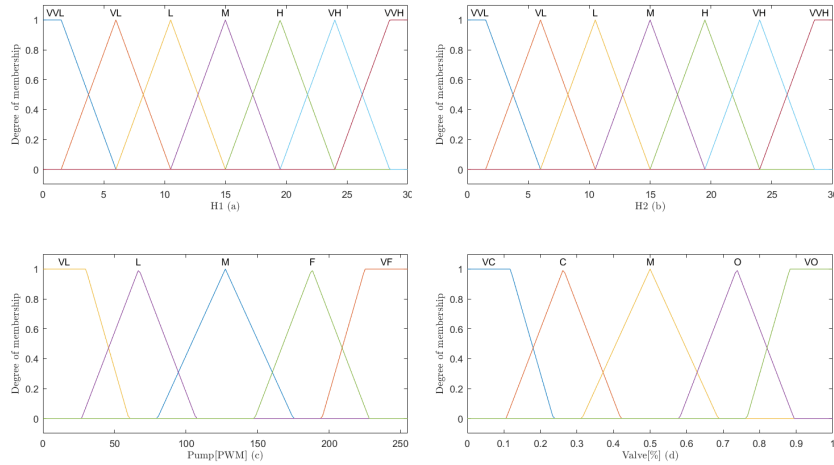


Fig. 5. Membership Functions. (a) IMF $H1$, (b) IMF $H2$, (c) OMF Pump and (d) OMF Valve

5 Analysis and Results

The experimental results are described in three subsections: (5.1) presents the construction of the real learning module from which the mathematical model was obtained, the user's interaction with the learning module is shown in Fig.6; (5.2) shows the details of the virtual environment developed for the learning module and (5.3) shows the implemented of the proposed control schemes.



Fig. 6. User interaction with the built learning module

5.1 Learning Module Construction

The Learning Module was developed based on the P&ID of Fig. 1 which consists of two tanks (T1 and T2) interconnected using a motorized valve (γ_2), a reservoir tank that stores the liquid to be driven by a direct current (DC) pump, which is responsible for carrying the fluid to T1 and T2, three manually activated valves that allow adding disturbances to the system and a set of manual valve and filter for maintenance of the reserve tank. The system includes two ultrasonic-type sensors to quantify the liquid level in each of the tanks.

The system structure was designed to be scalable, i.e., to add or remove module elements or redistribute them, so that new configurations can be tested to obtain new mathematical models, or to test new control algorithms according to user requirements and needs. The distribution of the elements of the system is shown in Fig.7.

For the identification of the dynamic model of the system, experimental tests were carried out with the real system, the data obtained were introduced in the identification algorithm, which allowed obtaining the dynamic parameters of the system through an algorithm based on optimization and validation by comparison with the mathematical model of the module. The process carried out is as follows (i) Excitation of the module, with different steps of both the pump and the motorized valve to know the output of the system at certain input values at a certain instant of time; (ii) Identification algorithm, the parameters of the model are identified based on the data obtained in the previous step. To reduce the error, an optimization algorithm is implemented that compares the

values obtained from the module with those obtained with the mathematical model as shown in Fig.8.

