New Interactive Books for Control Education [*]

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Abstract: This paper presents ongoing project to develop new interactive books for control education. The novelty of the proposed idea is to merge web-based solutions with LaTex text into a epub format. In such a way, classical interactive tools for control education are combined with static text and thus interactive books are created, being compatible with standard e-book readers. A book chapter about the teaching of second-order processes is presented as example to show the different steps and the results of the proposed idea. © *Copyright IFAC 2018.*

Keywords: control education, interactivity, e-books, web-based material

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 (Caballero et al., 2016). 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 (Dormido et al., 2005). Automatic control is a field with significant mathematical content including differential equations, linear algebra, differential geometry or complex variable among others (Braatz, 2013). 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 (Álvarez et al., 2013; Guzmán et al., 2008; Normey-Rico et al., 2009; Martínez et al., 2017).

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 (Guzmán et al., 2016).

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 e-books 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.

The ideas presented in this paper aim to merge these educational technologies, trying to include interactive tools

in e-book format or web-based solutions. As a result, interactive e-books will be developed to be accessible on classical e-book readers or through web browsers, that can be used as support to introductory courses on automatic control. A preliminary solution to this idea was developed in (González et al., 2013). In that work, a set of web-based interactive tools previously developed by the authors were modified in order to create Widget objects to be embedded in e-books. Then, these Widget objects were included in a e-book by using iBooks Author, a word processor tool to create e-books developed by Apple. The resulting e-books had the limitation to be used only in Apple devices, and on other hand, the book figures had to be opened by clicking on them in order to use the interactive capabilities (they were not directly interactive). Another important drawback was that the development of the e-books was a very time consuming task, what finally limits the use of the proposed ideas.

Nowadays, one of the most well-known programming environments to develop interactive tools is Sysquake, which is extensively used in the control education field. Sysquake is a suite of scientific software for numerical computation and visualization developed by Calerga Sarl (Piguet, 2015). Sysquake's main advantage over other software used in automatic control is its excellent support for interactive graphics, where graphical elements (traces as well as more common control elements such as sliders) are directly related to parameters. When the student manipulates a graphical element, the whole graphic, or graphics across multiple figures which show different aspects of the system under study, is/are updated continuously, which gives a much more direct and better understanding. Sysquake's programming language is largely compatible with Matlab, itself widely used in the domain of automatic control. Sysquake's main program is a native application running on Windows, macOS and Linux. It can also produce standalone programs with interactive graphics for easy distribution. Since 2013, Calerga has developed a new version of Sysquake in JavaScript to support interactive graphics on the Web and in e-books in standard web browsers and e-book formats, as well as tools to convert text and equations from Latex to HTML. Thus, Sysquake is used in this work as the kernel tool of the project for the development of the interactive tools that will be converted to web-based material and included in the interactive e-books.

The steps to follow in this work to create interactive e-books and web-based material are the following:

- To develop or reuse different interactive tools as standalone applications coded in Sysquake.
- To write the static text with the control theory to be included in the textbook using LaTeX as text editor.
- To combine the text and the interactive tools in e-book and web-based formats.

The resulting interactive resources will allow us to provide support of an introductory course on classical control theory. Notice also that the resulting interactive material can be used as support also for engineers training.

The rest of the paper is organized as follows. Section 2 deals with the impact and relevance of web-based material, interactive tools and e-books in education. Afterwards, the different tools from Calerga for the development of web-based material and e-books are described. Finally, an example based on a book chapter is shown to describe how a simple interactive e-book can be created. The paper ends with some concluding remarks.

2. WEB-BASED MATERIAL, INTERACTIVE TOOLS AND E-BOOKS FOR EDUCATION

Technology must be used to augment and magnify the abilities of the educators, and not to replace them. For this to be truly effective, the technology used must deliver a solution to a problem that no other method could successfully solve. It must also offer educators new methods to deliver highly engaging content to the learners. For instance, whiteboards have evolved to smart boards, homework is being assigned and collected through online platforms, and the once-banned smartphones and tablets are now encouraged to use in the classroom. Also, due to remote learning technologies and platforms, people can now access what they want to learn through a multitude of channels.

Teaching in classrooms is a lot of science and as much an art. One must abide by the written word, articulate your instructions around it and assess students based on textbook chapters. And so, textbooks become the bible of knowledge, customized to grade-levels and subjects, that makes the entire teaching-learning machinery work for educational institutions. However, with creativity, discovery, and joy of learning now becoming essential elements of 21st century classrooms, the straight-jacketed textbooks need a content makeover.

Interactive e-books (Schugar et al., 2013; Rozkurt and Bozkaya, 2015; Clark and Mayer, 2012; Morris and Lambe, 2017) come as a refreshing change for students and teachers. Accustomed to the click, swipe, and scrolls, the digital-savvy generation enjoys responsive content experience while learning in classrooms. Not only smartphones, tablets, apps, videos and interactive e-books can be learning tools for students, they can be great teaching tools for educators too. Educators express a positive opinion of educational technology, stating that the technology assists them in reinforcing and expanding content. After teaching for many years in the same pattern, the educators find teaching with the emerging technology quite motivating and interesting. With the help of interactive tools, video clips, and graphics, they can keep their lessons fresh and students actively engaged in lessons. It has been observed that students are more stimulated to learn when they can interact with hands-on learning tools, which the educational technology provides. Incorporating technology in the classrooms allows students to take greater control of their education because they indulge in more of interactive learning. Educational apps, interactive e-books and graphics provide students with a nearly endless supply of information and resources. All these tools support around the clock learning. So, it is important to incorporate technology into their curriculum. It is important to note here that expensive classroom technology solutions don't always result in effective teaching and learning. Even simple educational technology solutions can have a great impact on learning. By learning to use technology at a young age, students are developing the skills and knowledge that is important in current environment.

