PID Control WebLab with LMS Integration Using SCORM

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Abstract: Proportional-Integral-Derivative (PID) controller is an essential content of the Automation subjects in many Engineering degrees. The PID controller theory should be supported by some practices that help students to bring the "real world" into an otherwise theoretical education. This paper presents a PID Control WebLab that has been developed with a set of related learning resources using an innovative methodology. Traditional laboratories lessons have been adapted to an e-learning strategy based on a virtual laboratory embedded into a Shared Content Object Reference Model (SCORM) package along with a set of related learning resources. The result is a SCORM package including a learning path with specific theory, tests and a series of experiments where the assessment of the work performed by each student is recorded in the Learning Management System (LMS). The package itself constitutes a learning resource that can be reused in any SCORM supported LMS. This PID Control WebLab has been offered to 340 students of the "Industrial Automation" subject of the University of Jaén in the 2014-15 course. Several evaluations of this WebLab, also included in this paper, demonstrate that this proposal has produced excellent results in the knowledge obtained by the students, the WebLab has helped students to pass the subject final exam and it has been highly regarded by its users: the learners.

Keywords: Education Laboratory, Laboratory Techniques, Control Education, Motor Control, PID Controllers.

1. INTRODUCTION

The Proportional-Integral-Derivative control is one of the controllers most frequently used in industrial control system so it is an always present content in the curriculum of automation students. Many laboratories have been developed based on PID controller to ensure that students fully understand its operation (Dormido, 2008). Students of engineering degrees have done their laboratory practices in various ways depending on the type of laboratory. Nowadays, students can work in different types of laboratories: hands-on, virtual, remote, hybrid, virtual reality, etc. The WebLabs are laboratories (virtual, remote or hybrid) that are offered to students via a website and the Learning Management Systems (LMS) are the most widely used web platforms for e-learning in higher education. Almost all educational institutions, naturally including universities, use LMS to deliver online and blended/hybrid courses or improve the possibilities of the on-campus courses.

This article presents a WebLab whose main objective is to help students to understand the operation of PID control and learn to tune a P, a PD and a PI controller for a DC motor from a given specifications. The WebLab is formatted as a Shared Content Object Reference Model (SCORM) package (ADL, 2009) that can be uploaded in any SCORM-conformant LMS and interacts with it. SCORM is a collection of standards and specifications used to define e-learning contents that is supported by most of the LMS. Inside the WebLab there are four pages where students can find useful resources related to the PID control virtual lab. The student can navigate between these pages accessing to the resources through a learning path that has been programmed in a sequence. This sequence can be modified depending on the actions performed by the learners and their marks. Each page in the WebLab includes an automatic assessment whose result is recorded in the LMS and can later be viewed by the course teachers. The virtual Lab (VL) is a java Applet developed with Easy Java Simulations (EJS) (Esquembre, 2003) that is embedded in the third page of the WebLab. It communicates with the LMS through the SCORM Run Time Environment (RTE) sub-specification to obtain the learner identification. Each time a learner runs the VL, it offers three customized experiments based on the user identification, it records in the LMS the marks obtained by the learner and some comments about the work performed by the learner in each attempt. The learner can recover these comments during the current run of the VL or in subsequent runs of the software.

This WebLab has been presented to 340 students of the "Industrial Automation" subject of the University of Jaén in the 2014-15 course. Students were divided initially into two groups (control group and experimental group) in order to analyse the performance and effectiveness of the laboratory in various scenarios. The results demonstrate that student

learning can be enhanced through the effective use of this WebLab accessible on the Internet.

This paper is organized as follows; next Section explains the process used to develop the PID control WebLab, then, the WebLab structure, navigation and communications are described in Section 3. Section 4 clarifies the use scenario of the WebLab and additional resources and Section 5 shows results obtained by students and data about the use of the elements. Section 6 includes the evaluation processes and their findings and finally in Section 7 the conclusions are shown.

2. DEVELOPMENT OF THE PID CONTROL WEBLAB

This WebLab has been developed following a methodology to obtain an effective laboratory. The starting point for obtaining a laboratory is the selection of competencies and/or objectives from the list of competencies and objectives of the subject that students will acquire if they complete the laboratory. The global objectives and competencies related to the WebLab are:

- Basic knowledge of automatic control and its application to industrial automation.
- Learn what a regulator (controller) is.

