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Internet-based resources to support teaching of modelling, simulation and control of physiological systems in biomedical engineering courses

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Abstract: Engineering courses can benefit of the use of Internet-based resources to support teaching and online learning. A remote system can be an effective tool to be used in practical classes and to enhance the students' experimental skills. Online experimentation represents also a very important support in engineering teaching and can be used to improve the students learning process, for example in Biomedical Engineering courses, on topics such as modelling, simulation and control of physiological systems. This paper presents examples of web-based resources, including remote lab systems, to modelling, simulate and control physiological systems. Experimental setups are used to interact with the remote and virtual labs through a Web platform, where students can visualize and obtain data in real time from the remote systems. Some examples of online quizzes for assessment purposes are also presented.

Keywords: Internet-based resources; physiological systems; remote lab; systems and control; biomedical engineering.

1. INTRODUCTION

The development of Information and Communication Technologies (ICT) enables many benefits and advances regarding all components of the educational process and play increasingly a fundamental role to support teaching and online learning in engineering courses. In particular, the development of online experimentation resources represents an opportunity to create remote laboratories addressing several topics in different areas, for instance in topics of biomedical engineering courses (e.g. Malmivuo and Kybartaite (2014) or Amrita (2014)).

Higher education institutions have to provide learning experiences that engage and address the needs of society in the twenty-first century (Garrison and Vaughan, 2008). The transformation of teaching and learning on higher education is inevitable with the use of internet-based technologies (Newman *et al.*, 2004). The field of online learning, in general, should incorporate the potential of technology to address the challenges associated with providing a high quality learning experience in different educational contexts and using diverse technological supports and interfaces.

The availability of broadband connectivity is an opportunity to use innovative ways to help teachers and students use technology to improve education and foster the knowledge and skills, creating support networks for educators to communicate and share resources and experiences (ITU and UNESCO, 2013). Nowadays, experiential learning focuses on individual learning plays a central role within science and technology curricula at all levels of education (Zuperl and Virtic, 2013). Similar to traditional laboratories, remote labs provide students with particular engineering experience and allow them to explore systems and their real behaviours.

The development of remote and virtual labs can represent a valuable support for student's learning, enabling a wide access to the experiments and allowing the interaction in real time with the lab system to perform practical experiences, visualising and analysing the dynamic behaviour of the system. Internet-based resources to support teaching of modelling, simulation and control of physiological systems are very important for different subjects in biomedical engineering courses

This paper aims to present a set of resources that can be considered in subjects of Biomedical Engineering Master Courses. The next section describes the organization of the subject, section 3 presents some details of the Practical Works, section 4 shows two examples of online experiments, section 5 gives some examples of questions used in online quizzes and section 6 provides some conclusions.

2. THE ORGANIZATION OF THE SUBJECT

The resources presented here are considered in the subject "Computational Models of Physiological Processes" (CMPP) of the 3rd year (1st semester) of the Biomedical Engineering Master course at the University of Coimbra, Portugal. The first half part (7 weeks) of this subject is intended to develop the students' skills for mathematical modelling and simulation of the diverse physiological systems in human body, using computational tools. The organization of this part of CMPP, comprehends 14 hours of theoretical lessons (2 hours per week) and 21 hours of practical classes (3 hours per week). The syllabus includes the following topics (Dourado *et al.*, 2012):

- The general systems concepts introduced by the general systems theory of Bertalanffy (1969) and well developed in Flood and Carson (1993);

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- The description of linear systems by differential equations and Laplace Transform;
- Transfer function as a tool for systems analysis and understanding, using the connection between the dynamics and the transfer function characteristics;
- State-space representation, state equations, eigenstructure and its connections with stability and dynamic properties;
- Modelling of nonlinear systems by differential equations, singularity points, linearization, and local stability. Phase curves in state space and their importance as a portrait of fundamental properties of the nonlinear system;
- Chaotic behaviour of biological and physiological systems and the Feigenbaum (1979) constant.

