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Virtual tool of nonlinear model of interconnected tanks with PID control implementation using EJsS

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Abstract
This paper describes the development and implementation of a virtual tool (TANQUES EN SERIE PID) of a system of two interconnected tanks made in Easy Java/JavaScript Simulations (EJS,), a tool that seeks to motivate learning control concepts in engineering programs. The simulated model corresponds to the non-linear system of interconnected tanks, which presents graphically the behavior of tank levels on an open loop, this application allows varying physical input parameters of the process, as the cross section of the tanks, resistivity constants of the valves and the input flow of process. The system is also presented in closed loop, presenting the behavior when a PID controller is implemented to the process, controller and time constants can be modified to enter a disturbance to the model and by doing this we are verifying the time response and system reaction when subjected to a perturbation. The tool is verified comparing the results using Simulink and equilibrium equations.

Keywords: automatic control; virtual tool; teaching; nonlinear system; tanks; PID.

Implementación de una herramienta virtual del modelo no lineal de tanques interconectados con control PID utilizando EJsS

Resumen
Este articulo describe el desarrollo e implementación de una herramienta virtual (TANQUES EN SERIE PID) de un sistema de dos tanques interconectados, hecha en Easy Java/JavaScript Simulations (EJsS), herramienta que busca motivar el aprendizaje de conceptos de control en programas de ingeniería. El modelo simulado corresponde al sistema no lineal de tanques interconectados, donde se presenta de forma gráfica el comportamiento de los niveles de los tanques en lazo abierto, esta aplicación permite variar parámetros físicos de entrada del proceso, como la sección transversal de los tanques, las constantes de resistividad de las válvulas y el flujo de entrada del proceso. También se presenta el sistema en lazo cerrado, observando el comportamiento al implementar un controlador PID al proceso, en este se pueden ajustar las constantes del controlador y el tiempo para ingresar una perturbación al modelo, verificando así su respuesta en el tiempo y la reacción del sistema al ser sometido a una perturbación. La herramienta se verifica comparando los resultados obtenidos en Simulink y las ecuaciones de los puntos de equilibrio.

Palabras clave: control automático; herramienta virtual; enseñanza; sistema no lineal; tanques; PID.

1 Introduction

Over the last years there has been a significant increment in the amount of educational software, especially on undergraduate and postgraduate levels, this has taken education tools on to a next level, new learning and teaching styles has been adopted, generating in researchers, teachers, and students the autonomous and critic thinking [1]. Easy Java/JavaScript Simulations (EJsS) is a development tool, that allows the implementation of linear and nonlinear differential equations simulations, with graphs, buttons, and visual representations of the systems [2]. Allowing the

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development of complete simulations, that are interactive, and easy to use by the user. The software developed with EJS gives the user a closer experience to the real systems applications, some examples of developed software with EJS are: ball and beam system, pendulum and a tank system for the teaching the dynamic system modelling [2]. EJsS is still in developing, getting new features each year [3]. MATLAB is a matrixial software used for simulating all kind of mathematical models, is one of the most used software by researchers in all the world, it includes Simulink that allows the use of graphical elements to create simulations of linear and nonlinear models [4]. Control learning has been always a notable topic on engineering education, this due to the number of concepts involved and its close relation with real system applications, this means that is necessary a fully understanding of system modeling, control theory, instrumentation, power electronics, among others [5]. Nowadays specially in least developed countries there is a need to leave the dependency of paid software like MATLAB to carry out simulation of nonlinear systems, also there is the urgent of tools with low resource consumption and user friendly are demanded, these reasons motivated the authors to work into the development of the TANQUES EN SERIE PID simulation tool, to solve these problems, interconnected tanks system is chosen since it is one of the most used systems in system modeling.

Regarding tanks investigations, there are works like the one presented in [6] where linear and nonlinear control applications are made for a three interconnected tanks system. A notable work of control education using EJS is presented in [7] where some tools are developed using EJS for the teaching of automatic control. More recently EJS applications can be found in [8] where EJsS is integrated into the data analytics of the national Learning Management System for Singapore schools using the Moodle platform, or [9] where EJsS is used to develop physics fundamentals tools for undergraduate students.

In this paper a nonlinear interconnected tanks system in open loop and closed loop is developed using EJS, reviewed and compared against the results obtained in Simulink of MATLAB, this paper contains: introduction, interconnected tanks system modeling, nonlinear model, Equilibrium points, virtual tool TANQUES EN SERIE, development, Graphical user interface, results, and conclusions.

2 Interconnected tanks system modeling

The mathematical analysis of the system behavior is represented by nonlinear differential equations [10]. The system is shown in the Fig. 1, it includes two tanks interconnected serially, the input flow $Q_i(t)$ can be modified over time, as the tanks level increases or decreases. The tank levels are represented by $H_1(t)$and $H_2(t)$. The model is known as interconnected tanks since the liquid flow between tanks is denominated $Q_1(t)$, this is an output at the tank1 and an input at the tank 2. $Q_1(t)$ is assumed positive since the liquid flow will always be in direction from tank 1 to tank2.