And the specific objectives and competencies related to the WebLab are:

- Know and understand the regulators of type P, PD, PI and PID.
- Learn techniques for tuning the parameters of these regulators.
- Consolidate the concept of a settling time specified by absolute percentage of the final value of a system signal (2% or 5% criterion).
- Tune a controller for a servo system with a direct current motor (DC motor).

Based on these items three experiments have been designed to control a DC Motor similar to the system included in the:

1. Control of the angular position of a DC Motor using a P controller. The students should observe the behaviour of the system when the value of the proportional constant (*Kp*) is changed and they must calculate the value of *Kp* such that the system becomes critically damped.
2. Control of the angular position of a DC Motor using a PD controller. The students should reduce the order of the system equation by using the pole-zero cancellation criterion and they must calculate the *Kp* and *Kd* values such that the system responds to a step input with a given settling time (2% or 5% criterion).
3. Control of the angular velocity of a DC Motor using a PI controller. The students should reduce the order of the system equation using the pole-zero cancellation criterion and they must calculate the *Kp* and *Ki* values such that the system responds to a step input with a given settling time (2% or 5% criterion).

The students of "Industrial Automation" course of the University of Jaén work in the Control Laboratories using the plant-Feedback inc.'s mechanical unit model 33-100 (Fig. 1) that includes a DC Motor, so the experiments were developed thinking on a first-order simplified model of this system (Fig.2).

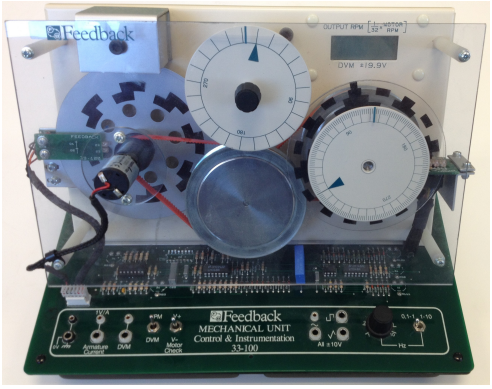

Fig. 1. Feedback inc.'s mechanical unit model 33-100.

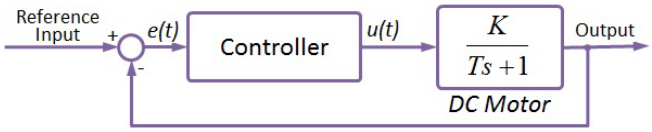

Fig. 2. Scheme of the System (control of angular velocity).

These experiments were implemented creating a virtual WebLab. The Easy Java Simulations (EJS) software was used to obtain a virtual laboratory (VL) applet that included the experiments. The applet was programmed in Java with a friendly graphic user interface (GUI) and imported the scormRTE java packet (Ruano, 2014) to create a scormRTE object that facilitated the VL-LMS communications through the SCORM API. This is very important because when the applet runs in a web page, one of the first things it does is to initiate communication with the LMS to get student ID. This way, the functioning of the VL is customized based on the learner:

- The DC motor is different for each student: the *K* (static gain of the system) and *T* (Time constant of the System) parameters are customized.
- The VL automatically stores in the LMS the most important actions taken by each student (number of attempts for each experiment, results introduced by the student and date/time). Later, students can privately check these data.
- The applet assesses the work done by the students in each of the three experiments and the obtained marks are stored in the LMS. Later, tutors can check these data.

