

Introducing Automatic Evaluation in Virtual Laboratories for Control Engineering at University of Extremadura. First Steps

Inés Tejado, Emiliano Pérez, Isaías González, Pilar Merchán, and Blas M. Vinagre

Abstract—In the last decades, the academic community has developed a huge variety of interactive resources to support teaching both in the classroom and in the laboratory, especially in engineering degrees. Among them, the use of virtual and remote laboratories (VRLs), which combine features of traditional laboratories with interactive simulations, is essential to students to acquire practical skills, i.e., obtain the technical know-how that will be their most important asset in their professional career. One of the current interests in this field focuses on reducing the assessment workload of the faculty staff. This paper describes the first steps in the introduction of automatic evaluation in virtual laboratories (VLs) built with Easy Java/Javascript Simulations (EJS/EjsS) for automatic control courses in engineering. With the final objective that the students can detect calculation errors, as well as misconceptions related to the theoretical background, two examples of VLs are given to show their utility to validate the student answers in a simple way. For illustration purposes, some exercises are proposed and solved with the VLs developed.

Keywords—Innovation, education, engineering, virtual laboratory, automatic evaluation.

I. INTRODUCTION

TEACHING in automatic control needs to have a balance of both a deep understanding of the mathematics behind the concepts and practical experience. To this respect, lab experimentation plays a key role to connect theory and practice [1]. As known, traditional hands-on labs involve high costs derived by equipment, space, and maintenance. Due to those facts, the trend in the last two decades is to integrate new pedagogical methodologies in the lab in order to reduce costs by substituting traditional labs with web-based laboratories, [2], [3]. Likewise, another benefit of such laboratories is students are no longer required to be physically present in a laboratory to work; instead, they can work on them at home or wherever they have an available Internet connection. This kind of labs is usually divided into two categories, according to the system's nature: virtual laboratories (VLs), which simulate a mathematical model of a physical plant, and remote laboratories (RLs), which provide access to a real physical plant located in a remote site through the Internet (another

classification can be found in, e.g., [4]). A current review on virtual and remote laboratories (VRLs) in control education is reported in [5], [6].

One of the current challenges in the topic of VRLs consists in introducing the choice of automated grading in the interactive tools so that faculty staff can reduce the amount of time devoted to correct the large number of exercises that are proposed to students for the evaluation of the different competences within the European Higher Education Area. This situation is even more complicated if one takes into account that enrollment in industrial engineering programs is increasing in the last years.

Strictly speaking, one of the main advantages of the VRLs is that, through them, students can carry out an autonomous learning, that is, they acquire a greater responsibility and an active role in the teaching-learning process. Hence, it seems evident that the automatic evaluation should be an inherent capability of the VRLs to take advantage of all their benefits.

Several approaches have been reported in the literature to include automatic evaluation into VRLs in, for example, the fields of chemistry [7], electronics [8], and control systems [9]. In that last work, an automatic evaluation element (AEE) was proposed for VRLs built with Easy Java Simulations (EJS) by using the server application Goodle grading management system. Although interesting and effective, this element only works in an outdated version of EJS. Likewise, from the authors' viewpoint, in most cases deep programming skills are required to implement and/or adapt such solutions to the developed environment of the resource.

Motivated by this context, this paper shows the first steps carried out in a pair of VLs built with Easy Java/Javascript Simulations, namely, the level control of a tank and the modelling of a resistor-inductor-capacitor (RLC) circuit, to enhance their utility including the automatic correction. To that aim, some Java/Javascript codes are added to the resources so that the student will be able to check if his/her calculations are correct or not. In particular, the student will write the result in a box created in the graphical-user interface (GUI) of the VL and press the check button. Then, a text message will appear to inform him/her about the correctness of the result but will not provide the correct one so the student has to repeat the calculation if necessary. In such a way, the student is envisioned to detect calculation fails, as well as misconceptions related to the theoretical background. It should

