Virtual Training System For Oxygen Distribution Control Through

Hardware-IN-THE-LOOP

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Carrera de Ingeniería en Electrónica E Instrumentación

Artículo académico, previo a la obtención del título de Ingeniero en Electrónica E Instrumentación

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1 de agosto del 2023

Virtual Training System for Oxygen Distribution Control through of Hardware-in-the-Loop

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Abstract. This work seeks to cover the need that most universities have at the time of doing internships, such as training their students in a great number of industrial processes, and achieving the best preparation, without having a great economy and space, for the implementation of different laboratories. For this reason, the industrial process of oxygen storage and distribution has been implemented in virtual reality, which is based on a physical process, with the following advantages: Use of little space, low cost in the implementation, presents no danger to the student and instructor, its design is based on an immersive system achieved with Unity software, the same that allows the implementation of sound, video, animation, in order to confuse the user's senses, It also interacts with different controllers such as PID, Logic Fuzzy and MPC in order to understand the operation of each control.

Keywords: Set Point, immersive system, Logic Fuzzy, MPC, PID

1   Introduction

From its beginnings, education aimed at increasing the discernment and understanding of the elements around us, there was nothing more imperative than this; it was thus that the first teachers devised techniques of sharing their knowledge, based on their beliefs, customs, and the best technology of their time. Over the years many of these techniques have evolved to adapt teaching to the needs of students, among which it can be emphasized a) the master class where the teacher is the fundamental pillar of teaching, b) the use of books to develop reasoning c) practices in laboratories to reinforce the knowledge acquired. [1] [2] [3][4] [5] [6] [7]

New technological innovations have produced different ways of communication, changing the teaching-learning process being increasingly systematic and results-oriented, during the COVID 19 pandemic the need to improve and create different teaching platforms was felt, since the existing techniques could not be applied properly, many institutions made great efforts in the development of practical and interactive applications that allow students clearly understand different teaching topics, resulting in a large number of applications, among which are: meeting rooms, normal and interactive virtual assessments, virtual reality applications, etc. in order to maintain the quality and effectiveness of teaching. [8] [9] [10]

There are different processes taken to virtual reality, whether industrial or robotic that are used for academic purposes, these are designed with many details based on physical environments, thus achieving an immersive environment, applied to education in the area of automation such environments should help students develop their skills through the management of an avatar, which interacts with the different processes managing to apply different actions such as: control actions, process information, visualization of control actions, warning signs, thus avoiding dangerous areas for the practitioner and the expense of repairs or implementation of the same. [11] [12] [13]

Thus, the present work is responsible for the industrial process of storage and distribution of oxygen developed in a virtual environment, which has two spherical tanks whose advantages are, improve the quality of the product, effective use of materials and a large amount of storage. In addition, the use of different control algorithms is planned, such as: PID (classic), which generates a corrective action based on the error that occurs due to the difference between the measured value and the desired value; is widely used due to its simplicity of design and good performance in slow processes [14], the great variety of compatible products, and the multiple methods of tuning that can be used, Fuzzy Logic, used to mathematically represent reasoning and imprecise or approximate ideas, the implementation of this algorithm is carried out based on three parameters that are: fuzzification, membership rules and defuzzification; [15] and, MPC whose function is to predict the future output of the object based on historical information and future inputs, [16] this algorithm determines the future control effect by optimizing the performance index, attributed to three principles: prediction model, displacement optimization and feedback. The same that will be found within a menu to compare the stability and operation, will be used the technique of HARDWARE-IN-THE-LOOP implemented in a Raspberry PI and virtualized in the Unity 3D graphics engine, which will have an interface very similar to the physical process. [17]

This work is made up of five sections, including the introduction, which details the elaboration of the virtual environment through the P&ID diagram of the physical industrial process. [18] [19]

2   Industrial Process

For automation engineering, it is vital to perform the most industrial practices, which leads to a dilemma, such as training your students in many industrial processes. if this means having a large economy to cover the costs involved in implementing and maintaining a physical process, as well as the space required by the physical process, not to mention that some of these processes can be dangerous. That's why processes are designed in virtual reality, the same ones that are based on physical processes, with the following advantages: It uses little space, is economical in the creation and maintenance, does not entail any danger for the student.