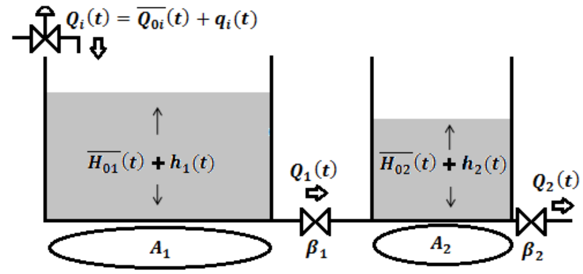

Figure 1. Interconnected tanks system.
Source: Authors.

2.1 Nonlinear model

The system model can be obtained from the conservation of mass principle, whereas the change of volume of the tank1 and tank2 relies on the variation of the input and output flows, the variation of liquid volume in tank1 can be expressed as the difference of the input flow $Q_i(t)$ and the output flow $Q_1(t)$ as it is shown in the eq. (1). Using the same reasoning of tank 1 volume for the tank2, the variation of liquid volume is show in eq. (2).

$$\frac{dV_1(t)}{dt} = Q_i(t) - Q_1(t) \quad (1)$$

$$\frac{dV_2(t)}{dt} = Q_1(t) - Q_2(t) \quad (2)$$

The flow between tanks 1 and 2 is dependent of $H_1(t)$ *and* $H_2(t)$, this means that if $H_1(t)$ is bigger, there will be more pressure. so $Q_1(t)$ will be, eq. (3).

$$Q_1(t) = \beta_1\sqrt{H_1(t) - H_2(t)} \quad (3)$$

And the flow in $Q_2(t)$ will be, eq. (4)

$$Q_2(t) = \beta_2\sqrt{H_2(t)} \quad (4)$$

The nonlinear space state representation of the tanks dynamics is given in by the differential equations show in eq. (5) and eq. (6).

$$\frac{dH_1(t)}{dt} = \frac{Q_i}{A_1} - \frac{\beta_1\sqrt{H_1(t) - H_2(t)}}{A_1} \quad (5)$$

$$\frac{dH_2(t)}{dt} = \frac{\beta_1\sqrt{H_1(t) - H_2(t)}}{A_2} - \frac{\beta_2\sqrt{H_2(t)}}{A_2} \quad (6)$$

$Q_i(t)$ input flow of tank1.
$H_1(t)$ level of liquid in tank 1.
$H_2(t)$ level of liquid in tank 2.
$\beta_1(t)$ *and* $\beta_2(t)$ are the valves constants.
$A_1(t)$ *and* $A_2(t)$ are the cross-sectional areas of the tanks.

If the input flow $Q_i(t)$ is equal to the output flow of the tank 1 $Q_1(t)$, and the flow between the tanks is equal to the output flow $Q_2(t)$, the system become into an equilibrium point, this guarantees that there is no level variation between the tanks.

The cross-sectional areas of the tanks $A_1(t)\ and\ A_2(t)$ and the valves constants $\beta_1(t)\ and\ \beta_2(t)$ are considered constants in the software. The differential equations of the model belong to the nonlinear space state model of the system, where the state vector is composed by the tank levels $H_1(t)$ and $H_2(t)$, and the input of the system is the flow $Q_i(t)$. These variables can be visualized in the simulation tool developed.

2.2 Equilibrium points

By making nonlinear state equations (eq. (5) and eq. (6)) equal to zero, equilibrium points are obtained eq. (7) and eq. (8).

$$\frac{Q_i}{A_1} - \frac{\beta_1\sqrt{H_{01}(t) - H_{02}(t)}}{A_1} = 0 \tag{7}$$

$$\frac{\beta_1\sqrt{H_{01}(t) - H_{02}(t)}}{A_2} - \frac{\beta_2\sqrt{H_{02}(t)}}{A_2} = 0 \tag{8}$$

Solving from eq. (7), eq. (9) is obtained.

$$\sqrt{H_{01}(t) - H_{02}(t)} = \frac{Q_i}{\beta_1} \tag{9}$$

Solving from eq. (8), eq. (10) is obtained.

$$\sqrt{H_{02}(t)} = \frac{\beta_1}{\beta_2}\sqrt{H_{01}(t) - H_{02}(t)} \tag{10}$$

Replacing eq. (9) in eq. (10) and solving for $H_{02}(t)$, eq. (11) is obtained.

$$H_{02}(t) = \left(\frac{Qi(t)}{\beta_2}\right)^2 \tag{11}$$

Now from replacing eq. (11) in eq. (9), eq. (12) is obtained.

$$H_{01}(t) = \left(\frac{Q_i(t)}{\beta_1}\right)^2 + \left(\frac{Q_i(t)}{\beta_2}\right)^2 \tag{12}$$

Eq. (11) and eq. (12) represent the generalized expressions for the equilibrium points. The system has multiple equilibrium points in function of the input flow $Qi(t)$. From the equilibrium point a linear model can be obtained, eq. (13).