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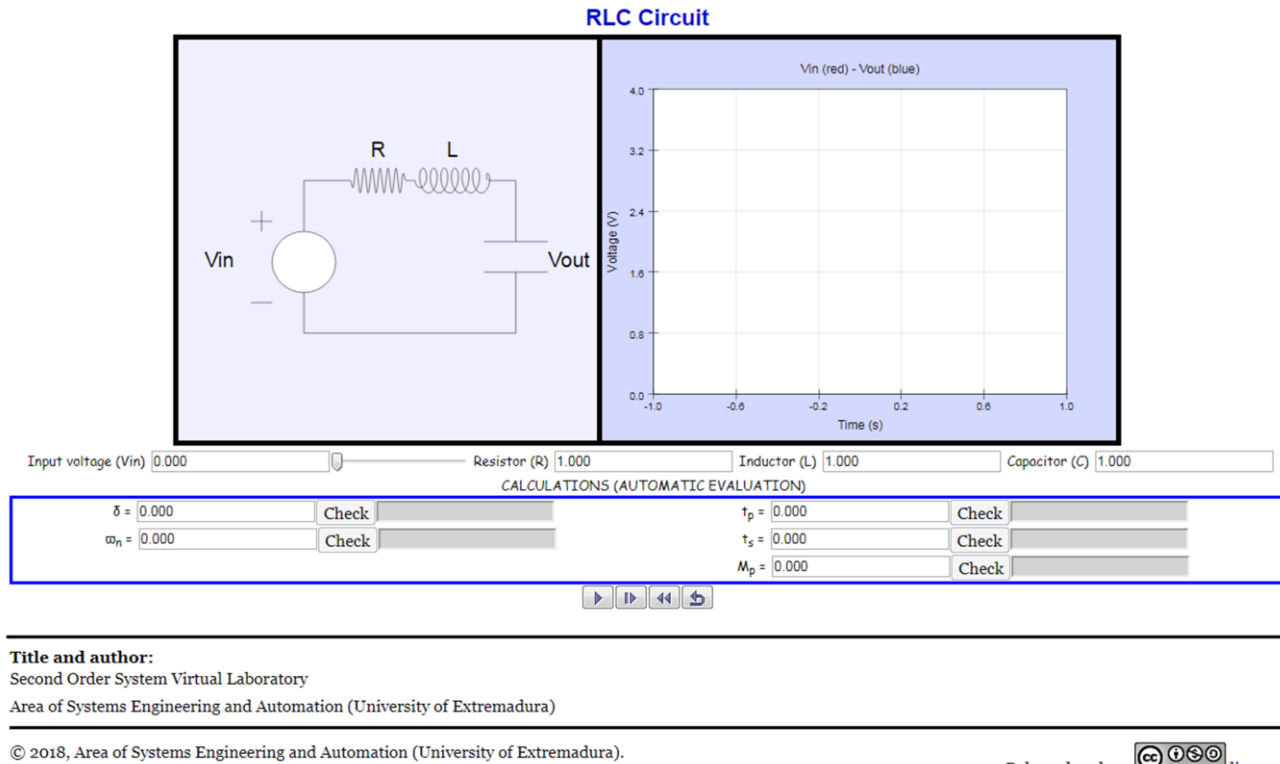


Fig. 1 HTML view of the VL for second order systems

be noted that Easy Java/Javascript Simulations, also known as EjsS (and, formerly, EJS), is a freeware authoring tool [10] delivered with easy-to-use features in order to facilitate the design of VRLs for teachers without programming expertise.

The remainder of this paper is organized as follows. Section II describes the educational VLs developed, namely, second order system modelling and level process control VLs, and how the automatic evaluation functionality is added. Section III gives some illustrative examples of use of the VLs developed. Finally, Section IV draws the concluding remarks.

II. DESCRIPTION OF VIRTUAL LABORATORIES

This section describes the two VLs developed for students of introductory courses of automatic control at the University of Extremadura. Both VLs are intended to: 1) make students familiar with the use of interactive computer tools that simulate the dynamic behavior of systems, 2) encourage their autonomous learning, and 3) detect misconceptions related to the theoretical background.

It is important to remark that the VLs which will be described next were conceived for students of introductory courses of automatic control. Thus, we focus on 'Introduction to Automation', a second-year obligatory course common in four Bachelor Degrees in Industrial Engineering taught at the University of Extremadura, namely, in Electronic Engineering and Automation, Electrical Engineering, Mechanical Engineering, and Material Engineering. This course has an academic load of 150 hours per student, including both theoretical and practical sessions and study hours. (Note that Bachelor Degrees in our university are of four-year duration.)

A. Second Order System Virtual Laboratory

The RLC circuit is a widely used example to introduce the dynamics of second order systems. This first VL implements such an electric circuit and is built by EjsS. The details of the VL and the way of introducing the automatic evaluation capability are given next. The HTML view of the laboratory is illustrated in Fig. 1.

From the viewpoint of students' learning, the main purpose of this laboratory is to help students to identify the effects of the parameters of a second order system on the system response, i.e., on the characteristics of the time response, by using interactive computer tools, and vice versa.

Considering a RLC circuit excited by an input voltage $v_i(t)$, the differential equation which relates it to the voltage measured at the terminals of the capacitor ($v_o(t)$) is

$$v_i(t) = LC \frac{d^2 v_o(t)}{dt^2} + RC \frac{dv_o(t)}{dt} + v_o(t) \quad (1)$$

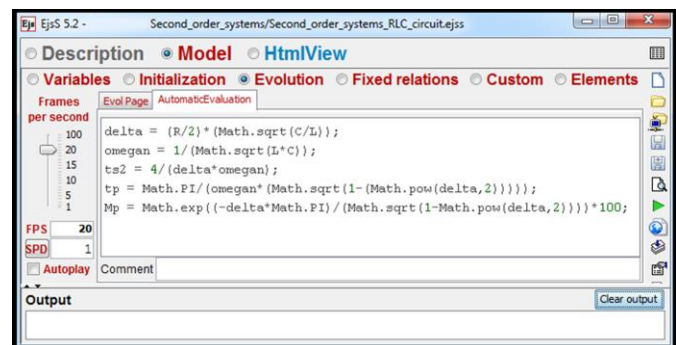


Fig. 2 Javascript code to calculate the system parameters and time domain characteristics in open-loop