Due to the growing demand for oxygen in the industry, different systems have been developed for the storage and distribution of this, these being useful, but not efficient, for which the use of spherical tanks is proposed since it has a greater advantage over cylindrical tanks, among these are, improve the quality of the product, effective use of materials, and large amount of storage. This is how the process to be implemented is based on the P&ID diagram in Fig. 1.
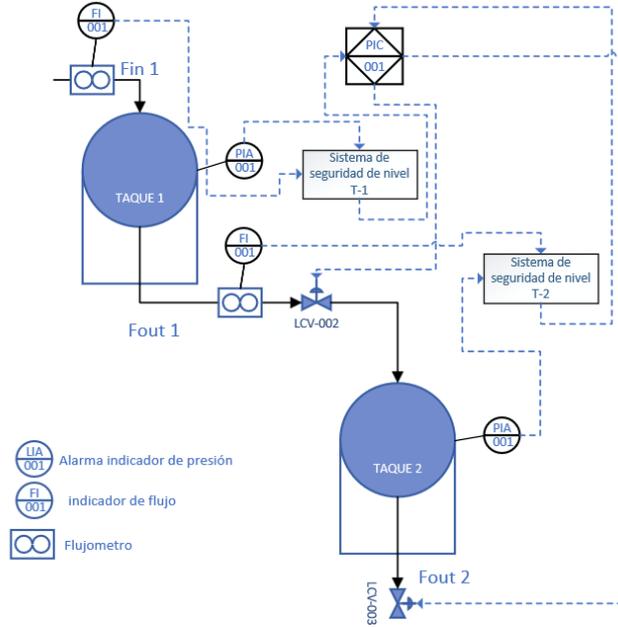
Fig. 1. P&ID diagram of the oxygen storage and distribution process.

This process has two tanks for the storage of oxygen, the first works at high pressure since it is fed directly from the oxygen generator the same one that works at high pressures, the second works at low pressure and is responsible for storing and distributing oxygen to the following processes, the mathematical model was based on the paper FCM Scheduled Multiple Model Controller for the Simulated Model Spherical Tank Process, with a modification by adding a second cascading tank, as can be seen in Figure 1, having the following expression in state spaces as the Mathematical model of the system,

$$
\begin{bmatrix} \dot{h}_1 \\ \dot{h}_2 \end{bmatrix} = \begin{bmatrix} \dfrac{-k_1\sqrt{2gh_1}}{\pi\left(2R_1h_1 - h_1^2\right)} & 0 \\ \dfrac{k_1\sqrt{2gh_1}}{\pi\left(2R_2h_2 - h_2^2\right)} & \dfrac{-k_2\sqrt{2gh_2}}{\pi\left(2R_2h_2 - h_2^2\right)} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} + \begin{bmatrix} \dfrac{q_1}{\pi\left(2R_1h_1 - h_1^2\right)} \\ 0 \end{bmatrix}
$$

where, q_1 represents the input stream; h_1 is the height of tank 1; h_2 is tank 2 height; a_1 is the opening valve 1; y a_2 is valve 2 opening.

In Fig. 2 is proposed as the methodology for the implementation of the oxygen storage and distribution process, which is composed of two parts, i) software formed by Unity 3D this has the virtual environment based on it P&ID diagram, the same that will allow the visualization also considers the physical characteristics of said process, MATLAB that has the different control algorithms that will be implemented and the Raspberry PI card will have the mathematical model of the system.
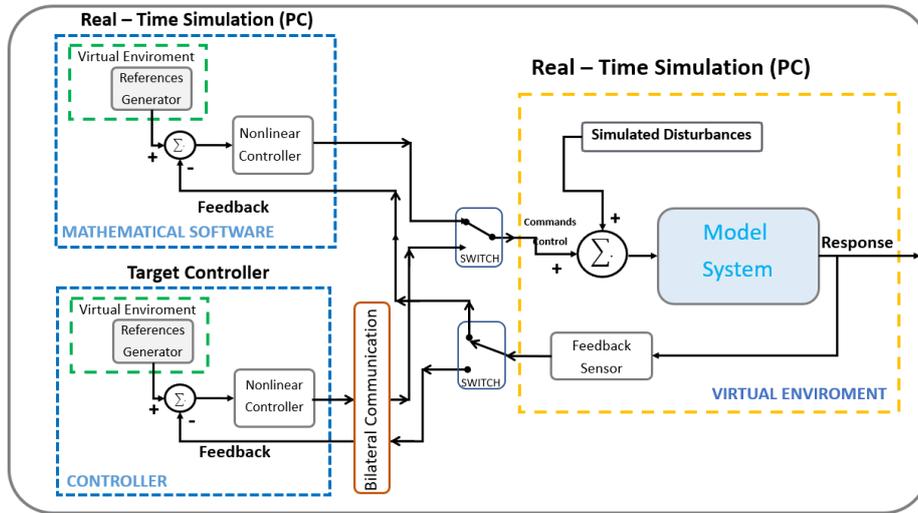
Fig. 2. Methodology for the control and visualization of industrial process