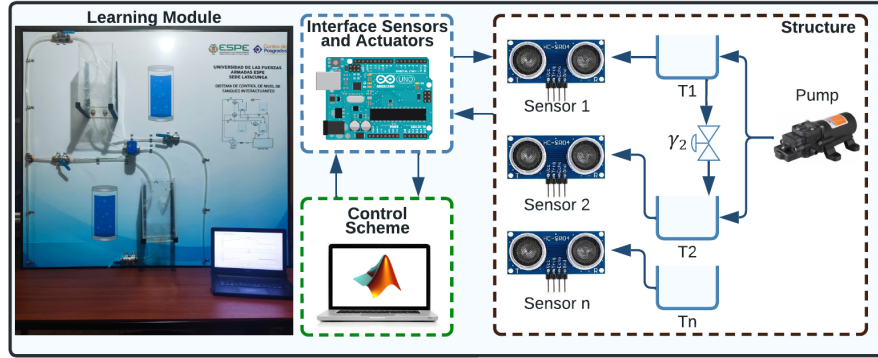


Fig. 7. Design elements of the Learning Module

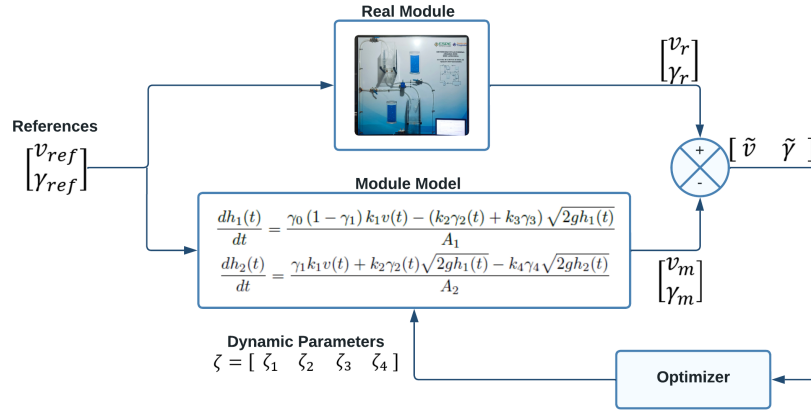


Fig. 8. Identification scheme

where, $\zeta = [\zeta_1 \zeta_2 \zeta_3 \zeta_4]$ represents the vector of pump (k_1) and valve gains (k_2 , k_3 y k_4) from equations (3) and (5).

5.2 Virtual Environment

In Fig.9(a) the real module and the virtualized module are visualized, it is observed that they have similar proportions and the same amount of control and

monitoring elements, they have the same layout to perform the scaling of the system. The virtual environment where the training module is located is designed in such a way that it resembles an engineering laboratory; Fig.9(b), has training modules, rest areas for students, shelves and furniture that resemble a teaching area. The area where the virtual module is located is set in a practice room, at the back of which there is a blackboard showing the trend graphs of the variables inherent to the process; Fig.9(c). Two main user levels are established; Fig.9(d), the student-user allows to visualize the operation and implement the control algorithms; teacher-user can carry out the opening of all the manual valves causing disturbances to the system that will directly influence the operation of the controller. The user-level teacher can manipulate the valves; Fig.9(e), when interacting with these elements within the virtual environment, the closing animation can be seen and a sound is played as a result of the opening or closing action. In the event of an overflow of the liquid in the tank due to an error in the control scheme, the fluid will start to fall from the tanks, alarm sounds are played and the teacher enters the room to check the status of the system, Fig.9(f). The system was developed on a computer with AMD Ryzen 7 5800H processor, NVIDIA RTX 3060 graphics card and 16.0 GB of RAM.

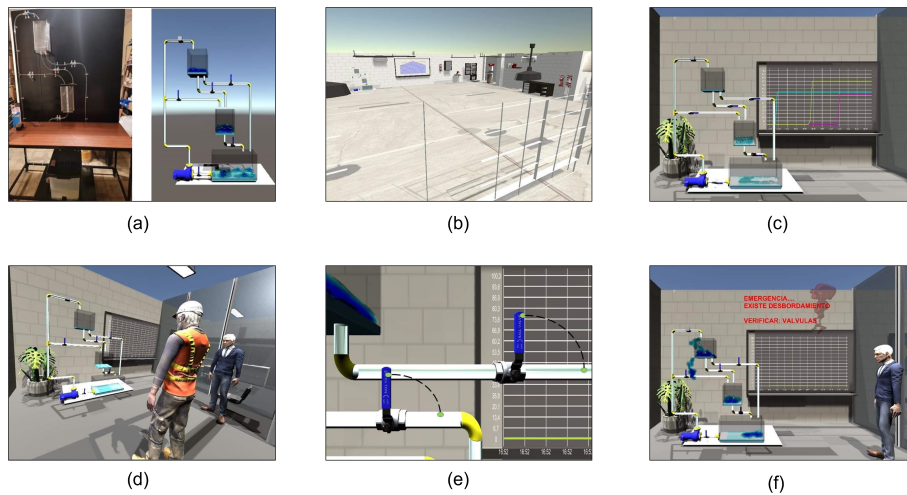


Fig. 9. Learning Module. (a) Real - Virtualized Module Comparison, (b) Laboratory Environment, (c) Module and Trends, (d) Users, (e) Valves Manipulation and (f) Tanks overflow

5.3 Implemented Control Schemes

For the experimentation with the virtual environment, the mathematical model was used with the gains obtained in the identification and optimization process;

a Matlab script was used for the simulation process. Fig.10 shows the response of the system to the different desired height values for tanks T1 and T2.