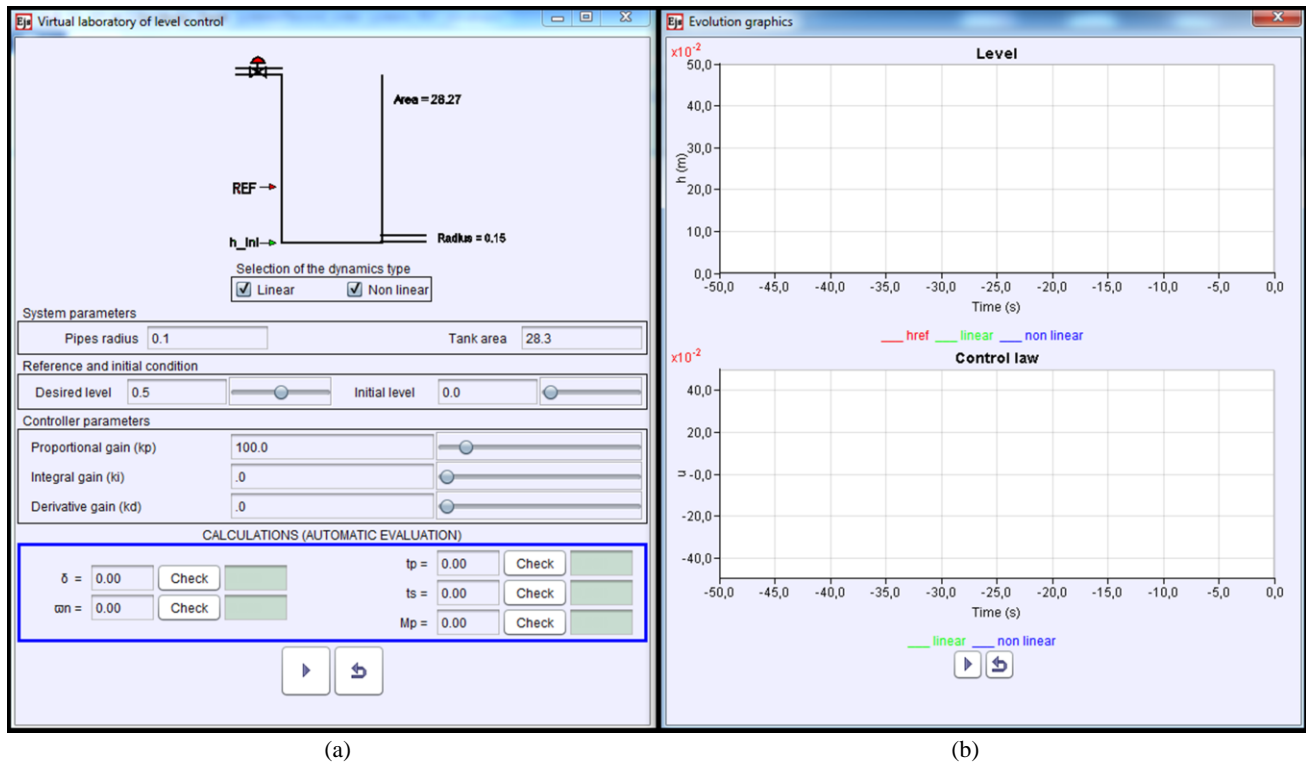


Fig. 3 GUI of the VL of level control: (a) Configuration window (b) Evolution graphic window

where R , L and C are the values of the electric components.

Applying the Laplace transform to (1) and considering initial conditions as zero, the system transfer function of the system is

$$G(s) = \frac{V_o(s)}{V_i(s)} = \frac{\frac{1}{LC}}{s^2 + \frac{R}{L}s + \frac{1}{LC}} \quad (2)$$

Notice that the static gain of the system is 1. Thus, the natural frequency and the damping ratio of the system are given by

$$\omega_n = \sqrt{\frac{1}{LC}} \quad (3)$$

$$\delta = \frac{R}{2} \sqrt{\frac{C}{L}} \quad (4)$$

From these values, and considering an underdamped system, it is possible to obtain the transient-response specifications, more precisely, peak time (denoted as t_p), settling time (t_s) and overshoot (M_p) by means of the well-known expressions for second order systems (see e.g. [11]):

$$t_p = \frac{\pi}{\omega_n \sqrt{1-\delta^2}} \quad (5)$$

$$t_s = \frac{4}{\delta \omega_n} \quad (6)$$

$$M_p = e^{\frac{-\delta\pi}{\sqrt{1-\delta^2}}} \quad (7)$$

It should be remarked that t_s in expression (6) is defined with 2% criterion.

Our first steps in the introduction of automatic evaluation in the VL are focused on programming the expressions of all parameters to be determined, namely, ω_n and δ and the aforementioned time domain characteristics, in one page of the section 'Evolution' in the menu *Model*, as shown in Fig. 2.

These values, the correct ones, will be compared with those introduced by the student by means of a Javascript function programmed in the 'Custom' page. To perform an effective comparison, a margin of error, in percentage, between the correct values and those introduced by the students is considered. It must be said that this error can be adjusted by the teacher; in the current version of the VL it is set to 10%.

The HTML view of the VL, as shown in Fig. 1, can be divided into two parts as follows. At the top, it has the graphical panels, consisting of a scheme of the circuit to be simulated on the left and the evolution plots versus time for the input and output voltages on the right. Below these, the panel with the input voltage to be applied and the values of the system parameters to be assigned are shown.