There is a set of resources that should be presented next to the VL in order to maximize the learning effectiveness of the WebLab. The following resources were created:

- General information about the WebLab (frame the WebLab in the curricula, objectives and competencies, structure of the WebLab, etc.).
- Theoretical contents and examples about the PID control, type of systems according to the dynamic behaviour, the settling time, the pole-zero cancellation criterion, etc.
- Pre-VL test (test prior to the VL), this test checks that students have the knowledge needed to successfully work on the PID experiments. There are some -multiple choice single response- questions about some concepts that students should master: Did they know what is *e(t)*? Could they calculate the PID controller constants from a control law? Could they distinguish between different types of control (P, PD, PI, PID)? Did they know the equation of the settling time (5%) of a first order system? Did they know what type of PID control works as a lag compensator? Did they know what type of control action operates as a self-adjustable offset? Did they know what type of PID control improves the transient-response?
- A manual that explains the GUI of the VL. It describes all the zones of the VL and the meaning of all the panels, buttons, displays, graphics, and other elements of the GUI.
- The experiment guides, these guides explain the steps the learner should take to perform the three experiments: control the angular position of a DC motor using a P controller, Control the angular position of the DC motor using a PD controller and control the angular velocity of the DC motor using a PI controller.
- A VL requirement document, this document describes the configuration options of the device on which the learner want to run the WebLab to avoid compatibility issues or lack of resources. It explains how to install and configure JAVA correctly to run an applet in the browser.
- A post-VL test, this test checks that students have mastered the concepts and obtained the desired skills. The test contains some multiple choice single response questions about some concepts that students should master: Could the students distinguish between the dynamic behaviour of an overdamped system, a critically damped system and an underdamped system? Did they know the definition of the term “settling time (X%)”? Could the student calculate the closed-loop/open-loop transfer function of a given system including a PI/PD controller? Could they decide what type of controller is the simplest (P, PD, PI, PID) to reach some specifications on a given system from its transfer function? Could the students identify the PID constants from a given control law?
- A forum, where students can communicate with the tutor writing their questions about the PID control WebLab and they can read and discuss the contributions of their peers and the tutor.

All these resources have been presented to students in ILIAS (ILIAS, 2015), the institutional LMS of the University of Jaén. The VL requirement document has been implemented as an ILIAS module and the forum has been implemented as an ILIAS forum. However, the rest of resources, including the VL, have been included in a SCORM package whose structure, sequencing, navigation and communication are described in the next section.

3. THE SCORM WEBLAB

SCORM is a set of standards and specifications for e-learning contents that are organized in three sub-specifications. These sub-specifications define the content aggregation model, the sequencing and navigation between the contents, and the SCORM-LMS communications. The SCORM package of the PID WebLab uses the three sub-specifications to define the Structure, Sequencing and Navigation and Communications.

3.1. SCORM package Structure

The SCORM package has been structured on 4 pages (Fig.3):

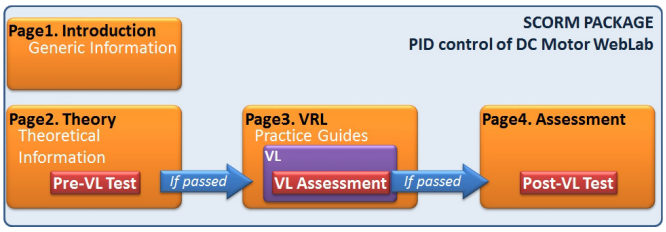

Fig. 3. Structure of the PID control of DC Motor WebLab.

Page 1. Introduction. This web page contains the generic information in a table that frames the lab in the curriculum and a section where the structure of the Weblab and an explanation on how to complete it are shown.

Page 2. Theory. This page contains the theoretical information needed to complete the VL and the pre-VL test with 7 multiple choice single response questions to check the learner knowledge about the theoretical contents of the page. The subsections of the theoretical contents included in this page are: 1) Introduction, 2) Controller Types, 3) P-controller (including an example of the position P-controller of a DC Motor), 4) PD-Controller (including an example of the angular position PD-controller of a DC Motor using the zero-pole cancellation criterion), 5) PI-controller (including an example of the angular velocity PI-controller of a DC Motor using the zero-pole cancellation criterion) and 6) PID-controller.

Page 3. VL. This page includes the experiment guides of the VL and the VL itself, which is a JAVA applet embedded at the bottom of the web page. The first subsection of this page includes a brief manual of the VL software and the following subsections correspond to the three experiments described in Section 1: 1) Control of the angular position of a DC Motor using a P controller, 2) Control of the angular position of a DC Motor using a PD controller and 3) Control of the angular velocity of a DC Motor using a PI controller. A colour code has been used in this page to facilitate to the student the understanding of the experiments (Fig. 5): white for normal explanations and step-by-step actions that the learner should do in the VL, yellow for observations that the student should perform in the VL and orange for important data and explanations of the practice assessments.

