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Physical Modeling based Simulators to Support Teaching in Automatic Control: the Rotatory Pendulum ⋆

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Abstract: Recently, teachers and researchers developed a huge variety of resources to support teaching, especially for engineering degrees. This paper describes the development of physical modeling based simulators in the Simulink©/Simscape™ environment as interactive tools to validate regulators in Automatic Control. This type of modeling uses a physical network approach to model building: only requires to join the physical components with physical connections to define the underlying dynamic equations of the system to be modeled. The simulator of the rotatory pendulum Qube™–Servo of Quanser© is given as an illustrative example.

Keywords: Education, Automatic Control, physical modeling, Simscape, pendulum.

1. INTRODUCTION

Currently, teachers and researchers developed a huge variety of resources to support teaching, especially for laboratory courses, in engineering degrees. In the Automatic Control field, there are a considerable number of specialized and general purpose modeling tools available for that end. In this paper we focus on those included in the MATLAB®/Simulink© package, due to their extended use for both the design and the simulation of control systems.

Nowadays, the potential of Simulink© has grown especially by adding a multitude of toolboxes, among which we are interested in emphasizing Simscape™ for physical modeling. It is an object-oriented modeling tool which is spreading in current simulation environments thanks to the use of the individual components of the model and their interconnections to define the underlying dynamic equations. Simscape™ is a powerful software package that extends the Simulink product with tools for modeling and simulation of physical systems, such as those with mechanical, electrical, hydraulic, thermal and pneumatic components. Unlike other Simulink blocks, Simscape ones directly represent physical elements or relationships. Then, a system model can be built in this environment in the same way that a physical system is assembled. Some examples of models developed in Simscape™ are: a memristor is shown in Zaplatilek (2011), an electric power assisted steering in Sjostedt (2009), solar cells in Khanna et al. (2013) and an automatic gearbox in Enocksson (2011). However, there are very little examples of Simscape based resources to support teaching and learning in classrooms. E.g., Fernandez de Canete et al. (2013) built a model of cardiovascular system for teaching of physiology for graduate medical students and Chen and Shang (2014), a DC motor for engineering courses.

Given this context, the aim of this paper is to show the advantages of using physical modeling to develop interactive resources to support teaching and learning in Automatic Control. Thus, the idea is to build a simulator for laboratory courses with which students can validate their designed controllers –as known, the use of real platforms needs a heavy budget in terms of resources, especially multiplicity of equipment–. As an example of application, the simulator of the rotatory pendulum Quanser© Qube™–Servo will be built in Simscape™. Hence, the main contribution of this paper is to present an educational platform to be used for students in laboratory courses of Automatic Control. Educational aspects and experience of use were not considered in the current version since it still is working.

The remainder of this paper is organized as follows. Section 2 gives the basis of physical modeling with Simscape™. Section 3 shows how to build the simulator based on the previously described tool. Possible control coursewares that may be carried out with the simulator in the laboratory are provided in Section 4. The conclusion is drawn in Section 5.

2. FUNDAMENTALS OF SIMSCAPE

Simscape™ is a toolbox for physical modeling developed by the MathWorks for Simulink© since version R2007a of the MATLAB® suite. It includes a *Foundation library*, which contains basic components for electrical, hydraulic, mechanical and thermal systems. Since version R2008b, users are even allowed to create their own physical models and even new physical domains thanks to the Simscape

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language. There are also more specialized toolboxes taking part of the Simscape product family, among which we can mention SimMechanics^{TM}, which is the package that we utilized to build the simulator presented in Section 3.