$$\begin{bmatrix}\dot{H}_1\\ \dot{H}_2\end{bmatrix} = \begin{bmatrix}\left.\frac{\partial f_1}{\partial H_1}\right|_{\overline{X_0}} & \left.\frac{\partial f_1}{\partial H_2}\right|_{\overline{X_0}}\\ \left.\frac{\partial f_2}{\partial H_1}\right|_{\overline{X_0}} & \left.\frac{\partial f_2}{\partial H_2}\right|_{\overline{X_0}}\end{bmatrix}\begin{bmatrix}h_1\\ h_2\end{bmatrix} + \begin{bmatrix}\left.\frac{\partial f_1}{\partial Q_i}\right|_{\overline{X_0}}\\ \left.\frac{\partial f_2}{\partial Q_i}\right|_{\overline{X_0}}\end{bmatrix} Q_i \tag{13}$$

3 The virtual tool TANQUES EN SERIE PID

3.1 Development

The virtual tool is developed using Easy Java Simulation (EJsS) software, it was created by Francisco Esquembre, it is an open-source software that allows the simulation of math models based on differential equations, wherever they are linear or nonlinear, plus the signals can be visualized in a classic manner and through didactic representations of the systems. EJsS allows the generation of .jar files that can be converted to .exe files, allowing an easy distribution of the generated software [2,11,12].

In the Fig. 2 the main window of EJsS can be seen, this window is composed by 5 sections: Work panel selector, Information panels, Workbar, Work panels, and Information messages.

The Work panel is made of 3 subpanels with the follow specific functions:

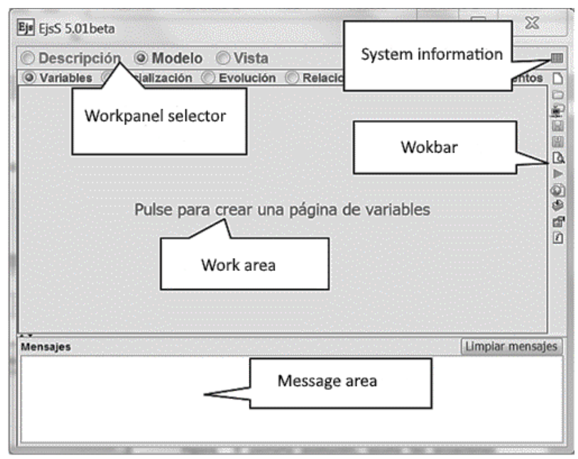

Figure 2. EJS software.
Source: Authors.

With the use of EJsS, the implementation of the nonlinear model is made using differential equations, also a closed loop is made using a PID controller, all of these using 2D graphical representations and time graphs of the most important functions, pause and play buttons are also included to control the simulation behavior, all the simulation parameters can be modified while the simulation is still running, thus resulting in a complete simulation tool.

3.2 Graphic user interface

The virtual tool has two tabs: “serie_no_lineal”, and “serie_no_lineal_controlado”, in each one of these tabs there are four sections, this can be seen in Fig. 3.

In the first section “1” there is a 2D animated graphical representation of the two interconnected tanks, there is a visual rendering of the tank levels, the input and output flows. This graph relies on the implemented differential equation of the model. The second “2” and the fourth “4” section introduce the graph of the tank1 and tank2 level functions respectively.

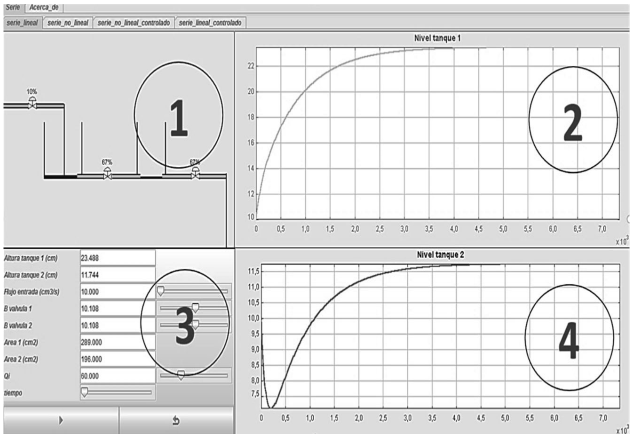

Figure 3. Interconnected tanks virtual tool sections.
Source: Authors.

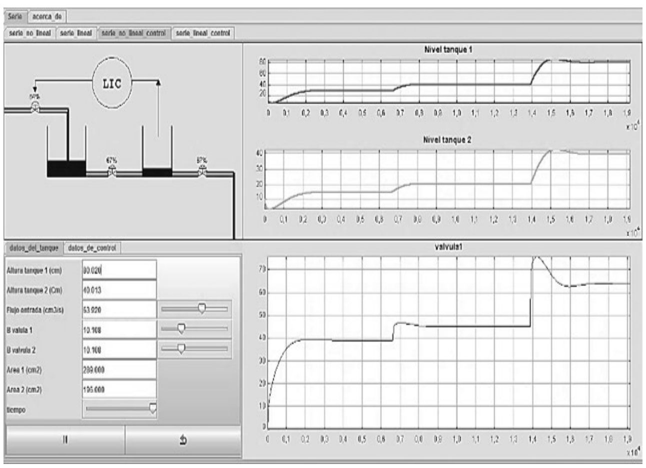

Figure 4. Nonlinear closed loop system tab.
Source: Authors.