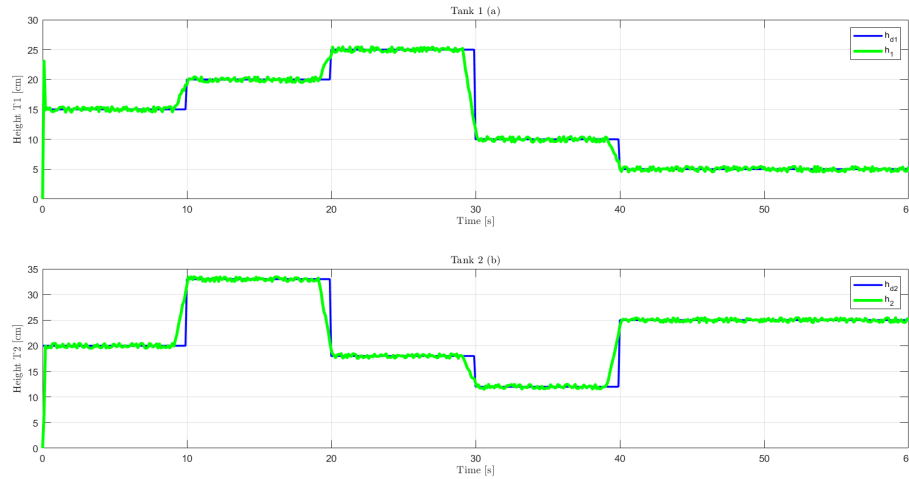


Fig. 10. Evolution of the system in the virtual environment. (a) Tank 1, (b) Tank 2

Disturbances were added to the system output to verify the behavior of future control actions, very small errors were obtained and in all cases the desired height value was reached in both T1 and T2. Similar results were obtained in both control schemes (Fuzzy and MPC).

6 Conclusions

The development of a virtual training system for a MIMO level control oriented to teaching-learning processes has succeeded in simulating the performance of the real learning module that was developed for engineering practices, allowing to copy its behavior and emulate it in an environment that is reliable, safe and free of risk for people. Provides a functional tool for future projects in the area of industrial automation for the implementation of multi variable control algorithms. The experimentation with the mathematical model has made it possible to evaluate the performance of the virtual training system, it was necessary to apply an algorithm of identification and optimization to obtain the dynamic parameters of the system for which tests were made to the physical learning module. The designed controllers allow correcting the disturbances produced by manipulating the load valves present in the modules. The system is scalable, i.e., the arrangement of the elements can be changed or, if required, increased or decreased.

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References

1. Rozo-García, F. Revisión de las tecnologías presentes en la industria 4.0.:Revista UIS Ingenierías (in Spanish), 19(2), 177–192. (2020).
doi:10.18273/revuin.v19n2-2020019
2. Moradiya, M. A. An .:Introduction to Automation in Industry. Azorobotics.(2018).
3. Xu, M., David, J. M., & Kim, S. H. The fourth industrial revolution.: Opportunities and challenges. International Journal of Financial Research, 9(2).(2018).
doi:10.5430/ijfr.v9n2p90
4. Kanji, G. K. Total quality managementThe second industrial revolution.:Total Quality Management, 1(1).
doi:10.1080/09544129000000001
5. Taalbi, J. Origins and pathways of innovation in the third industrial revolution.: Industrial and Corporate Change, 28(5).(2019).
doi:10.1093/icc/dty053
6. Peralta-Abarca, J. del C., Martínez-Bahena, B., & Enríquez-Urbano, J.: Industria 4.0. Inventio, 16(39).(2020).
doi.org/10.30973/inventio/2020.16.39/4
7. Liagkou, V., Salmas, D., & Stylios, C.: Realizing Virtual Reality Learning Environment for Industry 4.0. Procedia CIRP, 79.(2019).
doi.org/10.1016/j.procir.2019.02.025
8. Coding in C# in Unity for beginners. <https://unity.com/es/how-to/learning-c-sharp-unity-beginners> last accessed 2022/06/14.
9. Zambrano, J. I., Bermeo, D. A., Naranjo, C. A., & Andaluz, V. H. (2020, June).: Multi-user virtual system for training of the production and bottling process of soft drinks. In 2020 15th Iberian Conference on Information Systems and Technologies (CISTI) (pp. 1-7). IEEE.
10. Y. Liu, Q. Sun, Y. Tang, Y. Li, W. Jiang and J. Wu.: "Virtual reality system for industrial training," 2020 International Conference on Virtual Reality and Visualization (ICVRV), 2020, pp. 338-339. (2020).
doi:10.1109/ICVRV51359.2020.00091
11. T. KIHARA, E. MULI and L. CHEGE.: "Adoption of Virtualization by Government Organizations in Kenya," 2019 IST-Africa Week Conference (IST-Africa), 2019, pp. 1-10.
doi:10.23919/ISTAFRICA.2019.8764846
12. A. Martins, H. Costelha and C. Neves, "Shop Floor Virtualization and Industry 4.0," 2019 IEEE International Conference on Autonomous Robot Systems and Competitions (ICARSC),pp. 1-6, (2019).
doi:10.1109/ICARSC.2019.8733657
13. R. Beloiu.: "Virtualization of robotic operations," 2021 12th International Symposium on Advanced Topics in Electrical Engineering (ATEE), pp. 1-4.(2021).
doi:10.1109/ATEE52255.2021.9425336