Page 4. Final Test. This page contains just the post-VL test that consists of the 7 -multiple choice single response- questions which checks whether the student has achieved the skills indicated in the WebLab.

3.2. SCORM package Sequencing and Navigation

The sequencing and navigation between the pages of the SCORM are configured sequentially to advance from page 1, through page 2 and page 3 to page 4. There is some checking in page 2 and 3 to avoid access the next page if the completion status of the page is not "completed" (Fig.4). The VL applet is responsible for checking if the student has reached the completed status on page 3 (the learners reach the completed status when they pass the experiment 3). The applet also checks the status of completion of each experiment to prevent access to the following if they have not completed the current experiment.

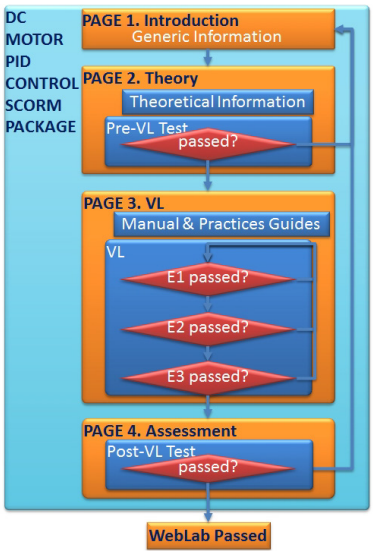

Fig. 4. Sequencing and Navigation of the SCORM WebLab.

3.3. SCORM package Communications

The four pages and the VL applet of the SCORM WebLab communicate with the ILIAS LMS. The pages include a helper JavaScript file called APIWrapper.js that makes use of the SCORM API and facilitates the communication programming. Communications begin when the page is loaded by the user browser by using the doInitialize() JavaScript function and finish with the doTerminated() JavaScript function (usually when the page is unloaded). The VL applet includes the scormRTE package that contains some objects with variables and methods to simplify the communications from java.

4. USAGE SCENARIOS

The WebLab has been used in the "Industrial Automation" subject of the University of Jaén. 340 students were enrolled in this subject in the 2014/15 course and 339 were registered in ILIAS. Registered students were divided in two ILIAS groups, each of them was able to access to a private virtual space (folder) in the platform where some resources were loaded:

- **Experimental Group**: 169 students. This group had access to a complete WebLab experience. To measure correctly the difference of knowledge acquired by the students, the Post-VL test was extracted from the WebLab SCORM package and it was loaded in the folder as an ILIAS test with the same characteristics. Some brief instructions were shown at the top of the folder, and then all the resources were loaded in order of use:
    - **Test previous to WebLab.** It is an ILIAS test identical to the Post-VL test that is used to measure the students' knowledge before accessing to the WebLab.
    - **Steps previous to WebLab.** This is the VL requirement documents implemented as an ILIAS module.
    - **WebLab PID DC Motor.** This is the WebLab SCORM package but with the first 3 pages only (without page 4).
    - **WebLab final test.** This is the Post-VL test included in page 4 of the original WebLab.
    - **WebLab survey.** It is a survey used to know the opinion of the students.
    - **Forum about the WebLab.** This is the forum used to help students.
    - **VL solution video.** This resource was not offered to students until the learning proposal had ended. It is an ILIAS module where there is embedded a video created with Adobe Connect software that shows a presentation and an example of the WebLab solution.
- **Control Group**: 170 students. This group had access to a limited WebLab experience. The format and resources presented to this group is exactly the

same as those described for the experimental group but the WebLab PID DC Motor is a reduced version that has only the page 3 of the VL (without pages 1, 2, and 4).

Participation in this learning proposal was voluntary and optional so there are many students who, having the opportunity to access the resources of the group, have not participated.

