A Remote Lab to Simulate the Physiological Process of Ingestion and Excretion of a Drug

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***Abstract*—Remote and virtual labs represent a very important support for online experimentation in engineering courses and can be used to improve the students learning process, providing, for example, experiments to simulate physiological processes in Biomedical Engineering subjects. This paper presents an online experiment, supported by a three-tank lab system to simulate an equivalent model of the physiological process of ingestion and excretion of a drug. A Web platform is used to interact with the remote and virtual labs, where students can visualize and obtain data in real time from the remote system and observe the dynamic behavior of the system considering a virtual representation.**

***Index Terms*—Biomedical engineering; online experimentation; physiological process; remote and virtual labs.**

I. INTRODUCTION

The understanding of physiological processes and their dynamics can represent a difficulty for students, which can be overcome by considering computer-based learning approaches with the support of online experimentation. Mathematical models and their representations have proven to be a valuable tool for the analysis and synthesis of physiological processes in the human body [1].

In recent years, applications based on this type of models can be found in major areas of influence as medical research, education and supporting clinical practices [2] and trial simulations complement experimental approaches [3] or medical simulations (a brief history starting in 1938 can be found in [4]).

Some generic purposes for physiological models, as simplified representations of a physiological system, have been identified [5]:

- To determine the structure of a system;
- To compute parameters of interest;
- To integrate information on a system;
- To predict responses to a perturbation;
- To derive mechanistic principles underlying the behavior of a system;
- To identify differences under different conditions;
- As an educational tool.

As an educational tool, the simulation of physiological systems can be a very helpful tool. Coupled with a theoretical explanation of the model behind the simulation, it allows students to observe and, in some cases, manipulate the behavior of a system in a low risk environment while providing an insight into the modelled system.

Therefore, the use of experimental modules to represent its structure and function can contribute significantly to understand it and improve the learning process, namely in Biomedical Engineering subjects.

Some physiological systems can be divided into different subsystems and modelled by compartmental models to represent the dynamics of the overall system. In this context, a laboratory system as the three-tank process has the necessary features to be a simplified representation of, for example, a system of ingestion and excretion of a drug.

The development of remote and virtual labs can represent a valuable support for students learning, enabling a wide access to the experiments and allowing the interaction in real time with the lab system to perform practical experiences, visualizing and analyzing the dynamic behavior of the system [6]. Experiential learning focuses on individual learning plays a central role within science and technology curriculum at all levels of higher education [7]. Similarly to traditional laboratories, remote labs provide students with particular engineering experience and allow them to explore the systems and their real behaviors.

Systems analysis is a very important topic in biomedical engineering because it is the basis to model, simulate and control different physiological processes [8].

This paper aims to describe an online experiment, designed to be accomplished in subjects about computational models of physiological processes and algorithms for diagnosis and self-regulation of a Master Degree on Biomedical Engineering, in a blended learning context.

II. THE PHYSIOLOGICAL PROCESS

This work considers the modelling and simulation of a system of ingestion and excretion of a drug. In biomedical terminology, this physiological process can be represented by a three-compartment system, modeling the gastrointestinal tract, the bloodstream, the bladder and their interactions (Fig. 1). In this case, it is assumed that the kidney is only one transition element. Being necessary to find a compartmental model of the process, an equivalent fluidic system can be developed.

The drug is taken orally or in an intravenous way, at a flow rate $u(t)$, goes to the intestines, where it reaches a quantity $x_1(t)$, and then it is absorbed by the bloodstream with a flow rate $d_1(t)$. The bloodstream, where the drug

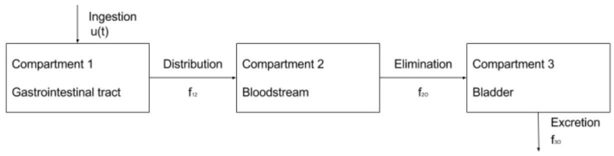

Figure 1. Three-compartment drug ingestion, metabolism and excretion model.

reaches a quantity $x_2(t)$, passes through the kidney (where it is assumed there is no absorption) with a flow rate $d_2(t)$ for elimination through the bladder. There, the quantity of drug is represented by $x_3(t)$ and is expelled into the urine, once in a while, at a flow rate $y(t)$. In this approach, for reasons of simplicity, other physiological actions are disregarded and the elimination of the drug by cellular metabolism is ignored [9].