At the bottom, the buttons for automatic evaluation are included. The laboratory has been conceived so that, from certain values of the electrical components of the circuit, the values of the parameters δ and ω_n of the system have to be calculated, as well as the time domain characteristics t_p , t_s , and M_p , and then inserted in the numerical fields enabled for that purpose. Once those values written, it is needed to press the 'Check' button to check if the calculations are correct. If they are correct, the box on the right of the corresponding parameter will appear in green with a "T" of true, or in red with an "F" (false) otherwise.

B. Level Process Control Virtual Laboratory

This VL consists of a configurable tank system controlled by a tunable proportional-integral-derivative (PID) controller. Both the linear and the nonlinear models of the system are implemented in the VL (the dynamics to be considered is

selectable), with the possibility of visualizing both the system response and the control signal of each or both models. This section describes the virtual laboratory developed with EJS, as well as how automatic evaluation is added. Fig. 3 shows the GUI of the laboratory.

From the viewpoint of students' learning, the objectives that are intended to be achieved with this VL are:

- Identify the effects of basic control actions on the time response of a system visually.
- Observe the effects of nonlinear dynamics in the behavior of systems.

Likewise, this laboratory aims to optimize the use of resources in the real laboratory, mainly equipment and time

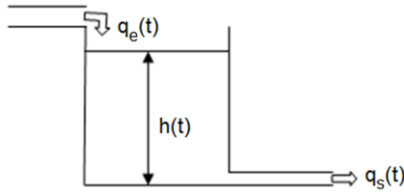


Fig. 4 Scheme of the level of a tank with input and output flows ($q_e(t)$ and $q_s(t)$, respectively)

invested by students to perform laboratory lessons.

As commented, this VL implements the level control of a configurable tank, with input and output flows, as shown in Fig. 4, where the height of the liquid is denoted as $h(t)$, the desired or reference level as h_{ref} , while the input and output flows are $q_e(t)$ and $q_s(t)$, respectively. To maintain the tank level at the desired value, a PID controller is going to be used. The system dynamics is given by the following equations:

$$q_e(t) - q_s(t) = A \frac{dh(t)}{dt} \quad (8)$$

$$q_s(t) = a\sqrt{2gh(t)} \quad (9)$$

$$q_e(t) = ku(t) \quad (10)$$

where a and A are the pipe and tank section, respectively, g is the acceleration of gravity, k is a constant of the inlet flow and $u(t)$ is the inlet flow of the tank. Both the pipes and the tank are considered cylindrical, so that their areas will be circular and will be given according to the radius of each, r and R , respectively. And combining (8) and (10), the dynamics of the system reduces to

$$\dot{h}(t) = -\frac{a}{A}\sqrt{2gh(t)} + \frac{k}{A}u(t) \quad (11)$$

The nonlinear model (11) can be linearised by applying the perturbation method, resulting in the following linear dynamic

$$\dot{h}(t) = -\frac{a^2g}{Aku_0}h(t) + \frac{k}{A}u(t) \quad (12)$$

where u_0 is the value of the input at the equilibrium point. Both the nonlinear and the linear models (11) and (12) are implemented in the LV, with the possibility of selecting one or both.

From model (12), and considering initial conditions as zero, the system transfer function is

$$G(s) = \frac{H(s)}{U(s)} = \frac{K_l}{T_l s + 1} \quad (13)$$

where $K_l = \frac{k^2 u_0}{a^2 g}$ and $T_l = \frac{A k u_0}{a^2 g}$. Thus, the closed-loop transfer function with the PID controller will be

$$G_{cl}(s) = \frac{\frac{K_l}{T_l + K_l k_d} (k_d s^2 + k_p s + k_i)}{s^2 + \frac{1 + K_l k_p}{T_l + K_l k_d} s + \frac{K_l k_i}{T_l + K_l k_d}} \quad (14)$$

Therefore, the natural frequency of the closed-loop system

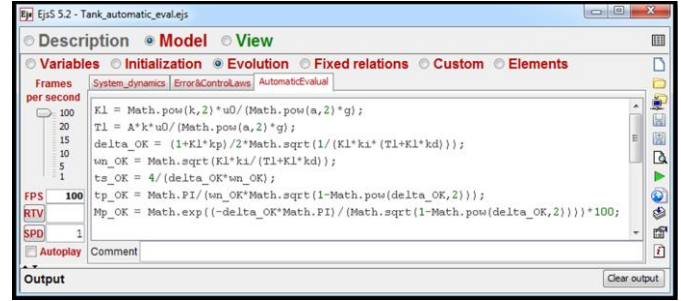


Fig. 5 Java code to calculate the system parameters and time domain characteristics in closed-loop

is expressed as

$$\omega_n = \sqrt{\frac{K_l k_i}{T_l + K_l k_d}} \quad (15)$$

whereas the damping ratio is given by

$$\delta = \frac{1 + K_l k_p}{2} \sqrt{\frac{1}{K_l k_i (T_l + K_l k_d)}} \quad (16)$$

Again, from the parameters δ and ω_n , it is possible to obtain the values of the characteristics of the step response of the system by using expressions (5)-(7).

Therefore, to include automatic evaluation in this VL, expressions (15) and (16), as well as the corresponding relations between ω_n and δ and the aforementioned time domain characteristics, are programmed in one page of the section 'Evolution' in the menu *Model*, as shown in Fig. 5. In a similar way to the previous VL, the values resulting of these calculations (the correct values) will be compared with those introduced by the student by means of a Java function programmed in the 'Custom' page. To perform an effective comparison, again a margin of error, in percentage, between the correct values and those introduced by the students is considered. It must be said that this error can be adjusted by the teacher; in the current version of the VL it is set to $\pm 10\%$.