3 Virtual Environment

The scheme of the proposed virtual environment will achieve a better experience for teaching and learning, since it is focused on human machine interaction, and an immersive virtual environment, with scenarios of the oxygen storage and distribution system in addition to sounds, which will guarantee the best understanding and management of said system as shown in Fig. 3.
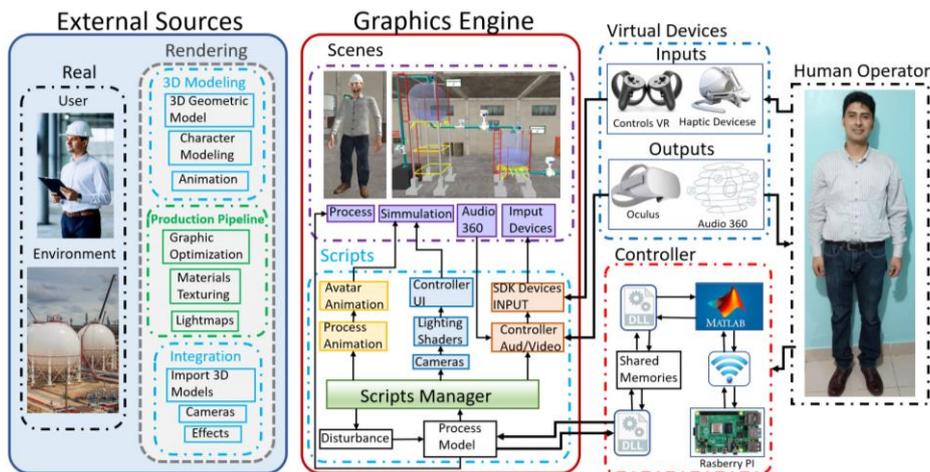

Fig. 3. Proposed schematic of the virtual simulator

In Fig. 3 is composed of the following phases **i) External Sources,** which contains two fundamental parts, which are: *a) virtualization of the scenario* itself that is based on a physical system in addition to the P&ID diagram of the process, this environment tries to simulate as real as possible the work environment, adding some pros such as the

visualization of control actions, sounds, lights and above all friendly and interactive; *b) Avatar* is based on the anthropomorphic aspects of a man, with the help of CAD tools, the 3DS Max and SketchUp software are added layers that provide realism to it, once finished it is exported in .fbx the same that is compatible with Unity 3D. **ii) Graphics Engine** for this application Unity was used, because it is a graphic development platform, available for Microsoft Windows, Mac OS and Linux [20], the same that can be divided into two parts *a) Scenes* implements the resources that the previous item has, in other words the virtual scenario made up of images, sounds, which will allow to deceive the senses, has an interface (UI) the same that allows the easy interaction of the user with the simulator achieving the modification of activities or actions, and the avatar in .fbx format, in addition all this environment has been implemented with a graphic representation in real time, managing to visualize the control actions, errors and the filling effect in the anchors; *b) Scripts* contains the relevant typologies that allow the correct functioning of the virtual simulator, since inside are the behaviors of the process such as disturbances, libraries (SDK-Software Development Kit) that allow communication and interaction between scripts and input devices, lighting, sounds and simulation of oxygen consumption as if it were in a physical process. achieving an immersive, friendly, and interactive environment with the user.