Applying the fluidic systems principles, the mass balance of each compartment provides the differential equations for the mathematical model of the overall system. Assuming that $x_1(t)$, $x_2(t)$ and $x_3(t)$ are the corresponding levels (quantities) and the flow coefficients k_1, k_2 and k_3 are related with the fluidic resistances (R_1, R_2 and R_3) by:

$$k_1 = \frac{1}{R_1} \quad , k_2 = \frac{1}{R_2} \quad , k_3 = \frac{1}{R_3}. \qquad (1)$$

the following equations are obtained:

$$\begin{aligned} \frac{dx_1(t)}{dt} &= -k_1 x_1(t) + k_1 x_2(t) + u(t) \\ \frac{dx_2(t)}{dt} &= k_1 x_1(t) - (k_1 + k_2) x_2(t) \\ \frac{dx_3(t)}{dt} &= -k_3 x_3(t) + d_2(t) \\ d_1(t) &= k_1[x_1(t) - x_2(t)] \\ d_2(t) &= k_2 x_2(t) \\ y(t) &= k_3 x_3(t) \end{aligned} \qquad (2)$$

This mathematical model of the ingestion and excretion of a drug can be used for different exercises and experiments as, for example, simulation of the dynamic behavior of the system, analysis of the system's sensibility to the values of different parameters and design of several types of controllers for a non-linear process.

III. EXPERIMENTAL SETUP

An obvious equivalent representation of the model for the ingestion, progression and excretion of a drug is the amount of fluid in leaking tanks, where the mass of a drug in each physiological element is represented by the change in each water tank level from a reference level.

A. The three-tank system

In this work, a three-tank system (DTS200 system by Amira [10]) is considered to build an equivalent fluidic model of the physiological process. This system is not the ideal equivalent model because the tanks are connected with coupled masses. To obtain a better representation of the three-compartment model, the three-tank system was divided into two sections separating the gastrointestinal tract and the bloodstream from the bladder (a scheme of this division can be seen in Fig. 2). By using such partition, the level constraint imposed by the right tank (given the coupled masses) on the remaining is eliminated.

In this system, the flow pumped by $pump_1$, in section 1, represents the inflow for the first compartment. The tank, in section 2, is used as a virtual bladder, absorbing the perturbation caused by the drug intake. The water level in this tank is controlled by the second pump ($pump_2$), which is acting as a virtual kidney.

B. The Web platform

A Web-based computational platform (simulating an interaction with the remote laboratory) was adopted in order to cover network-based failures of the remote laboratory (for example an offline server or if the power is down), allowing the user to perform a drug ingestion simulation (Fig. 3 provides an overview of the user interface). The user has also an option to save the simulation data and to show an animation (Fig. 4), mimicking the evolution of the system when it is used online.

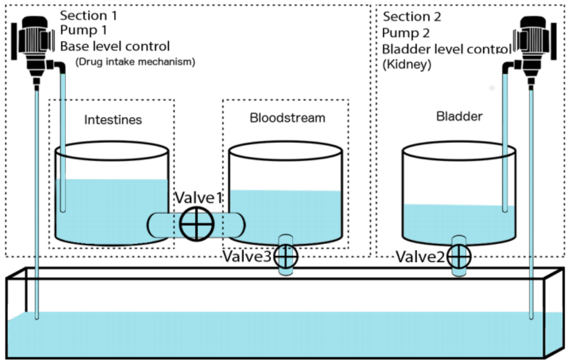

Figure 2. Scheme for the division of the three-tank system.

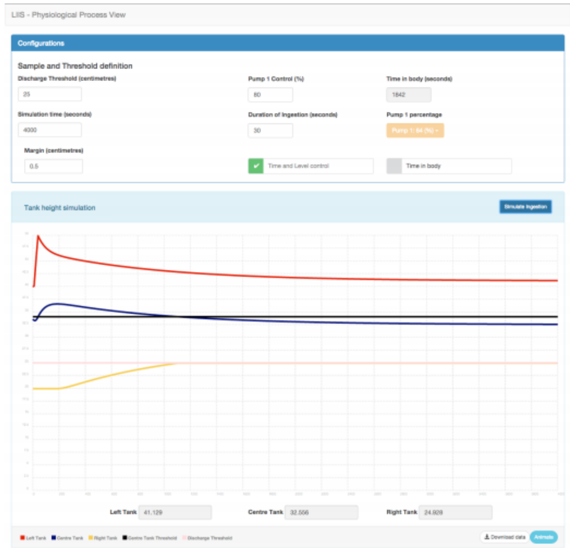

Figure 3. Interface of the virtual lab for a simulation of a drug ingestion.

