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Virtual Control Labs Experimentation: The Water Tank System

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Abstract: This paper describes a new way to perform automated experiments using virtual laboratories. Experiments are developed and executed using a new software tool: the Experiment Editor. This tool uses virtual laboratories applications designed with educational purposes. The main features/advantages of the Experiment Editor are: 1) the possibility of modifying the initial functionality of the laboratories (i.e. adding new controllers to the plant), 2) analyzing the obtained results during the experiment and performing complex or repetitive tasks in a simple way, 3) and any others explained in the paper. To illustrate the utility of the Experiment Editor a very well-known system is used: the water tank system.

Keywords: Easy java(script) Simulations, Experimentation Language, Experiments, Simulations, Virtual Laboratories

1. INTRODUCTION

The benefits of using virtual labs (VLs) are indisputable. They have become the “must-have” in the modern, open, and successful teaching environment Kunc et al. (2011). VLs have several advantages over traditional ones: usage costs are drastically reduced, more students have access to them in a simpler way, augmented reality enhances the understanding of the phenomena study and many more Balamuralithara and Woods (2009); De Jong et al. (2013); Domingues et al. (2010); Goodwin et al. (2011).

Generally, interactive tools used in Control Education have certain gaps that have not been fulfilled until now. These tools use ad-hoc software that enable the user to change some parameters, visualize them and, in best cases, have a real-time view of the process of the plant. Something as simple as stopping the process when an important event occurs is extremely complicated for the end user to achieve. Also, repetitive tasks as collecting the output of a system 100 times to perform a statistical analysis are tedious and without educational value. Consider, for instance, a virtual lab with only a PI controller implementation, adding a new fuzzy logic controller for the same lab implies that the lab must be redesigned completely, which entails having knowledge to do it and spend a lot of time.

This paper presents a new interactive environment for VLs that fulfills these gaps. This environment is developed for Easy java Simulations (EjsS), but with the idea of keeping it open to other tools or languages as JavaScript. The environment uses a script language that enables the user to perform automated experiments for any lab without having programming skills. The language allows accessing and modifying every aspect of the lab (variables, functions, graphic interface). Therefore, it is possible to add new functionality to the lab, record the output values, perform statistical analysis of data and repeat experiments tracking changes of the process in real-time with just a click.

Although the paper is focused in VLs, the environment is accessible to remote and hybrid laboratories. Remote and hybrid laboratories use hardware at remote locations Ma and Nickerson (2006), therefore, the features that can be illustrated using the interactive environment to develop experiments are more limited. This is the reason why the environment is presented using a virtual lab of a Water Tank System.

The paper is organized as follows. First, Section II describes the Water Tank System, offering a quick view of the system, the virtual laboratory and the proposed controllers. Section III discusses the environment developed to perform experiments with virtual labs, the experiments script language and the improvements that it adds to the educational experience. Section IV shows some experiment examples with the Water Tank System. Finally, Section V discusses the results and describes further work.

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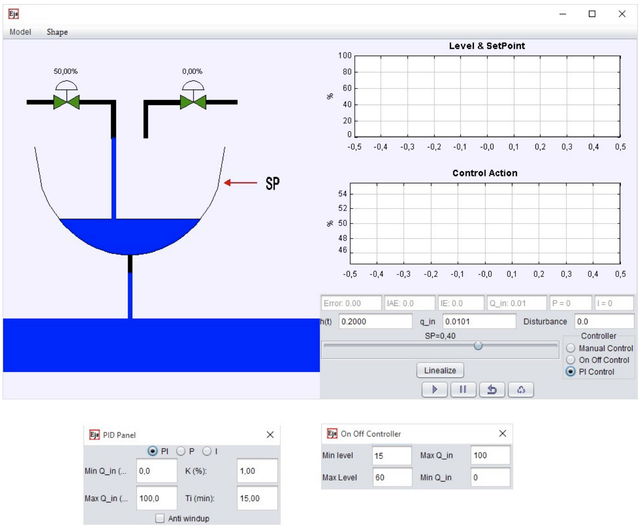

Fig. 1. Water Tank interface

2. THE WATER TANK SYSTEM

To develop the VL, a laboratory plant was modeled. The plant corresponds to a single tank water system. Figure 1 shows a snapshot of this VL.