As can be observed from Fig. 3, the GUI of the VL consists of two parts: the configuration window, on the left side, and the window with the graphical evolution of the tank level and control signal, on the right. In Fig. 3(a), the student can assign values to the following variables:

- System parameters: radius of pipes (r , then $a = \pi r^2$) and tank area (A). It should be remarked that the remainder parameters that intervene in the system dynamics, namely, k and g , are fixed in the simulations ($k = 8 \cdot 10^{-2}$ and $g = 9.8 \text{ m/s}^2$).
- Reference level (h_{ref}) and initial level (h_{ini}): they both should be numbers between 0 and 1.

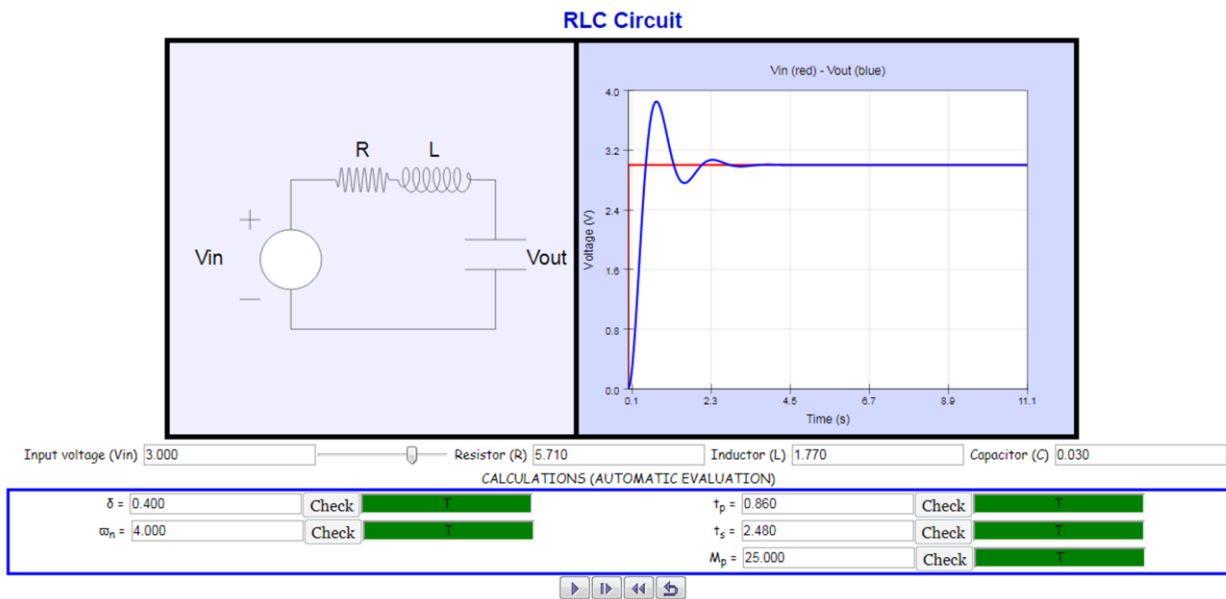
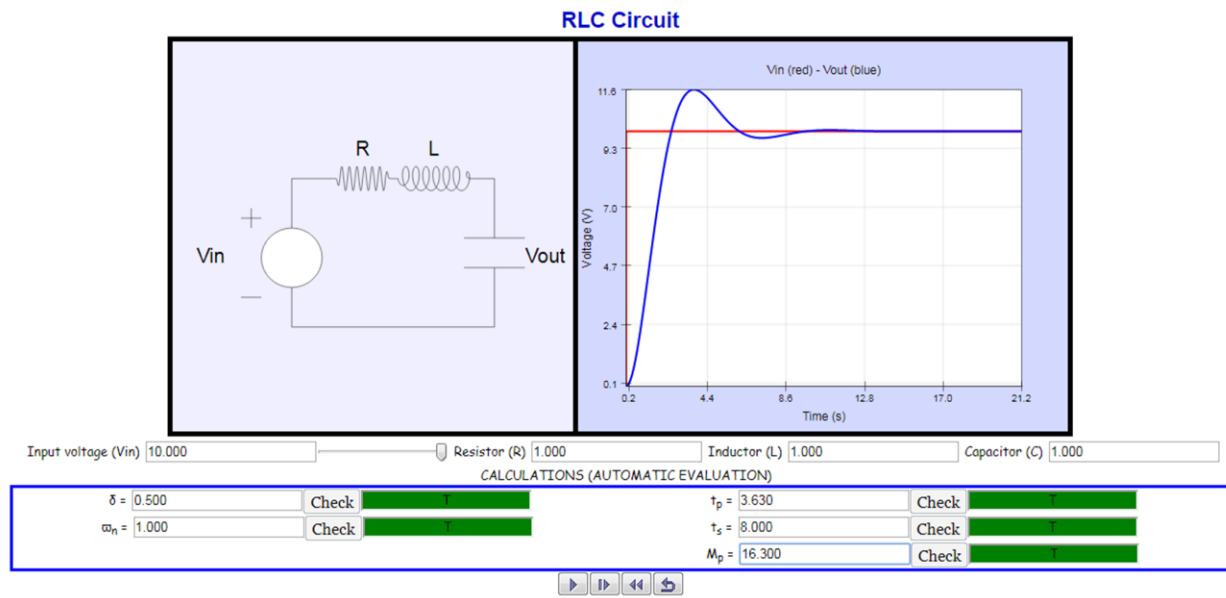


Fig. 6 Results of the exercises proposed using the second order system VL: (a) Exercise 1 (b) Exercise 2

- Controller parameters: proportional gain (k_p), integral gain (k_i), and derivative gain (k_d).