5. USAGE DATA AND RESULTS

The detailed analysis of the usage data provides many conclusions; some of the highlights are listed below:

- Averages time data are not very reliable: the standard deviation is very high. This is probably due to students who enter pages but after work they do not close them, thus the counting time is not real, hence the big deviation.
- Initial participation is low: The "test previous to WebLab" is completed by 71 of the 170 students in the control group (41.76%) and 69 of the 169 students in the experimental group (40.82). These poor data can be explained by the optional characteristic of the WebLab. Participation in the final examination of the subject has also been low (57.94%), this may mean that many students have not followed the course and therefore optional proposals like the WebLabs.
- Initial knowledge level is low: Average score of the "test previous to WebLab" in the control group is 4.16 (SD 0.85) and 4.49 (SD 2.15) in the experimental group.
- The experimental group results for VL are better: The VL was passed by a larger number of students in the experimental group (41 students, 59.4% of those who accessed test previous to WebLab) than in the control group (22 students, 31% of those who accessed test previous to WebLab). In addition these students obtained better marks: 9.18 (SD 0.68) vs. 6.36 (SD 0.85). The resources included in page 1 and page 2 of the WebLab in the experimental group, which were not included in the WebLab of the control group, have helped students.
- The number of students completing and passing the learning proposal is low: the number of students who passed the final test in the experimental group is 32 (46.38% of those who accessed the test previous to WebLab) and in the control group is 16 (22.54% of those who made the previous test), it is exactly half the students in the experimental group (Fig. 5-6).
- Final knowledge level of the students who successfully completed the learning proposals is high: Average score of the "WebLab final test" in the control group is 7.95 (SD 1.73) and in the experimental group is 8.39 (SD 1.75). WebLabs have been positive for student knowledge.

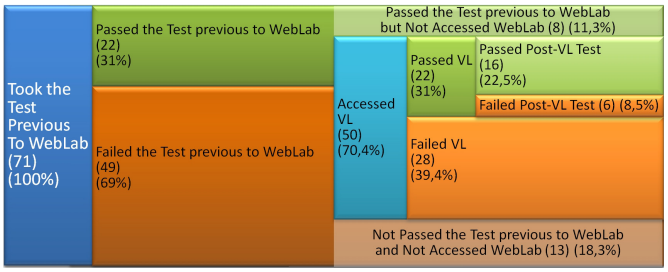

Fig. 5. Control Group summary graph.

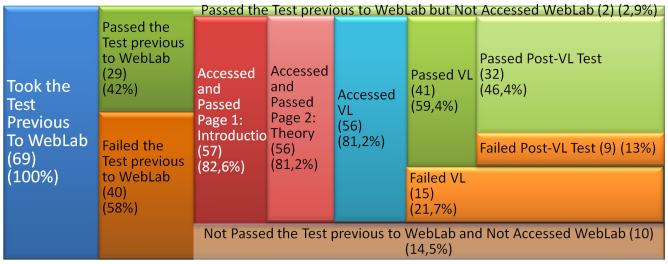

Fig. 6. Experimental Group Summary Graph.

The VL is effective because students passing WebLabs have increased their knowledge. But the effectiveness of the WebLab based on SCORM package described in this work is much higher than the learning effectiveness of a laboratory by itself. The number of students passing the completed WebLab (3 pages) is the biggest and the marks are the highest.

The student participation in the final exam of the subject has not been very high: 197 of 340 students (57.94%), and the results have not been positive because only 61 student have passed the exam (17.94%, 30.96% of those who participated) with an average mark of 6.52 (SD 0.76). These data are much better for students who passed the final test of WebLabs (Fig.11):

- Experimental group: 28 students of those 32 who passed the final test participated in the final exam of the subject, 14 students (50%) passed the final exam with an average mark of 6.88 (SD 1.02).
- Control group: 14 students of those 16 who passed the final test participated in the final exam of the subject, 9 students (64.29%) passed the final exam with an average mark of 6.84 (SD 0.47).

6. EVALUATION PROCESSES

The evaluation of a laboratory is a complex task that has been performed by different ways in the specialized research papers. In this paper several evaluations methods have been used.

