IEEE Report
Interactive books for control education

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1. Introduction

In engineering, education is characterized as a discipline with a strong experimental content, where the student needs to put into practice the knowledge acquired during the course. When scientists and engineers are studying a particular system or they are understanding the physical laws that describe their behavior, often they use computers to calculate and graphically represent different magnitudes. This aspect is perfectly reflected in the field of automatic control [3]. Automatic control is a field with significant mathematical content including differential equations, linear algebra, differential geometry or complex variable among others [2]. Graphical representation has been always used as support in automatic control education for years. Most relevant automatic control concepts such as systems interconnection, frequency response, stability analysis, time response or root locus are displayed graphically. This type of representation has been considered for years an excellent route to introduce automatic control concepts.

In this sense, many educational resources are today available in the control engineering area with impressive graphical representations: virtual and remote labs, interactive tools, learning management systems, multimedia material, etc. Among these resources, interactive tools have specially demonstrated to be a powerful support for education in the last recent years. Interactive tools are considered a great stimulus to enhance the students' intuition. They attempt to demystify abstract mathematical concepts through visualization for specifically chosen examples. These tools have been presented as a great support for control education varying from basic concepts until more advanced ones [1], [5] - [12].

Interactivity and graphical visualization have contributed and helped to make control education more attractive and interesting. Learning by discovering is one of the paradigms that exploit this kind of interactive tools. The key point is that in the automatic control field, there exist many concepts which are hard to grasp by analytic developments but they are quite easy to understand through graphical visualization or interactive manipulation [11].

So, interactive tools stand out as one of the educational techniques with greater impact; they have been established as an excellent complement to teaching in the control engineering field, although most of them are standalone applications and need to be used in a computer. On the other hand, the use of eBooks or web-based material are becoming more and more widespread: they are portable, accessible, and offer the possibility of enriching the text with other digital content as an added advantage. And the most important issue, they provide mobility (they can be run in Tables and Smartphones). Such books or web-based solutions are being presented today as a magnificent teacher support tool and educational resource for students.

This project aims to allow for the merging of these two educational technologies, trying to include interactive tools in eBook format or web-based solutions. As a result, interactive eBooks will be developed to be accessible on classical eBook readers or through web browsers, that can be used as support to introductory courses on automatic control.

2. Project objectives and meetings

The different objectives of the projects were the following:

- To analyze and to decide the theory and the interactive graphics to be included in the resulting interactive books. Finally, basic modelling issues and results based on PID control were selected.
- To develop the different interactive tools as standalone applications: a short group of simple interactive tools were coded in Sysquake language.
- To write the text including the control theory to be included in the textbooks and associated with the interactive graphics. The text was written in LaTeX in order to be easily combined with the Sysquake code.
- To combine the text and the interactive tools in eBook formats.
- To make the resulting eBooks compatible with most existing eBook readers, as well as creating web-based solutions.

Two different meetings were performed during the project duration:

- The first one was celebrated using Skype in March 2018 with Yves Piguet, the CEO of Calerga S.L. This meeting was mainly dedicated to analyze how the text written in LaTeX could be combined with the interactive tools implemented in Sysquake. The idea was to require to Calerga a clear procedure and algorithm that allows the user to do this task as simple as possible.
- The second meeting was hold at the University of Almería. All the participants of the project attended this meeting together with Yves Piguet from Calerga S.L., who came to Almería for several days to work together with the project team. In the following, see some pictures of the meeting.
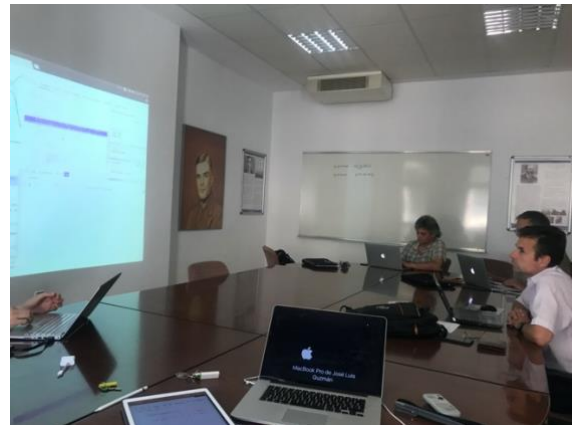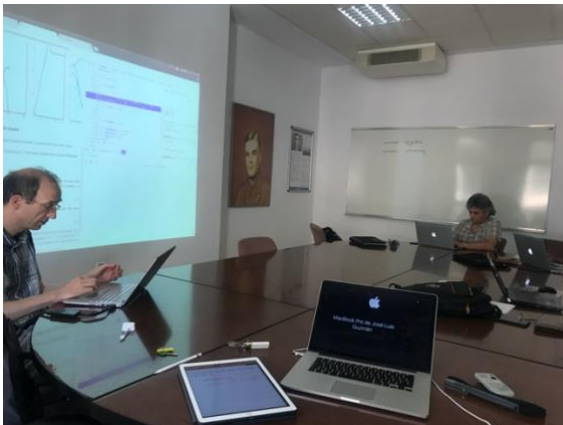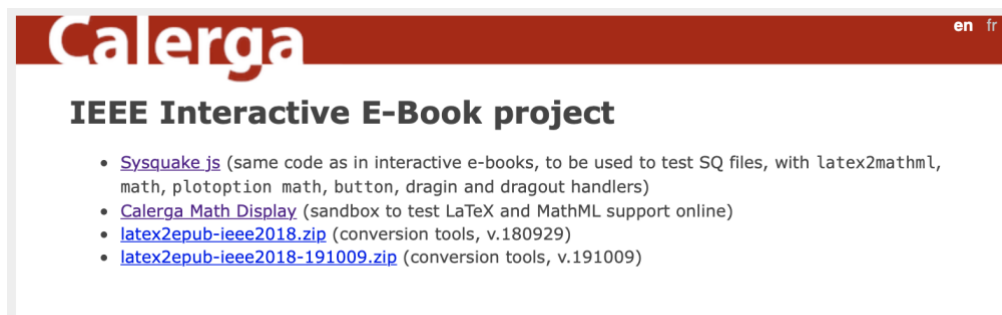
3. Results