The practical classes consider the following four computational works:

- Simulation of the evolution of the population of a biological species;
- Simulation of the ingestion and excretion of a drug;
- Study of the dynamics of artificial ventilation of a patient;
- Study of the state space representation of systems and the phase curves.

These Practical Works are carried on using Matlab©/SIMULINK© environment (Mathworks Inc.) for computational simulation and the Python language to implement some applications, and are also supported by different internet-based resources, including introductory texts, quizzes and online experiments. Two of these practical works use two experiments supported by hybrid laboratories with interactive computer applications that allow carrying out remote experiments using real laboratory systems existing at the Laboratory of Industrial Informatics and Systems (LIIS) of the Department of Informatics Engineering of the University of Coimbra.

3. THE PRACTICAL WORKS

In groups of two, students accomplish the Practical Works (spending 2 weeks in each) briefly described in the following subsections. In computational terms, students use the toolboxes of Matlab and Simulink and are also encouraged to use the Python language with some mathematical modules to build stand-alone applications.

3.1 Simulation of the evolution of the population of a biological species

Considering a biological species (insects, for example) as a system whose individuals live an integer number of years, and supposing that the population grows with a certain limitation, the temporal evolution of the population is simulated using a simplified model in the form of the non-linear difference equation (1) (Flood, 1993).

$$x_{k+1} = Ax_k(1 - x_k) = f(x_k), \qquad x_k \in [0, 1] \qquad (1)$$

In this equation, x_k is a fraction of the population's maximum value in year k and A is a positive constant that depends on the environmental conditions (the availability of food and water, the climate effect, etc.).

The students, after implementing the model, simulate it and analyse the influence of the values of the initial population and of the constant A on the temporal evolution of the population of the biological species. Figure 1 presents the evolution of the population during 30 years, considering the initial relative population of 10% and the parameter A of 3.5.

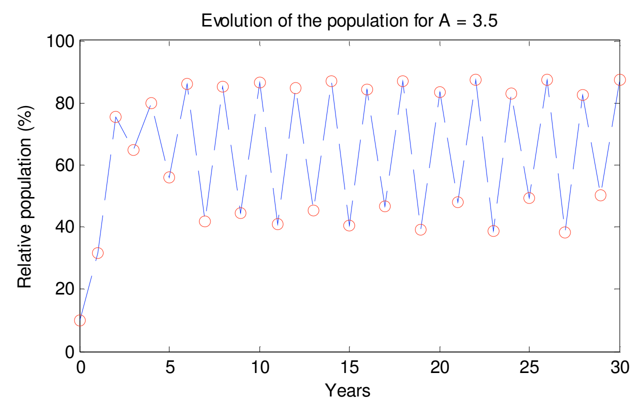

Fig. 1. Results of the simulation of the evolution of the population of a biological species.

3.2 Simulation of the ingestion and excretion of a drug

The main objectives of this practical work are to use methods of numerical integration of functions and to consider numerical methods to simulate continuous systems modelled by differential equations. As an example, it is considered the ingestion and excretion of a drug shown in Fig. 2 (Bruce, 2001).

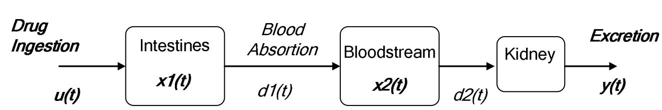

Fig. 2. Diagram of the system of ingestion and excretion of a drug.

The drug is taken orally or in an intravenous way, at a 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 reaches a quantity $x_2(t)$, passes through the kidney (where it is assumed there is no absorption) with a flow rate $d_2(t)$ that expels the drug at a rate $y(t)$, passing it into the urine. In this approach, for reasons of simplicity, other physiological actions are disregarded and the elimination of the drug by cellular metabolism is ignored.

In medical terminology the process is multi-compartmental. Assuming the kidney is only one transition element, the process has only two compartments. Being necessary to find a compartmental model of the process, an equivalent fluidic system can be developed, as shown in Fig. 3.