14. Cobo, E. B., & Andaluz, V. H. (2021, September): Virtual Training System for Robotic Applications in Industrial Processes. In International Conference on Augmented Reality, Virtual Reality and Computer Graphics (pp. 717-734). Springer, Cham.
15. Petkov, E., & Angelov, V. (2020, June). Virtual Reality Training System for Specialists Who Operate on High-Voltage Switchgears in an Oil Plant in Russia. In Proceedings of the 21st International Conference on Computer Systems and Technologies' 20 (pp. 266-269). doi:10.1145/3407982.3408003
16. Romo, J. E., Tipantasi, G. R., Andaluz, V. H., & Sanchez, J. S. (2019, June). Virtual training on pumping stations for drinking water supply systems. In International Conference on Augmented Reality, Virtual Reality and Computer Graphics (pp. 410-429). Springer, Cham. doi:10.1007/978-3-030-25999-0_34
17. Ortiz, J. S., Palacios-Navarro, G., Andaluz, V. H., & Guevara, B. S. (2021). Virtual reality-based framework to simulate control algorithms for robotic assistance and rehabilitation tasks through a standing wheelchair. *Sensors*, 21(15), 5083. doi:10.3390/s21155083
18. Ruiz, R. J., Saravia, J. L., Andaluz, V. H., & Sánchez, J. S. (2022). Virtual Training System for Unmanned Aerial Vehicle Control Teaching–Learning Processes. *Electronics*, 11(16), 2613. doi:10.3390/electronics11162613
19. Vrgović, P., Pekić, J., Mirković, M., Anderla, A., & Leković, B. (2022). Prolonged Emergency Remote Teaching: Sustainable E-Learning or Human Capital Stuck in Online Limbo?. *Sustainability*, 14(8), 4584. doi:10.3390/su14084584
20. Guillén-Gámez, F., Cabero-Almenara, J., Llorente-Cejudo, C., & Palacios-Rodríguez, A. (2021). Differential analysis of the years of experience of higher education teachers, their digital competence and use of digital resources: Comparative research methods. *Technology, Knowledge and Learning*, 1-21. doi:10.1007/s10758-021-09531-4
21. L. S. d. O. Almeida, A. B. Lugli, T. C. Pimenta, M. V. C. e. Silva, J. P. C. Henriques and R. P. Mesquita, "Virtualization of an Aluminum Cans Production Line Using Virtual Reality," 2020 27th International Conference on Mixed Design of Integrated Circuits and System (MIXDES), 2020, pp. 282-287. doi:10.23919/MIXDES49814.2020.9156023
22. C. J. T. Hinojosa, J. J. F. Cabrera, H. R. C. Mora and N. V. O. Garzón, "An Augmented Reality based E-Learning Tool for Engineering," 2021 IEEE Colombian Conference on Communications and Computing (COLCOM), , pp. 1-6.(2021). doi:10.1109/COLCOM52710.2021.9486294
23. Diseño/Ingeniería (in Spanish): <https://www.solidworks.com/es/domain/design-engineering> last accessed 2022/07/21.
24. Andaluz, G.M. et al. (2016): Modeling Dynamic of the Human-Wheelchair System Applied to NMPC. In: Kubota, N., Kiguchi, K., Liu, H., Obo, T. (eds) Intelligent Robotics and Applications. ICIRA 2016. Lecture Notes in Computer Science(), vol 9835. Springer, Cham. doi:10.1007/978-3-319-43518-3_18