2.1 Description of the System

The system is described by the following nonlinear differential equation "(1)", which models the mass conservation:

$$A\frac{dh(t)}{dt} = q(t) - a\sqrt{2gh(t)}, \tag{1}$$

where *h(t)* represents the height of the water tank, A the area or section of the tank, a the output orifice area, g the gravity acceleration at sea level and *q(t)* the input flow.

For a stationary state $(dh(t)/dt = 0)$ characterized for $h_0 = h(t)|_{t\to\infty}$ and $q_0 = q(t)|_{q\to\infty}$, equilibrium condition, "(2)", is deduced from the model given in "(1)":

$$q_0 = a\sqrt{2gh_0}. \tag{2}$$

As the model is nonlinear, it is linearized near the operation point given by (h_0, q_0). The system variables *h(t)* and *q(t)* are represented as:

$$h(t) = h_0 + \overline{h}(t) \tag{3}$$
$$q(t) = q_0 + \overline{q}(t) \tag{4}$$

Developing Taylor series of the nonlinear model and choosing only the first order development terms, it is obtained:

$$\sqrt{h(t)}|_{h_0} \approx \sqrt{h_0} + \frac{1}{2\sqrt{h_0}}h(t) - h_0, \tag{5}$$

and using "(3)","(4)" and "(5)" in "(1)", we get:

$$\frac{d\overline{h}(t)}{dt} = \frac{\overline{q}(t)}{A} - \frac{a}{A}\sqrt{\frac{g}{2h_0}}\overline{h}(t) \tag{6}$$

The integration of the differential equation starting from zero initial conditions, $\overline{h}_0 = 0$, when considering a small variation in the constant flow to the point of equilibrium ($\overline{q}(t) = \Delta q$) provides the temporal evolution of the tank height from point h_0 to a new value h_1 close to the previous one.

$$\overline{h}(t) = \frac{\Delta q}{a}\sqrt{\frac{2h_0}{g}}(1 - e^{-(\frac{a}{A}\sqrt{\frac{g}{2h_0}})t}) \tag{7}$$

where the new height $h_1 = h_0 + \Delta h = h_0 + \overline{h}(t \to \infty) = h_0 + \frac{\Delta q}{a}\sqrt{\frac{2h_0}{g}}$.

So the model can be represented in an approximate way with a linear dynamic first-order model:

$$\tau\frac{d\overline{h}(t)}{dt} + \overline{h}(t) = k\overline{q}(t) \tag{8}$$

Where $\tau = \frac{A}{a}\sqrt{\frac{2h_0}{g}}$ and $k = \frac{\tau}{A}$.

2.2 The Virtual Laboratory

The virtual laboratory was developed using EjsS. EjsS is a freeware, open-source tool developed in Java, specifically designed for the creation of interactive dynamic applications Christian and Esquembre (2007). EjsS simulations are created by specifying a model to be run by the EjsS engine and by building a view to visualize a graphical representation of the system modeled and to interact with it, Vargas et al. (2009); Farias et al. (2010); Fabregas et al. (2011).

The virtual laboratory interface, Fig. 1, has a top menu to choose the shape of the tank and between the lineal and non-lineal model. The graphical representation of the tank, the water level, and the two valves is shown on the left part of the interface. The right part includes two plots, the top one to visualize the percentage of the current level of water in the tank and the set point, and the one below displays the percentage of opening of the water inlet valve. Immediately after the plots, there are some non-editable parameters that give important information to the user to configure the possible controllers. Buttons for pausing, playing and resetting the application are also present in the lower part of the application.

Two additional dialog windows provide the users with options to vary the control operations. It is possible for the user to choose between a manual control, a PI/P controller and an On-Off controller, these options are shown at the bottom of the image. When using the PI/P controller mode (bottom right part of 1), the related PI parameters can be adjusted using the PI dialog. Similarly, the On-Off parameters can be set in the On-Off dialog (bottom left part of 1). Choosing either of the controllers, the set points can be established from the slider located at the right part of the window or from the visual representation by arrows shown at the right of the tank .

The interface also allows users to save measurements, to take snapshots of the evolution of the main variables of the process, or to record Matlab files (.m files). With these data, using Matlab or SysQuake, users can analyze their experimental results or use them to prepare other experiences.