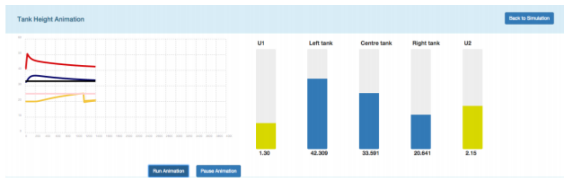

Figure 4. Animation option for the simulation of a drug ingestion.

The interface includes a configuration panel where some parameters can be settled. The user can define the discharge threshold, the simulation duration, the flow rate for $pump_1$ and the duration of ingestion, in case of option for manually control is activated.

The remote lab is accessed through the Web platform using an interface (Fig. 5) that allows users to remotely simulate the ingestion of a drug using an equivalent fluidic model based on the three-tank lab system, where the valve between the left and the central tank is open 75% and the exit valve from the central tank is only open 25%. The central tank is not coupled to the right tank (the valve between both tanks is closed) isolating the right tank and the exit valve of the right tank is completely open.

To remotely interact with the three-tank system, the setup considers wired communications between the sensors and the micro-computer, acting as server and gateway. In addition, a live Webcam feed is also included, in order to compare the sensor data with the real water tanks level. To administrate the access to the remote lab, a management system is provided by the platform, based on a first-come, first-served approach, with the establishment of a maximum threshold for individual usage time.

Using the Web platform to interact with the remote and virtual lab, users can visualize the graphical representation of the water tanks level and its history and obtain data in real time from the remote or virtual system. For example, Fig. 6 shows the result of two consecutive ingestions.

A Moodle platform is also available with tutorial information, guidelines to carry out the experiments using the experimental setup and quizzes for self-assessment.

IV. CONCLUSION

This work aims to show how a remote and virtual lab can be used to enhance the learning process of students of Biomedical Engineering subjects in topics as model identification and control of physiological systems.

This lab is an example of online experimentation, where an experimental setup, comprising a three-tank system, is used to simulate an equivalent model of the physiological process of ingestion and excretion of a drug. The interaction with the remote system or the virtual representation is done through a Web platform. These experiments can also be used in other engineering courses.

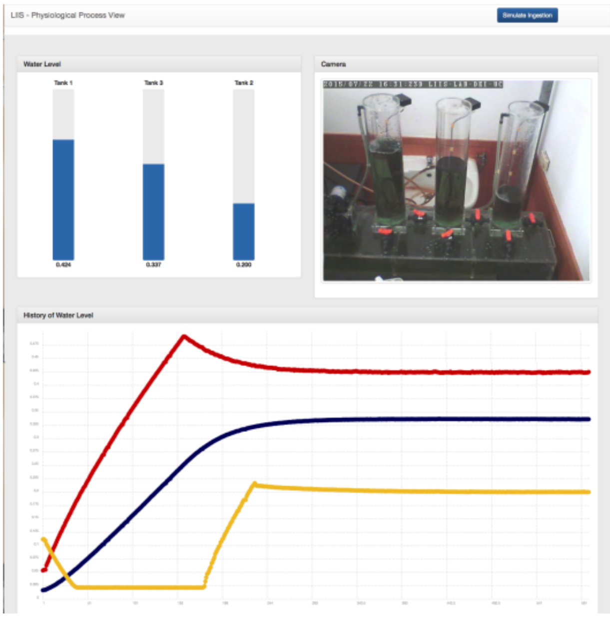

Figure 5. Interface of the remote lab using a three-tank system for online experimentation.

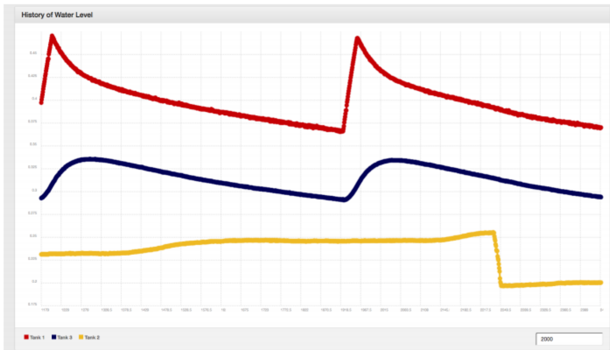

Figure 6. Screenshot showing the result of two consecutive ingestions.

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