The third “3” section display the parameters of the mathematical model that can be modified by the user, this includes A_1, A_2, β_1, β_2, and Q_i; there is a time slider, this is used to slow down or accelerate the simulation. This section also includes a play/pause and a reset button. All of this can be seen in more detail in the Fig. 5.

When the user is simulating a closed loop-controlled system in the respective tab (Fig. 4), in the third section a sub-tab appears, where the PID parameters can be modified by the user, this includes Kp, Ki, Kd and the reference, this can be seen in Fig. 6.

Note that in Fig. 4 when the user is in the “Serie_no_lineal_controlado” (closed loop system), a graph for the input valve function (controlled signal) versus time appears below the level tanks graphs.

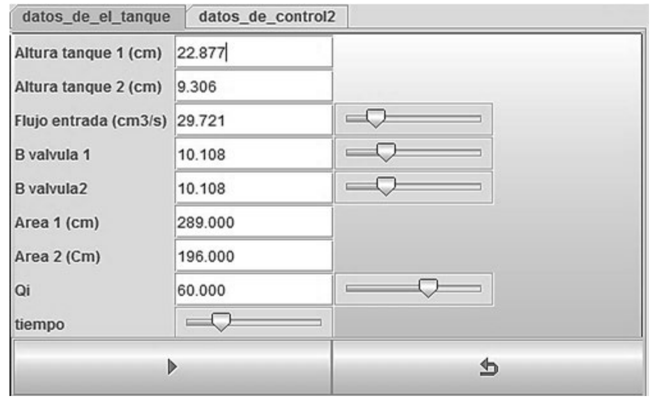

Figure 5. Model parameters modification in the virtual tool.
Source: Authors.

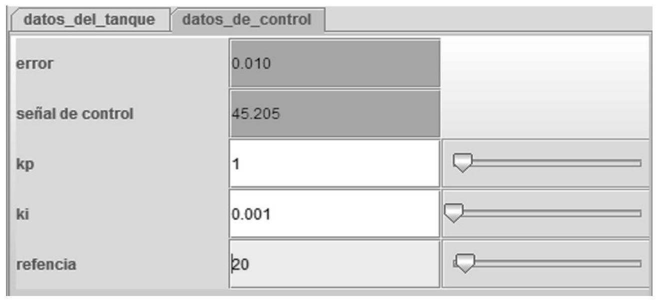

Figure 6. PID parameters modification in the virtual tool.
Source: Authors.

4 Results

4.1. Validation of the model

To validate the virtual tool results, the following parameters were used: $A_1 = 289\ cm^2$,$A_2 = 196\ cm^2$, input flow $Q_i = 60 \frac{cm^3}{seg}$, resistivity constant of the valves $\beta_1 = \beta_2 = 10.108$. These parameters are introduced into the developed tool and set to run, after the system settles, the level in tank 1 is of 70.470cm and the level in tank 2 is of 35.235 cm, Fig. 7.

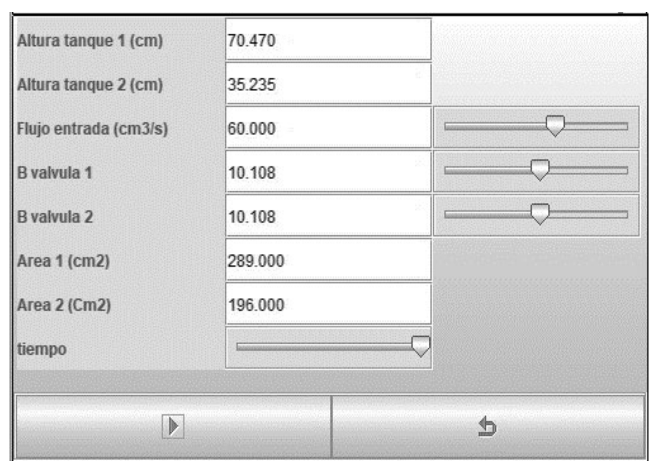

Figure 7. Parameters in the virtual tool, input flow of 60 cm3/s.
Source: Authors.

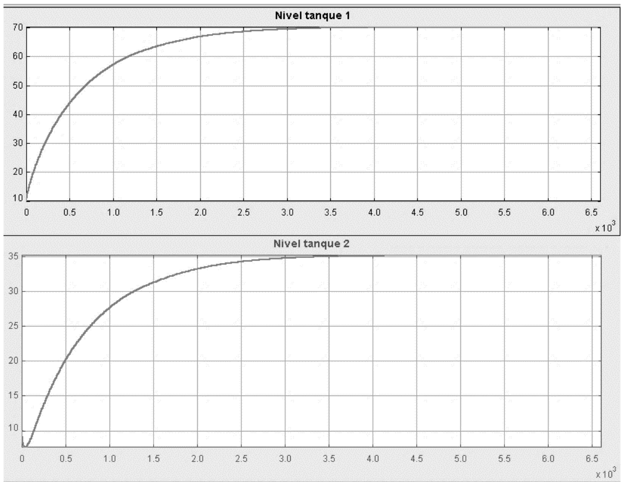

Figure 8. Tank 1 and tank 2 levels in the virtual tool.
Source: Authors.