Simscape models use a physical network approach to model building: components (blocks) corresponding to physical elements are joined by lines corresponding to the physical connections that transmit power. This approach allows for the description of the physical structure of a system rather than the causal mathematics. Because the components use physical connections, the models match the structure of the system being developed. Simscape^{TM} automatically constructs from the model the equations that characterize the system behavior, which are in turn integrated with the rest of the Simulink model. Simscape function and utilities support functionality common to other Simulink products that use physical connections between their blocks. It is important to know that, to view a signal in Simscape^{TM}, a sensor has to be introduced, and then the sensor needs to be converted to a standard Simulink signal by means of a block *PS-Simulink Converter* to be monitored using e.g. a *Scope*. And viceversa, regular Simulink signals must be converted into physical signals using the block *Simulink-PS Converter*. Refer to e.g. The MathWorks Inc. (2015a); Esfandiari and Lu (2014); Miller and Wendlandt (2012); Sjostedt (2009) for more details and examples of how to build models in Simscape^{TM}.

Meanwhile, SimMechanics^{TM} extends physical modeling capability of Simscape^{TM} providing a multibody simulation environment in 3D. It provides fundamental building blocks from the mechanical domain that can be assembled into models of physical components. To create such a virtual space, it is possible to import computer-aided design (CAD) models of the system components, from which an automatically generated 3D animation lets visualize the system dynamics (refer to The MathWorks Inc. (2015b)). In our case, we used SolidWorks to create the CAD models of the system's components.

It should be remarked that the students do not need to learn Simscape^{TM} to use the simulator. The fundamentals described above are given to help potential developers of this kind of tools.

Fig. 1. Quanser© Qube^{TM}–Servo platform

3. THE QUANSER QUBE^{TM}–SERVO SIMULATOR

This section describes how to build the simulator for the rotatory pendulum Qube^{TM}–Servo of Quanser© illustrated in Fig. 1 in the Simulink©/SimMechanics^{TM} environment.

3.1 Describing the platform

The Qube^{TM}–Servo is a low cost teaching platform with fully integrated components, ideal for introducing students to basic control concepts. Essentially, it consists of a brushed DC motor with optical encoder position feedback, a pulse width modulation (PWM) amplifier and data acquisition electronics, all mounted within a sturdy, precision-machined aluminium housing. Two modules, an aluminium inertial disc and a sensed angle pendulum arm, can be connected to the output shaft of the motor via a tool-less quick connect interface. Refer to Quanser Inc. (2014a) for more details of the platform.

3.2 Building the model

As commented above, the main components of the Qube^{TM}–Servo are the DC motor, the pendulum arm and the encoders. The appearance of the simulator is shown Fig. 2, in which the whole model of the system in SimMechanics^{TM} is illustrated in Fig. 3. Each of the mentioned components will be modeled in a separate way in the following subsections. It should be said that the simulator is created with blocks from the *Foundation library* of Simscape^{TM} and the *First generation* library of SimMechanics^{TM}.

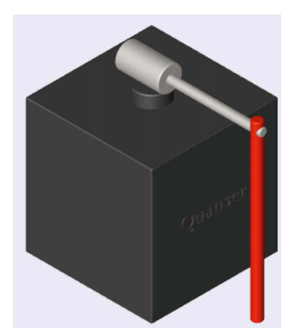

Fig. 2. Appearance of the simulator of the Quanser© Qube–Servo

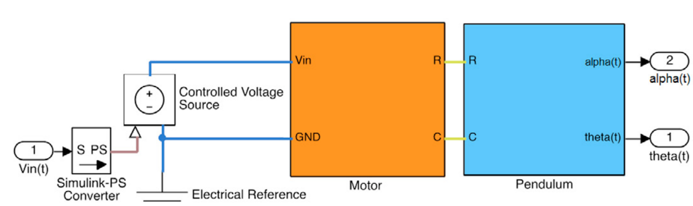

Fig. 3. Model of the Quanser© Qube–Servo in SimMechanics^{TM}

DC motor The model of the DC motor is obtained from the electromechanical transducer elements that constitute the electric machine: a resistor in series with a coil and, as the output, the rotating reference (an inertial load) and the friction, which is modeled as a rotational damper (see Quanser Inc. (2014b)). The details of this subsystem are shown in Fig. 4, which is worth noting that Simulink