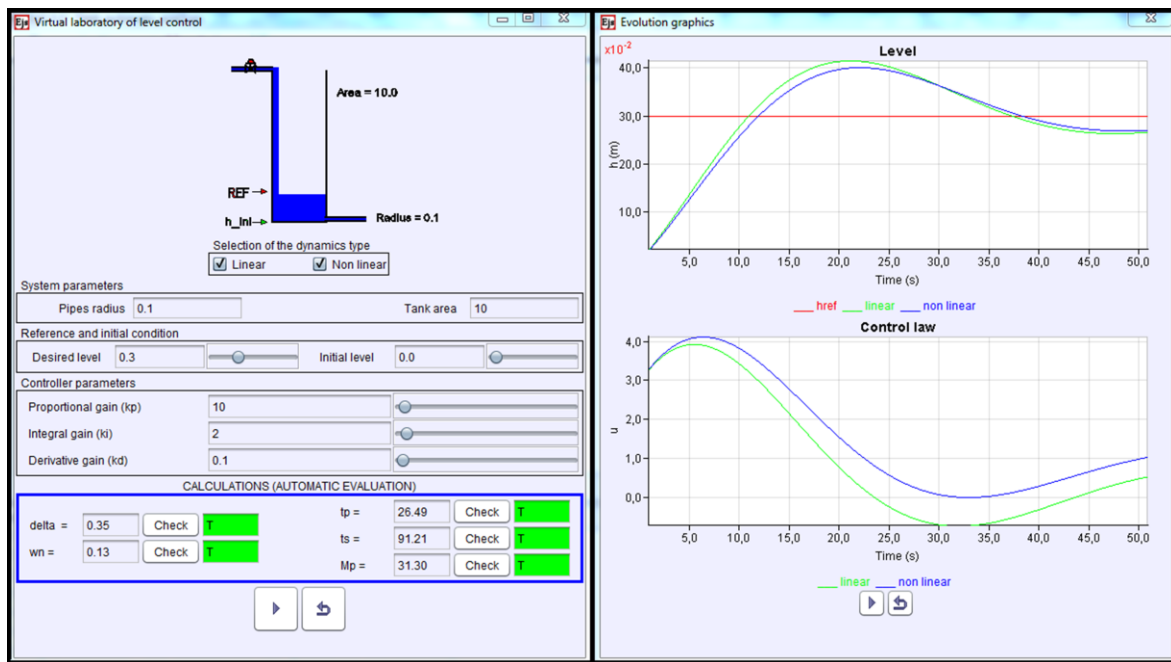
The buttons for automatic evaluation are included at the bottom of this window. Similar to the previous VL, for a given exercise, it is necessary to write the values of all the parameters δ , ω_n , t_p , t_s , and M_p (in %), or some of them, in the numerical fields enabled for that purpose and press the 'Check' button to check if the calculations are correct. Again, if they are correct, the box on the right of the corresponding parameter will appear in green with a "T" of true, or in red with an "F" (false) otherwise.

In the window on the right (Fig. 3(b)), the system response when applying the designed PID controller corresponding to the selected (linear and/or nonlinear model), together with the reference, can be observed in the graphic at the top (colored green, blue and red, respectively). In the bottom graphic, the

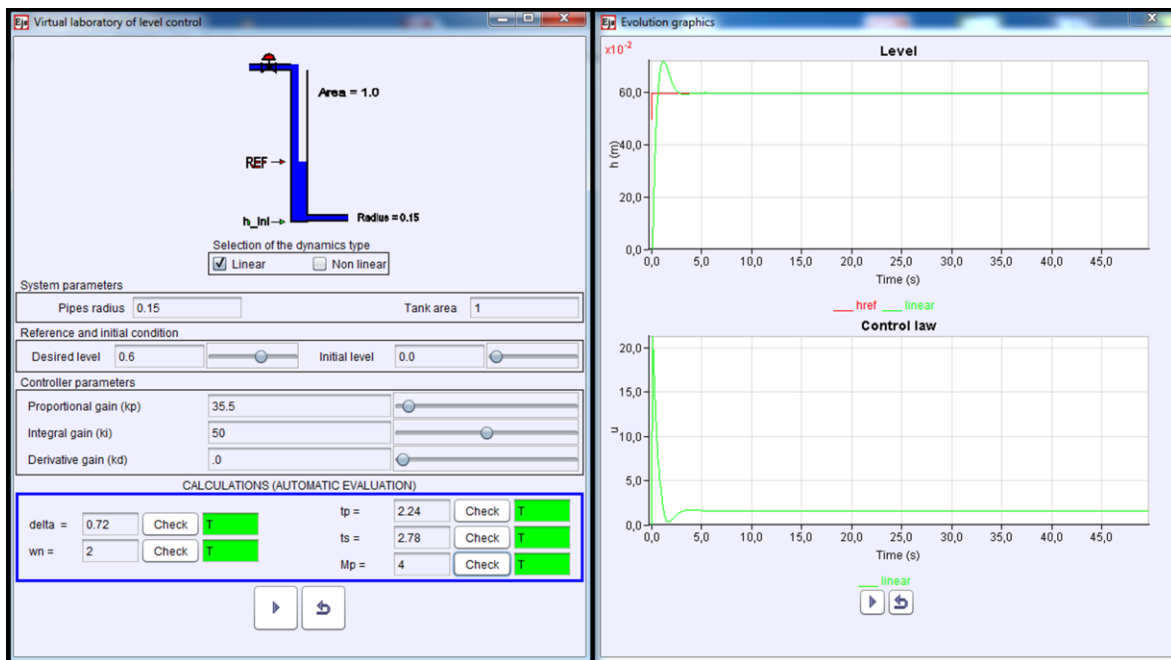
control laws corresponding to the linear and/or nonlinear cases are plotted.