The results of the project can be grouped at different levels. We obtained results from a technical point of view where, in cooperation with Calerga S.L., different libraries were developed as support to the creation of interactive books. On the other hand, from a scientific point of view, an conference paper was published in an international workshop celebrated in Belgium about control education. Finally, from a teaching point of view, an example of interactive book was developed that is accessible from any device in ePub and web-based formats. The results were evaluated in different devices (Samsung, Apple and Xiaomi Smparhones and tables) with different operation systems (iOS, Mac OS, Android, Windows 10).

3.1 Software libraries

As a result of the collaboration with Calerga, different programming libraries were developed to allow the conversion from Syquake code to Html and MathML code. Moreover, an online display tester was also developed to check the create MathML code from LaTeX equations.

Also, a set of conversion tools was created to aumatically convert all material into a single Html+Javascript file or an ePub flie including the eBook.

3.2 Publications

The preliminary results of the project were presented and published at the IFAC Conference on Advances in PID Control, celebrated in Ghent, Belgium in 2018. The paper is published in the IFAC-PapersOnline repository:
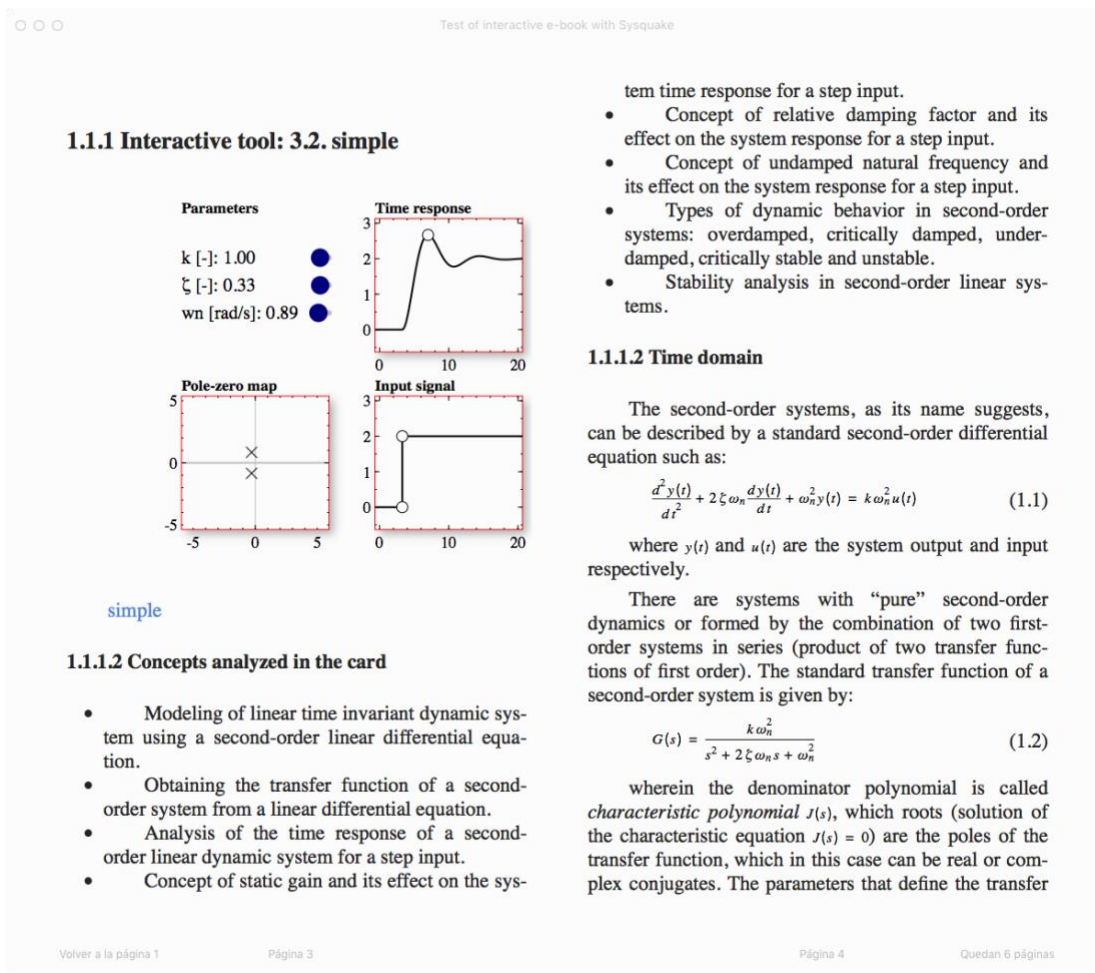
On other hand, the project was promoted in the networks of international projects through the divulgation department of the University of Almería.
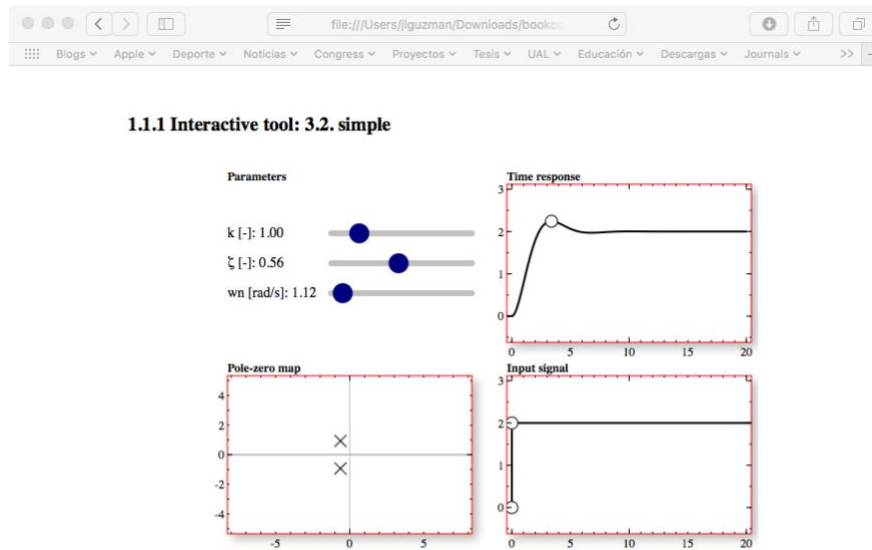
3.3 Teaching material. Interactive book