Measure of the improvement of the knowledge acquired by the learners: Students in the experimental and control groups completed the same test before and after completing the WebLab and differences between scores on each of the

tests provide insight into the learning effectiveness of the WebLab. The average mark improvement is approximately 30% (29.9% and 31.3%). This confirms that the WebLab and related resources have produced an improvement in the level of knowledge of students who have followed the two learning proposals (WebLab with VL and WebLab with 3 pages) and therefore the WebLab is effective.

WebLab and Subject Assessment: The data obtained in the final examination by students who successfully completed the WebLabs is much better than the average of the course. The percentage of students who participated in the final exam is much higher: 28 of 32 in the experimental group and 14 of 16 in the control group (87.5% in both cases) versus 197 of 340 the entire course (57.94%, nearly 30% better). Also the percentage of students who passed the final exam is much higher: 14 of 28 in the experimental group (50%) and 9 of 14 in the control group (64.29%) compared with 61 of 197 in the entire course (30.96%, nearly 20% and 34% better). There are many factors that can affect these results so it cannot be established that it is determined only by the overcoming of the WebLabs, but there is a direct correlation.

Opinion of the learners: The results of the surveys completed by the students of the experimental and control group help to validate the effectiveness of this learning proposal. All results have been positive (Fig. 7 and 8).

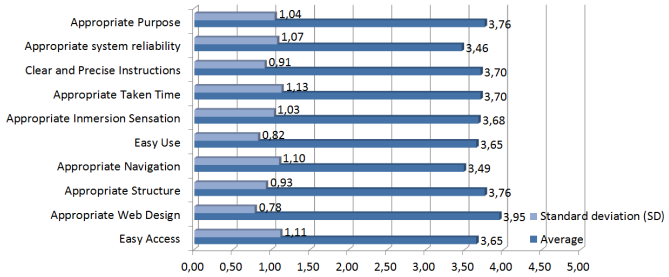

Fig. 7. WebLab aspects Rating (Experimental Group).

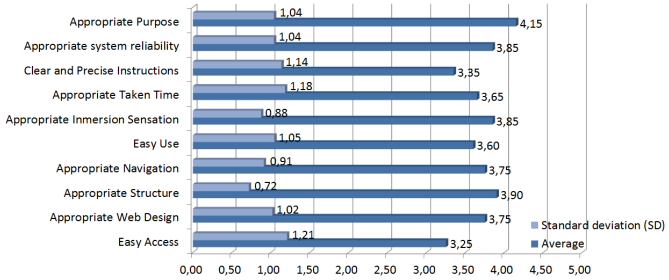

Fig. 8. WebLab aspects Rating (Control Group).

The most representative data indicate that final rating of the WebLab in the experimental group is 3.78 (SD 0.79) and in the control group is 3.85 (SD 0.67) (Fig. 9).

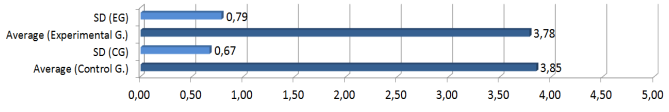

Fig. 9. WebLab Final Rating (two groups).

All this data confirm that the students have validated positively the WebLabs.

7. CONCLUSIONS

A proposal of WebLab based on a SCORM package that has been used in the "Industrial Automation" subject in the University of Jaén has been shown in this paper. A VL to deepen the knowledge of PID controllers has been created to get some proposed skills and objectives. The WebLab has been developed using a new methodology that seeks the learning effectiveness of the laboratories, and the VL has been embedded in it as a Java applet. Two versions of the WebLab have been used to check the effectiveness of the resources included in the WebLab next to the VL.

The evaluation processes based on the usage data and results provided by the learners demonstrate several conclusions:

- The WebLab structure based on 4 pages and all the related resources shown in previous sections help to complete and pass the laboratory. It is an effective learning resource. Learners successfully completing the WebLab improve their knowledge level in the assessed competencies and objectives. Students of the experimental group that participated in this proposal and successfully completed the WebLab achieved an average increment of 29.9% in their knowledge level. The WebLab is more effective when it contains all the resources.
- The passing of the virtual laboratory (at any scenario) helps to pass the course itself.
- Students have validated very positively the WebLab. The assessment received was 3.85 in the control group and 3.78 out of 5 in the experimental group.

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