4   Control Algorithms

The scheme proposed in Fig. 4 is used for the control of the industrial process of storage and distribution of oxygen, it is composed of two stages, the first contains the different control algorithms such as PID, Fuzzy Logic and MPC implemented in the MATLAB software, these controllers are responsible for controlling the storage capacity of two spherical tanks one of high pressure fed directly by the generator, the other of low pressure for the distribution of oxygen in order to be used in different industrial processes, the second stage contains the mathematical model of the process implemented in a Raspberry PI card, which communicates with the Unity software, which shows in a graphic and immersive way the behavior of the industrial process. [21] [22]
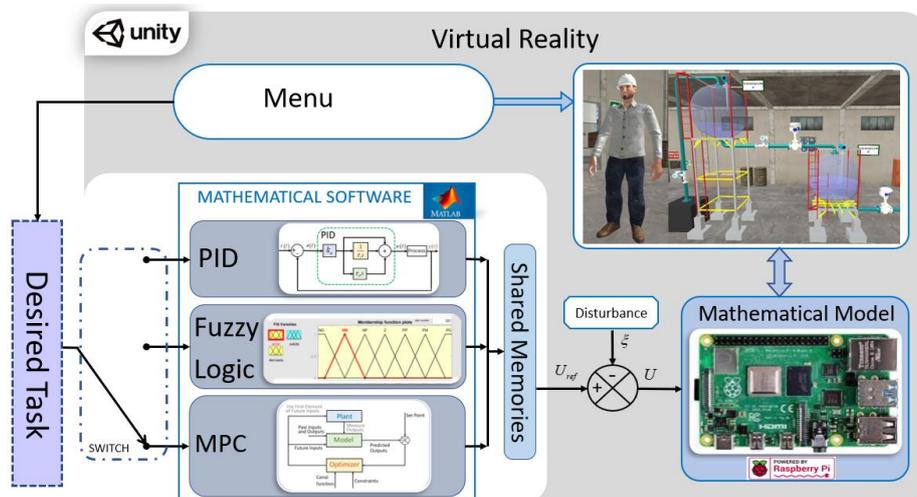

Fig. 4. Esquema propuesto del simulador virtual mediante HIL

Here's how to perform the different drivers: PID (Proportional Integral Derivative) very popular in the industries for the control of processes due to its easy implementation as can be seen in Fig. 5 a), for provides a quick response, also eliminates the error of the system produced by the difference between the measured value and the desired, its capacity is limited when the parameters vary or when the parameters are unknown [23]. The expression obtained for the PID control can be seen in Fig. 5 b).
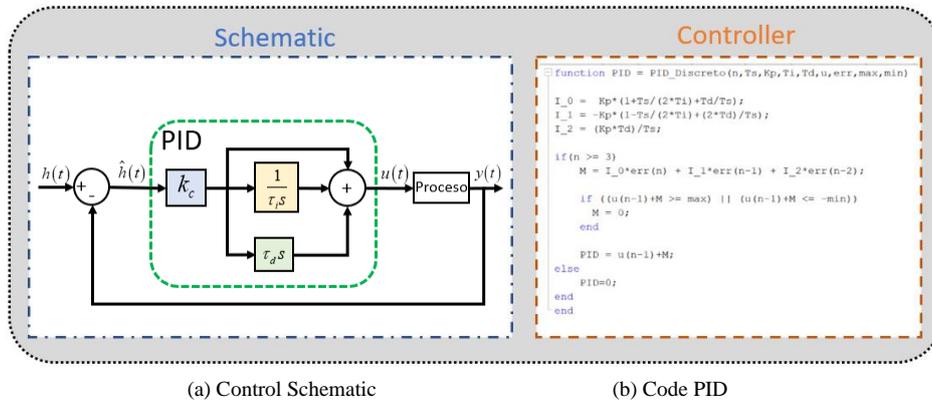

(a) Control Schematic   (b) Code PID

Fig. 5. PID Controller

Fuzzy logic this controller operates with fuzzy sets, so called because they do not have well-defined limits, in other words, the elements can belong or not to a certain set, different operations can be performed between the sets such as union, intersection and complement. [24]