The results are also displayed in a graphical manner in the virtual tool developed, Fig. 8.

To validate the results obtained in Fig. 7 and Fig. 8, the values are replaced into the equilibrium points equations, eq. (11) and eq. (12). The results obtained a for tank 1 and tank 2 respectively are displayed in eq. (14) and eq (15) respectively.

$$\mathrm{H}_{01}(\mathrm{t}) = \left(\frac{\mathrm{Q_i(t)}}{\beta_1}\right)^2 + \left(\frac{\mathrm{Q_i(t)}}{\beta_2}\right)^2 = 70.470 \quad (14)$$

$$\mathrm{H}_{02}(\mathrm{t}) = \left(\frac{\mathrm{Qi(t)}}{\beta_2}\right)^2 = 35.235 \quad (15)$$

The results obtained through the equations and the developed software are almost the same.

To give another example using the virtual tool, the same parameters of Fig. 7 are used, then after the system settles the input flow is modified from $Q_i = 60\frac{cm^3}{seg}$ to $Q_i = 70\frac{cm^3}{seg}$, the tanks levels after the system settle are: tank 1=95.919cms and tank 2=47.957cms respectively, this can be seen in Figs. 9 and 10.

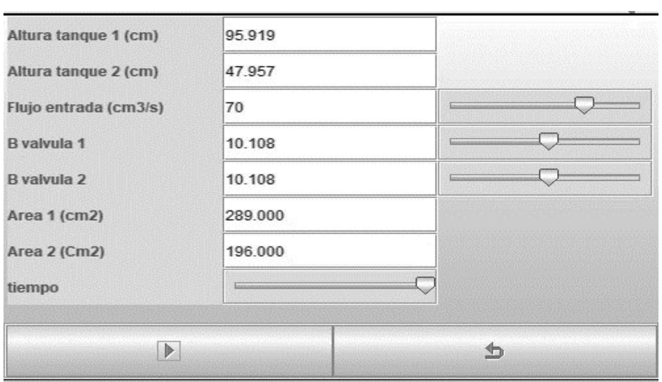

Figure 9. Parameters in the virtual tool, input flow of 70 cm3/s.
Source: Authors.

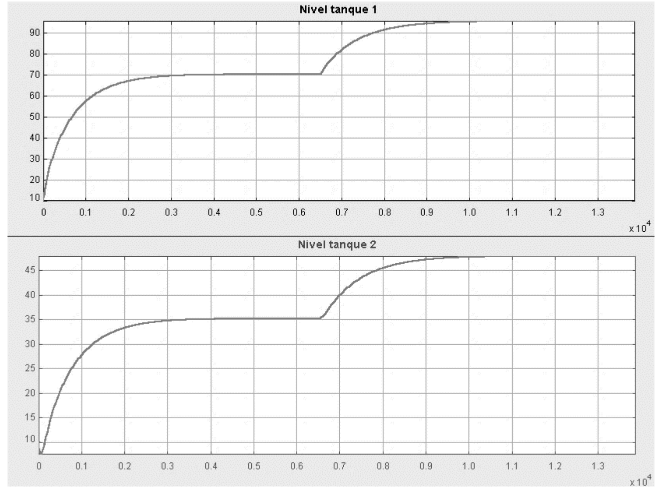

Figure 10. Tank 1 and tank 2 levels in the virtual tool.
Source: Authors.

These results are verified using eq. (11) and eq. (12), then eq. (16) and eq. (17) are obtained.

$$\boldsymbol{H_{01}(t)} = \left(\frac{\boldsymbol{Q_i(t)}}{\boldsymbol{\beta_1}}\right)^2 + \left(\frac{\boldsymbol{Q_i(t)}}{\boldsymbol{\beta_2}}\right)^2 = \mathbf{95.917} \quad (16)$$

$$\boldsymbol{H_{02}(t)} = \left(\frac{\boldsymbol{Qi(t)}}{\boldsymbol{\beta_2}}\right)^2 = \mathbf{47.959} \quad (17)$$

The Nonlinear differential equations are implemented in Simulink as shown in Fig. 11, the input flow is represented by a step signal, it starts at 60cm3/s then at 6600 seconds is modified to 70cm3/S, this can be seen in Fig. 12. The obtained signals for tank 1 and tank 2 levels are displayed in Figs. 12 and 13 respectively, the results obtained in Simulink match the ones obtained in the virtual tool (Fig. 10) and with the theoretical calculations, in the Table 1 a comparison