III. EXAMPLES OF USE

This section gives some illustrative examples of possible exercises to be carried out by using the VLs developed. Next, several control problems that can be studied by using the second order system and the level control VLs are addressed, respectively, to: 1) identify the parameters of a second order system that correspond to a certain underdamped step response, and 2) design a proportional-integral (PI) controller so that the step response of the system in closed-loop fulfils given specifications.



(a)



(b)

Fig. 7 Results of the exercises proposed using the level control VL: (a) Exercise 1 (b) Exercise 2

A. Second Order System Modelling

Two different examples are considered next which will be solved using the second order system VL.

1) Exercise 1

Given a system with $R = L = C = 1$, calculate the values of the transient-response specifications of the system when applying an input voltage of 10 V.

Solution:

Substituting the values of the circuit components in equations (3)-(4), one can obtain that $\delta = 0.5$ and $\omega_n = 1$ rad/s. And using (5)-(7), the time domain characteristics of the

step response of the system are: $t_p = 3.63$ s, $t_s = 8$ s, and $M_p = 16.3\%$. Fig. 6(a) shows a screenshot of the VL once these results are checked.

2) Exercise 2

Determine the values of the system parameters R , L and C so that the open-loop system response is characterized by an overshoot of 25% and a settling time of 2.48 s. Verify those values in the system response for an input voltage of 3 V.

Solution:

The way of solving this second exercise is the opposite than the followed in previous one. From the time domain specifications of M_p and t_s , the values of δ and ω_n are 0.4 and

4 rad/s, respectively. Hence, the values of the circuit components are obtained from (3)-(4) as follows: $R = 5.71$, $L = 1.77$, and $C = 0.03$. Checking the results of this exercise is illustrated in Fig. 6(b).

B. Level Control

In this case, the exercises that can be solved with this VL are also two.

1) Exercise 1

Calculate the characteristics of the system step response, namely, t_p , t_s , and M_p in closed-loop when applying a PID controller with $k_p = 10$, $k_i = 2$, and $k_d = 0.1$. The system is given by $r = 0.1$, $A = 10$, $h_{ini} = 0$, $h_{ref} = 0.3$. Observe both the linear and nonlinear responses of the system.

Solution:

To obtain the time domain characteristics, firstly it is needed to obtain the values of δ and ω_n solving the set of equations (15)-(16). After that, it is possible to obtain the values of t_p , t_s , and M_p from equations (5)-(7). The results are: $\delta = 0.35$, $\omega_n = 0.13$ rad/s, $t_p = 26.49$ s, $t_s = 91.21$ s, and $M_p = 31.30\%$. Fig. 7(a) shows a screenshot of the VL when the correctness of the calculated results is checked.

2) Exercise 2

Design a PI controller for the linear model of the system so that the response to a reference level of 0.6 m (constant) is characterized by $M_p \leq 11\%$ and $t_s \leq 3$ s, considering the following values for the simulation: $r = 0.15$, $A = 1$, $h_{ini} = 0$, $k = 8 \cdot 10^{-2}$, $g = 9.8$ m/s². Obtain the system response and verify that the design specifications are met.

Solution:

This second exercise can be solved in the inverse way of exercise 1 as follows. Firstly, one needs to choose a desired value for M_p and ω_n so that the corresponding value of t_s fulfills the design specification. In this case, $M_p = 4\%$ is taken, which results in $\delta = 0.72$, and $\omega_n = 2$ rad/s. From these two values and solving the set of equations (15)-(16), it is possible to determine the values of the controller parameters as: $k_p = 35.5$ and $k_i = 50$. The remaining parameters are: $t_p = 2.24$ s, $t_s = 2.78$ s. A screenshot of the VL when the accuracy of the calculated results is checked is illustrated in Fig. 8(b).