In addition, each set is represented by a membership function or membership function, the same one containing values of the degree of belonging of a variable to a fuzzy set, the function has an operating range from 0 to 1, with 1 being the maximum and 0 being the minimum membership value, as illustrated in Figure 6 (a), it also shows the block diagram of a fuzzy system with the 4 parts that are: Fuzzification; Rule base; Inference engine; and Defuzzification [24]. You can see the code implemented for the controller in Fig. 6 (b).
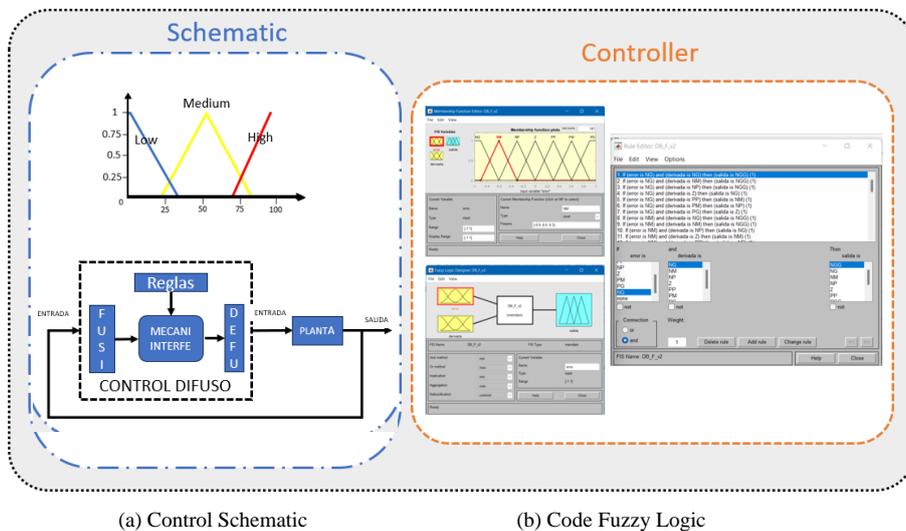

(a) Control Schematic   (b) Code Fuzzy Logic

Fig. 6. Fuzzy Logic Controller

MPC This control can predict future output, based on historical information, and future input, by optimizing the performance index this is attributed to three principles: Prediction model; displacement optimization; and feedback correction [25]

Through these it is possible to perform a more precise calculation of the control actions in each space of the sample [25] [26], The expression obtained for the control of the process can be observed and its schematic can be seen in Fig. 7.
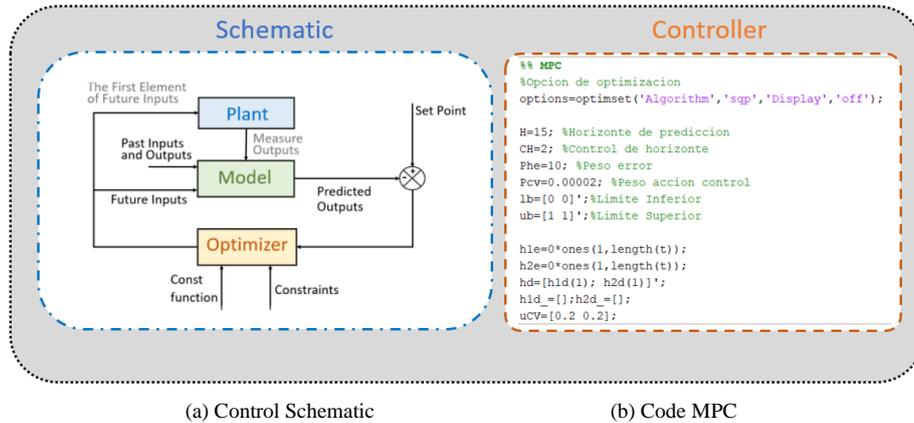

(a) Control Schematic   (b) Code MPC

Fig. 7. MPC Controller

5   Analysis and Result

In the virtual environment you can interact with a control board where you can select with a menu the different controllers and a trend board, the same one that has a screen to see the control actions of each controller, in order to compare them visually, there are also sounds that simulate the physical process such as the generator motor, and the storage process for which it is divided into two parts. [27]

A) *Virtual Environment.* In Fig. 8 shows the elements used to implement an oxygen storage and distribution system using the HIL technique, where the mathematical model is implemented in the Raspberry PI card, the different controllers are in MATLAB. It uses a computer whose characteristics are Windows 11 Home operating system, Intel Core i5 10TH GEN processor, DDR4 16GB ram, NVIDIA GeForce GTX 6GB DDR5 graphics card. Communication between the Raspberry PI card with MATLAB is through the TCPIP protocol, and Between MATLAB with Unity is done through shared memories.
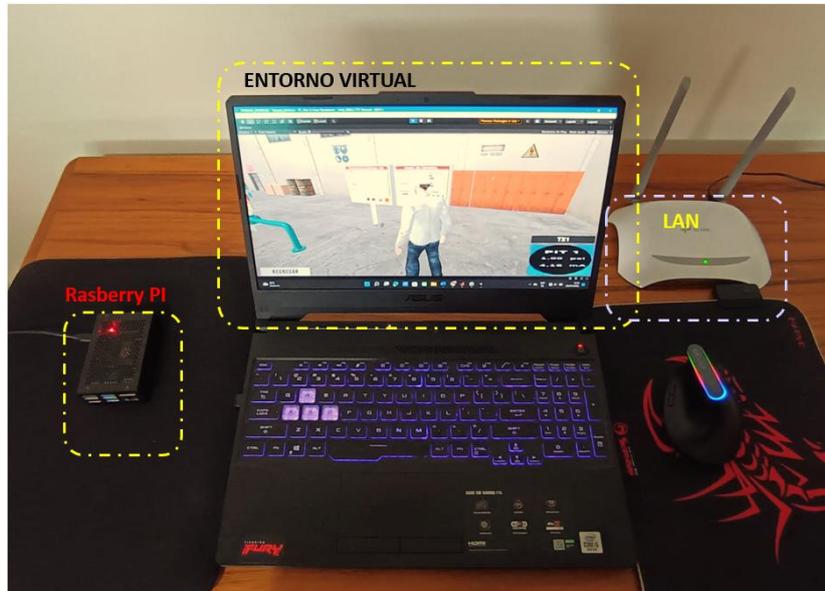
Fig. 8. HIL Implementation of the oxygen storage and distribution process