Finally, an interactive book was created including some examples of modelling and control concepts. Notice that the project was focused on technological aspects and not too much teaching chapters were include. However, thank you to the resulting conversion tools described in the previous section, new interactive tools are planned to be written and developed very soon. In the following link, some examples of the developed books can be downloaded:

https://calerga.com/contrib/ebooks/ifac-pid-2018/

The following figure shows a screenshot of the resulting book run from an iPad using the eBook reader:

○ ○ ○   Test of interactive e-book with Sysquake

1.1.1 Interactive tool: 3.2. simple

Parameters

k [-]: 1.00 ●
ζ [-]: 0.33 ●
wn [rad/s]: 0.89 ●

Time response

Pole-zero map

Input signal

simple

1.1.2 Concepts analyzed in the card

- Modeling of linear time invariant dynamic system using a second-order linear differential equation.
- Obtaining the transfer function of a second-order system from a linear differential equation.
- Analysis of the time response of a second-order linear dynamic system for a step input.
- Concept of static gain and its effect on the sys-

tem time response for a step input.
- Concept of relative damping factor and its effect on the system response for a step input.
- Concept of undamped natural frequency and its effect on the system response for a step input.
- Types of dynamic behavior in second-order systems: overdamped, critically damped, underdamped, critically stable and unstable.
- Stability analysis in second-order linear systems.

1.1.1.2 Time domain

The second-order systems, as its name suggests, can be described by a standard second-order differential equation such as:

$$\frac{d^2 y(t)}{dt^2} + 2\zeta\omega_n\frac{dy(t)}{dt} + \omega_n^2 y(t) = k\omega_n^2 u(t) \qquad (1.1)$$

where $y(t)$ and $u(t)$ are the system output and input respectively.

There are systems with "pure" second-order dynamics or formed by the combination of two first-order systems in series (product of two transfer functions of first order). The standard transfer function of a second-order system is given by:

$$G(s) = \frac{k\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2} \qquad (1.2)$$

wherein the denominator polynomial is called *characteristic polynomial* $J(s)$, which roots (solution of the characteristic equation $J(s) = 0$) are the poles of the transfer function, which in this case can be real or complex conjugates. The parameters that define the transfer

On the other hand, the following figure shows a screenshot of the book run from a web browser in a computer:

4. Conclusions

This project has presented a methodology and procedure about how it is possible to develop interactive books that can be highly useful as support to control education. Thanks to the collaboration with Carlega S.L. and the support given by the IEEE CSS, it has been possible to create a set of tools that allow the combination of interactive tools developed in Sysquake with text written in LaTeX. These tools are very powerful and allow the lectures to use their previous material without starting to create the books from the scratch. Moreover, notice that the resulting education material can be accessed from any device, what opens the audience of the interactive books.

As future work, a full book with a complete course about control education is planned to be written.

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