IV. BRIEF BIBLIOMETRIC NOTE

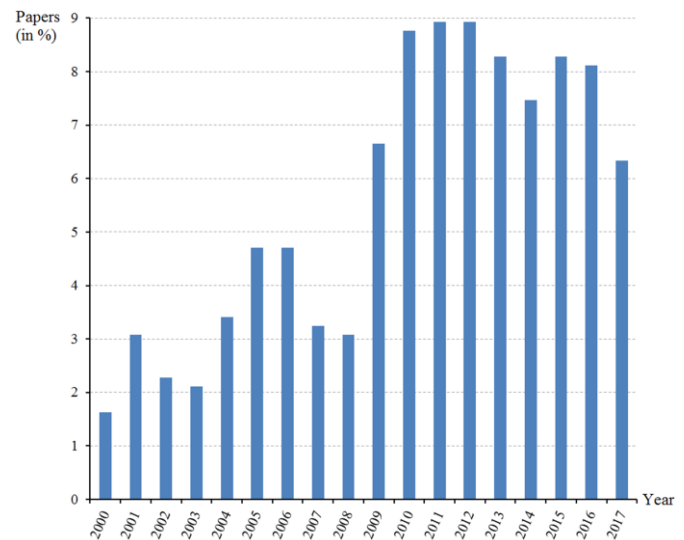
Here, a brief bibliometric note on current VRL trends in engineering education is provided.

To retrieve data, we performed the following query:

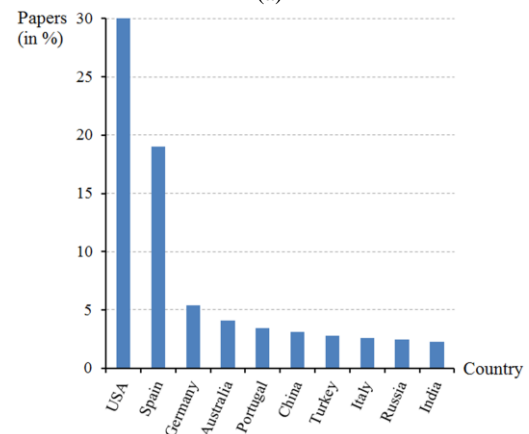
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topic = ((TITLE-ABS-KEY ("engineering education"
OR "education in engineering") AND TITLE-ABS-KEY
("virtual laborator*" OR "remote laborator*"))
AND (LIMIT-TO (SUBJAREA, "ENGI")) AND (LIMIT-TO
(PUBYEAR, 2017) OR LIMIT-TO (PUBYEAR, 2016) OR
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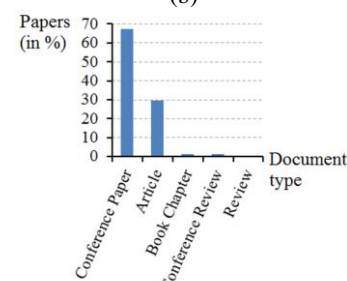
for the time span 2000-2017 on Scopus database limited to the engineering subarea (query carried out on 27 February, 2018). Notice that the asterisk pattern character is used to catch both terms "laboratory" or "laboratories". It should be mentioned



(a)



(b)



(c)

Fig. 10 Bibliometric results on current VRL trends in engineering education for the period 2000-2017. Number of papers (in %) shorted by: (a) Year (b) Country (the first 10) (c) Type of document

that only data from Scopus database were analyzed because in that database, because, unlike the ISI Web of Science database, in Scopus it is possible to search for a topic in the keywords, title and abstract of a document, independently. Therefore, it is easy to perform this kind of search.

The total number of documents found after this query is 616. The three most cited papers of this search are [1], [12], [13]: the first work analyzes current trends in RLs, whereas the last two include reflections about current trends in control learning in engineering education.

The number of documents obtained after the query are shown in Fig. 10 classified by year, country and type of document, in all cases expressed in percentage with respect to the total number of documents. Regarding the evolution of the number of publications in the last 17 years (see Fig. 10(a)), it should be noted that there is a significant increase especially in 2010 with respect to the previous year (the number of papers published in that year is more than double that in 2009). In what publications by countries are concerned (in Fig. 10(b)), it is important to highlight the second position of Spain, which gives an idea of the level of interest on engineering education that there is in the authors' country. And, from Fig. 10(c) it can be concluded that the documents are mostly published in conference proceedings and journals.

V. CONCLUSION

This paper has described the first steps in the introduction of automatic evaluation in virtual laboratories (VLs) built with Easy Java/Javascript Simulations (EJS/EjsS) for introductory courses of automatic control in engineering degrees in order to, from the academic community point of view, reduce their assessment workload, and, for students, detect calculation errors, as well as misconceptions related to the theoretical background. Two examples of VLs were given to illustrate how to enhance their utility to validate the student answers in a simple way in EJS/EjsS.

More precisely, some Java/Javascript codes and check buttons were added to the resources so that the student will be able to check if his/her calculations are correct or not. Such a solution, although simple in comparison with other existing methods, is effective, especially taking into the final purpose of the VLs, i.e., that the student can detect calculation errors, as well as misconceptions related to the theoretical background. Furthermore, advanced programming skills are not required.

Our future efforts will focus on: 1) using the VLs developed in our classes to find the real utility for students, and 2) studying other methods of automatic evaluation for laboratories built in EJS/EjsS, as well as their suitability for the use expected to be given in our courses, especially relating to programming efforts for the instructors.

ACKNOWLEDGMENT

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entitled "Integration of Automatic Evaluation Systems in Interactive Tools for Teaching Support in Subjects of the area of Systems Engineering and Automation" within which this work is framed.

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