The implementation of the Hardware-in-the-loop technique is shown in Figure 8 and Fig. 9, for the development of the virtual environment the 3Ds MAX software is used, the same one that serves for the design of the avatar, and the other implemented elements, these are saved with the extension .fbx that is compatible with Unity, each element created is imported, in order to assemble the environment taking into consideration the P&ID diagram, in addition Figure 9 shows that the environment is interactive and intuitive with the user, because it contains a virtual control center, which has a menu where you can select from the PID controllers, FUZZY and MPC, as well as starting the system, managing to control the process using the peripherals of the computer, managing to visualize the evolution of the variables in an HMI interface. The plant has 4 alarms the level that are: **low low (LL)**, indicates that the amount is extremely low, **low (L)** if the level is low, **high (H)** if the amount is high, and **high high (HH)** shows that the amount is extremely high, also implemented visual effects and sounds that provide more realism for the user.

Fig. 9. Realism effects in the process.

B) *Control Algorithms.* In Fig. 10 you can see the behavior of the three controllers, the same ones that work according to the desired value or setpoint, where the highest peak of over shut is the PID control, and with an establishment time of 35 S, the Fuzzy and MPC controllers do not have an overdrive and each of them has an establishment time of 28S and 15 S respectively, being the MPC controller in shorter installation time in both tank one and tank two.
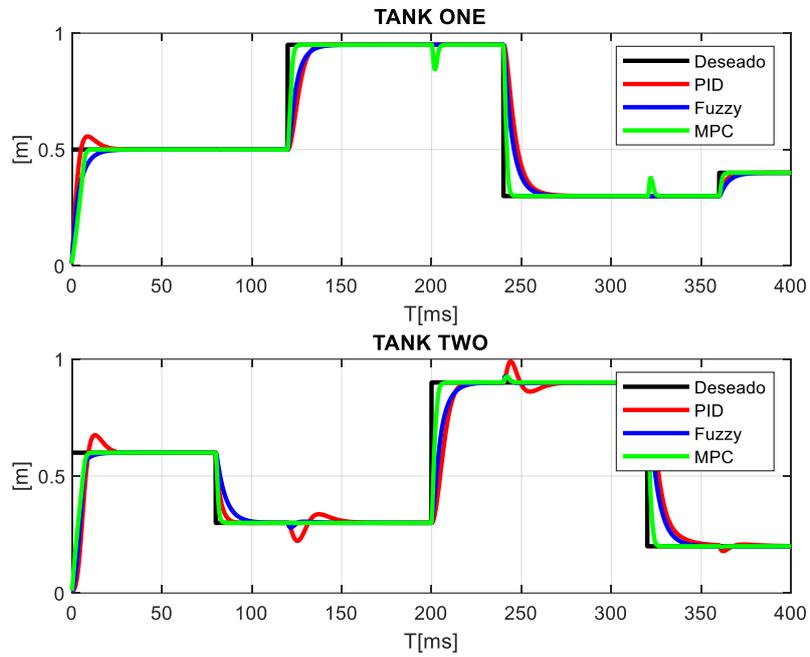
Fig. 10. Control actions of PID, Fuzzy and MPC controllers for tank 1 and tank 2