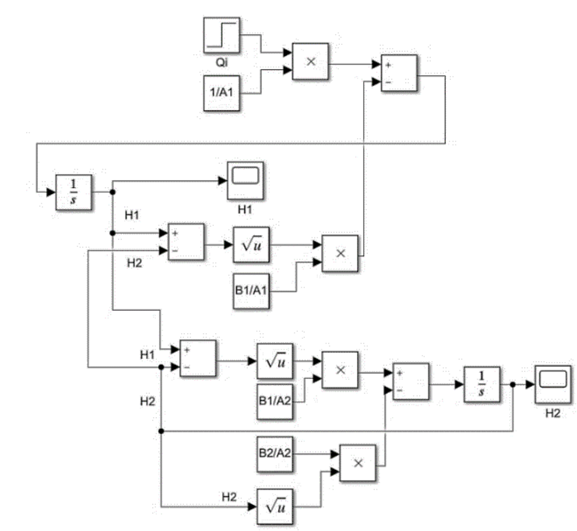

Figure 11. Nonlinear interconnected tanks model in Simulink.
Source: Authors.

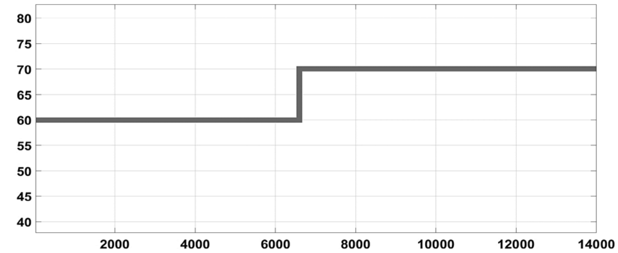

Figure 12. Input flow in Simulink.
Source: Authors

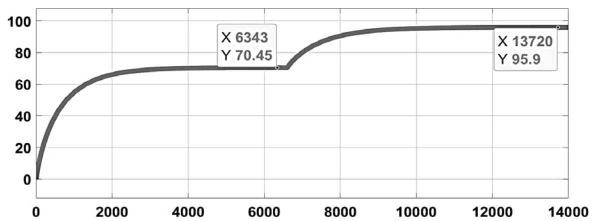

Figure 13. Tank 1 level in Simulink.
Source: Authors.

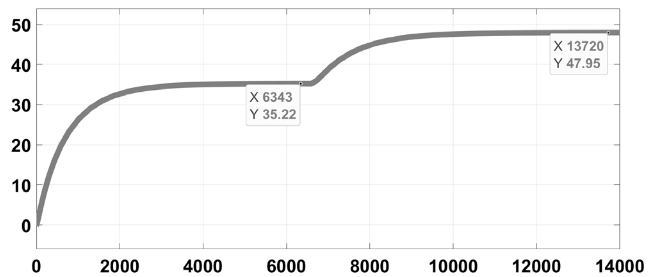

Figure 14. Tank 2 level in Simulink.
Source: Authors.

Table 1.
Obtained results.

Method	Tank 1 level (cm3/s)	Tank 2 level (cm3/s)
Equilibrium point equations Qi=60cm3/s	70.470	35.235
Virtual tool Qi=60 cm3/s	70.470	35.235
Simulink Qi=60 cm3/s	70.45	35.22
Equilibrium point equations Qi=70 cm3/s	95.917	47.959
Virtual tool Qi=70 cm3/s	95.919	47.957
Simulink Qi=70 cm3/s	95.9	47.95

Source: Authors.

between all the obtained equilibrium points is set forth. The signals obtained in the virtual tool in Fig. 10 can be directly compared with the signals obtained in Figs. 12 and 13, they are practically the same in terms of time response.

4.2 PID controller verification

As stated earlier the developed virtual tool can simulate the nonlinear model of the tanks with a PID controller in a closed loop, where the reference is the level in the tank 2 and the controlled variable is the input flow Qi. When the virtual tool is in the "serie_no_lineal_control" tab, the data panels of Figs. 5 and 6 are accessible, the tanks parameters and PID controller parameters can be modified, the subsequent parameters are used: Kp=5, Ki=0.03 and Kd=0.5, this can be seen in Fig. 15.

In Fig.16 the tank 1 and tank 2 levels obtained in the virtual tool can be seen, the variation of the input flow Qi (controlled variable) is show in Fig. 17.

To verify the results obtained in Figs. 16 and 17, a simulation in Simulink is performed, adding a PID controller and closing the loop to the system show in Fig. 11 the system of Fig. 18 is obtained.