Fig. 11 you can see the behavior of the valves, opening and closing them, as indicated by the controller, where it can be seen that the MPC control is faster than the other controllers, at the time of sending the adjustment signals in the valves.
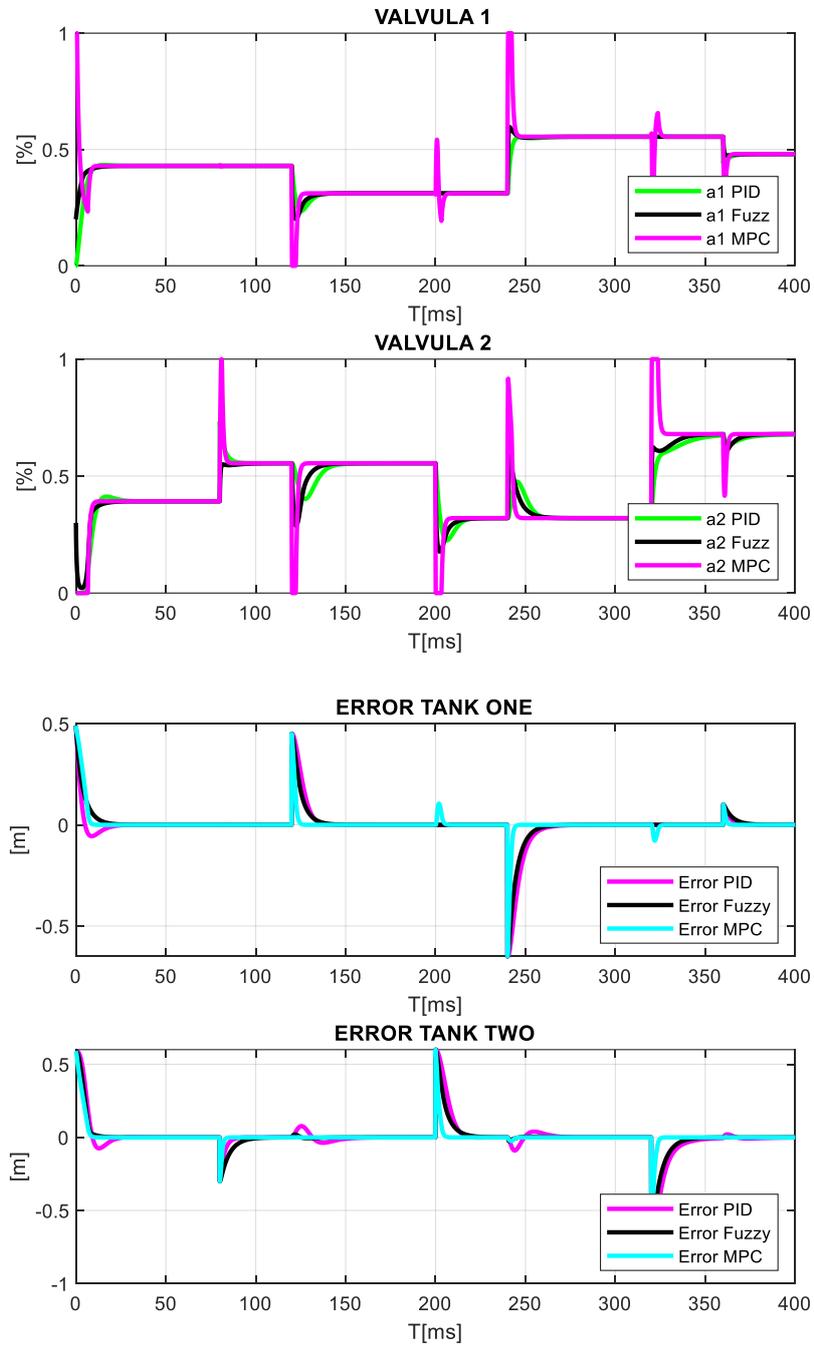
Fig. 11. Behavior of valves 1 and 2 And tank errors

6   Conclusions

The system is very intuitive and didactic, since it allows the user to interact with the industrial process, with the following advantages, there is no damage of any kind, it is not spent on construction It allows to move around the virtual environment, listen and visualize how the system works from different angles, such as the physical process, in addition three controllers are used, In order to determine which controller best suits the environment, taking into account the times of establishment and impulse of the same, and see how each of the controllers works. An adjustment can be made in the operating time, as well as in the tuning of the PID control, over time a robust test can be performed to have another comparison parameter between the different controllers. The controller with the best performance is the MPC as you can see in Figure 10.

7   Referencias

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