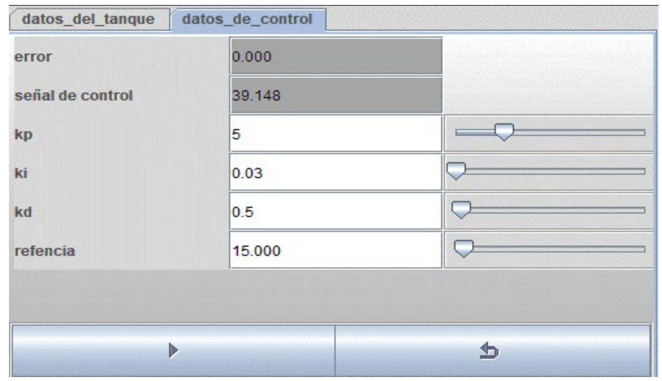

Figure 15. PID parameters in the virtual tool.
Source: Authors

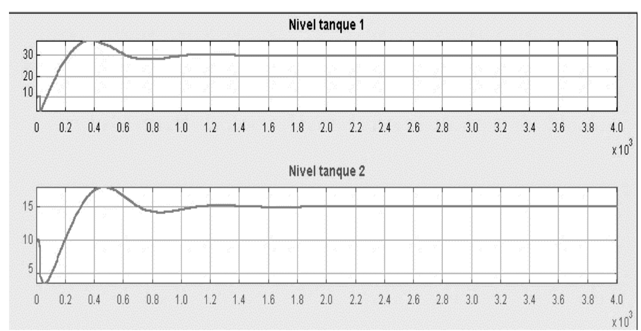

Figure 16. Tank 1 and Tank 2 levels obtained in the virtual tool.
Source: Authors

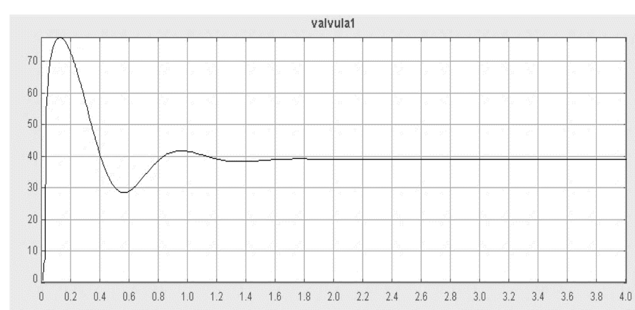

Figure 17. Control signal, Qi in the virtual tool.
Source: Authors

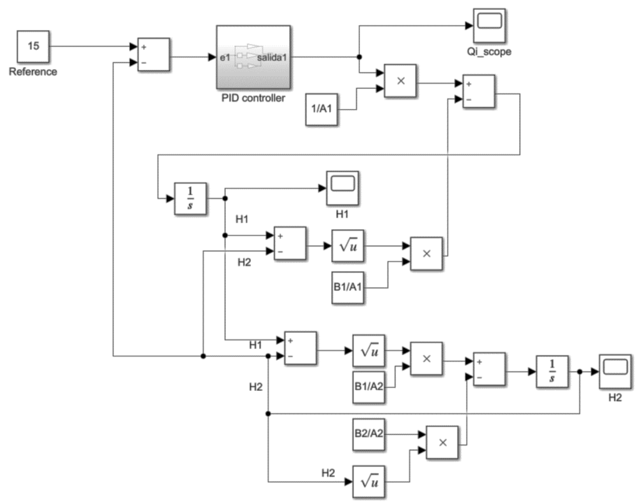

Figure 18. Closed loop simulation in Simulink.
Source: Authors

In Fig. 19 the PID controller implemented in Simulink is displayed, note that the same parameters of the Fig. 15 were used.

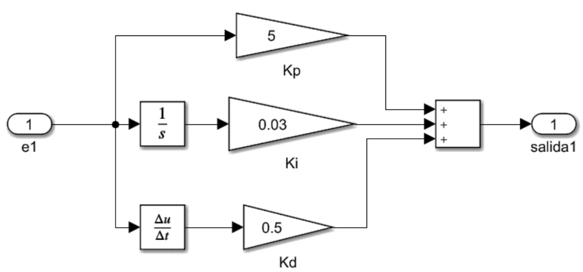

Figure 19. PID controller in Simulink.
Source: Authors

The tank 2 level signal obtained in the Simulink simulation is displayed in the Fig. 20, the signal is almost the same of the one displayed in Fig. 16, both have a maximum peak of approximately 17cm at 500 seconds, both signals settle at around 1300 seconds.

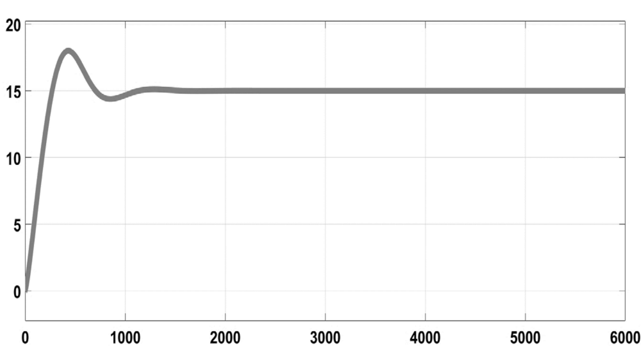

Figure 20. Tank 2 level signal in Simulink.
Source: Authors

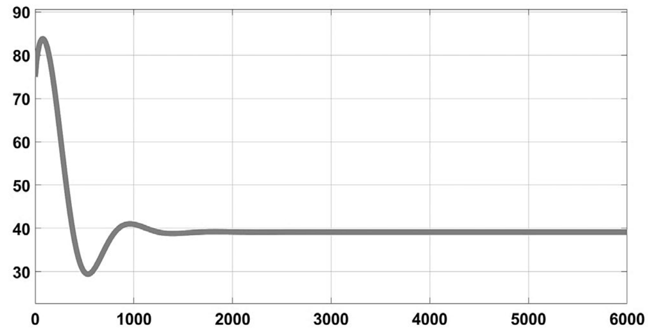

Figure 21. Control signal in Simulink.
Source: Authors

The input flow signal (control signal) obtained in Simulink is presented in Fig. 21, it is almost the same one obtained in Fig. 16, both signals have a maximum peak of almost 85, a minimum of 30, and settle at around 1300 seconds.

5 Conclusions

This work proves that the open-source software Easy Java Simulations can be used to implement fully functional, interactive and didactic simulations of nonlinear liquid level models with applied control strategies, in this case with a PID controller. Time response of tank level and valve signals can be studied in detail through the virtual tool developed, making easier the study of the nonlinear model, PID controller design, equilibrium points, and stability of continuous systems. The nonlinear model and PID parameters can be modified while the simulation is still running. The platform allows the application of PID controllers to the nonlinear model of interconnected tanks, this gives total freedom to the user, also the signals time response can be seen in time graphics or in a more didactic way in a 2D representation, this includes tanks levels, flows and valve variations.

The software results were validated using equations and simulations performed in Simulink of MATLAB. As future work, the platform is intended to be benchmarked as a teaching tool, also more functions will be added including Linear model, space state model, state variable feedback controller, among another's. TANQUES EN SERIE PID stablishes as one of the most complete user-friendly simulation tools available nowadays in the world for nonlinear PID simulation, remaining lightweight, needing few system resources, being reliable and with proved accuracy.

References

[1] Miranda, J. et al., The core components of education 4.0 in higher education: Three case studies in engineering education, Comput. Electr. Eng., 93, art. 107278, 2021, DOI: https://doi.org/10.1016/j.compeleceng.2021.107278.

[2] Esquembre, F., Using easy Java simulations to create scientific simulations in Java, IEEE Reg. 8 EUROCON 2003 Comput. as a Tool - Proc., vol. A, pp. 20–23, 2003. DOI: https://doi.org/10.1109/EURCON.2003.1247971.

[3] Chacon, J., Besada-Portas, E., Carazo-Barbero, G., and Lopez-Orozco, J.A., Enhancing EJsS with extension plugins, Electronics, 10(3), art. 242, 2021, DOI: https://doi.org/10.3390/electronics10030242

[4] Mathworks, Simulink, [online]. 2024. [accessed Mar. 24,2024]. Available at: https://es.mathworks.com/products/simulink.html

[5] Freeman, S. et al., Active learning increases student performance in science, engineering, and mathematics., Proc. Natl. Acad. Sci. U. S. A., 111(23), pp. 8410–8415, 2014, DOI: https://doi.org/10.1073/pnas.1319030111.

[6] Bistak, P., and Huba, M., Three-Tank virtual laboratory for input saturation control based on Matlab, IFAC-PapersOnLine, 49(6), pp. 207–212, 2016. DOI: https://doi.org/10.1016/j.ifacol.2016.07.178.

[7] Ramírez-Ramírez, M., Ramírez-Scarpetta, J.M., and Fernández-Samacá, L., Interactive animations for learning by playing concepts of control systems. 21st Mediterr. Conf. Control Autom. MED 2013 - Conf. Proc., pp. 573–577, 2013, DOI: https://doi.org/10.1109/MED.2013.6608779.

[8] Wee, L.K., Tan, D., Clemente, F.J.G. and Esquembre, F., Easy JavaScript Simulation (EJSS) for Singapore, J. Phys. Conf. Ser., 2693(1), art. 012017, 2024, DOI: https://doi.org/10.1088/1742-6596/2693/1/012017.

[9] Galán-Díaz, J.J., Garrido, S.F., García-Diez, A.I., Graña-López, M.Á., Filgueira-Vizoso, A., and Castro-Santos, L., Assessment of engineering undergraduates active learning experience using computer simulations, Int. J. Eng. Educ., 40(2), pp. 358–367, 2024.

[10] Grygiel, R., Bieda, R., and Blachuta, M., On significance of second-order dynamics for coupled tanks systems, 1, pp. 1016–1021, 2016.

[11] Farias, G., De Keyser, R., Dormido, S., and Esquembre, F., Developing Networked control labs: a Matlab and easy Java simulations approach, Industrial Electronics, IEEE Transactions on, 57(10), pp. 3266–3275, 2010 DOI: https://doi.org/10.1109/TIE.2010.2041130.

[12] Dormido, S., Esquembre, F., Farias, G., and Sánchez, J., Adding interactivity to existing Simulink models using Easy Java Simulations, Proc. 44th IEEE Conf. Decis. Control. Eur. Control Conf. CDC-ECC '05, 2005, pp. 4163–4168, 2005. DOI: https://doi.org/10.1109/CDC.2005.1582815.

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