Digital content has revolutionized the way people distribute and access information on virtually every platform. It has created new, better and more efficient channels of communication and radically transformed the way in which people connect and interact with the world. From getting their news and catching up with friends, to shopping for goods and downloading a book there is hardly anything that can't be done now using an electronic device. One industry that has been dramatically influenced is publishing. Years ago, the introduction of e-books onto the market redefined the process of selling, purchasing and reading books. Initially, it was just a static page rendered on the screen of the digital device. Soon after emerged more features that allowed users to click on a link or listen to audio files. The developments in digital content publishing have steadily kept pace with the rapid evolvement of smartphones and tablets. Now, interactive e-books are dominating the landscape, ushering in a new level of reading experience for people, as well as fresh opportunities for businesses and organizations. Whether an author, marketer, corporate executive, publisher, or another type of content distributor, there is considerable value in using interactive e-books for digital publishing. However, one field that it is particularly advantageous for is education. Some may argue that traditional forms of learning, such as printed textbooks, are better for students and that incorporating technology in the classroom would only act as a disruption or distraction. But, as many educators recently have pointed out digital tools can be used to help, not hurt, the efforts of teachers. The applications must operate consistently and uniformly across all devices.

It is important to understand that interactive e-books are not simply digital replications of printed text (Woodward, 2014). They are designed and created using a distinct process individual to that material. The goal is not just to make the content accessible on a mobile device but, rather, to deliver the highest quality and most effective experience possible for the learner (Schugar et al., 2013). When producing content for electronic distribution, publishers can now leverage a wide range of technologies that make the content more engaging.

Because the material is more engaging, it makes it more meaningful. Learners can use the method that works best for them and, in turn, can get a more effective educational experience. By incorporating self-assessments, audio explanations and other features, users can make a stronger connection with the material. Interactive e-books allow the material and information to come alive.

Another benefit of this form of content publishing is that it facilitates convenience. Learners can highlight and search the text, take notes, etc. And it is not the end-user that interactive e-books benefit. While the textbook has worked so effectively for so long as the basic classroom learning resource, educational institutes and publishers have a true opportunity (that sooner or later someone will grab) to present highly immersive and engaging content that can help learners retain information through highly interactive practices.

The next section describes a set of tools to create interactive e-books in a easy way.

3. TOOLS TO CREATE INTERACTIVE E-BOOKS

The base material to create e-books is a set of LaTeX files (.tex), EPS or PDF files for static graphics, and Sysquake interactive applications. The static part of the book is written with any suitable authoring tool, such as a text editor with support for LaTeX macros and live preview, and drawing applications.

The interactive applications are developed and tested in Sysquake. They are made of a main text file (.sq) which defines the general figure layout and declares which functions are called to compute results, to draw figures and to react to user interactions. In many cases, the functions are implemented directly in the same file. They can rely on integrated functions for numerical computation, including real and complex arithmetic, linear algebra, statistics, and automatic control design and analysis. For more advanced uses where the integrated functions are the elementary bricks used for custom algorithms, it can be more convenient to store the source code in separate text files which constitute easy-to-reuse libraries. The same application can be used with different data sets. For instance in automatic control, systems of first or second order, with or without integrator, can be combined with PID controllers where the integral and/or derivative terms are set to 0. The kind of figures which are displayed can also be selected to illustrate different approaches to robustness and performance analysis or to design.

The e-book to be created is an epub file, actually a zip file (a compressed archive file) with a `.epub` extension and a special content. The content most important parts (file entries in the archive) are the table of content as an XML file with specific elements, and XHTML files with other file types common on the web (CSS, PNG, GIF, JS, etc.) The conversion from TEX, EPS, PDF, PNG, SQ and LML to EPUB is described below.

(1) tex files are concatenated and converted into a single XML file with `ntpxml`, a custom tool. The mapping between LaTeX structures and XML elements is mostly one-to-one. Simple TeX commands with their arguments, LaTeX commands with their arguments, and LaTeX environments with their arguments and content, are converted to properly nested XML constructs. See Figure 1 for an example.

```
The parameters that define the transfer
function are:
\begin{itemize}
\item $k$ is the \emph{static gain} or
canonical gain of the system.
```

```
The parameters that define the transfer
function are:</par>
<par>
<itemize><item/><math>k</math> is
the <emph>static gain</emph> or
canonical gain of the system.
```

Fig. 1. Example snippets of conversion from LaTeX (top) to XML (bottom).

(2) EPS files are converted to PDF with `epstopdf`, a utility based on the free PostScript interpreter GhostScript.

(3) PDF files are converted to svg with the open-source application `inkscape` called in batch mode (option `--export-plain-svg`).

(4) The size of PNG files is obtained with the `identify` utility, a member of the free image conversion suite ImageMagick.

(5) sq and sqd files, with the lml files they depend on, are converted to JS (Javascript) with Sysquake JavaScript transpiler. The result relies on the same JavaScript implementation of all the functions and interactive graphics as the mobile version of Sysquake which runs in web browsers. See Figure 2 for an example.

(6) xml files are converted to XHTML with a custom application written in Sysquake used in batch mode. This is where the mapping from LaTeX constructs to HTML elements is performed. Macros specific to the original LaTeX files are implemented in a custom library; macro definitions, typically in package and style files, are not used directly at this time. The size of images and a special LaTeX command for inserting interactive applications are handled appropriately. A more challenging part is the translation of equations, first to MathML, then to SVG, an XML-based format for vector graphics, which is still better supported in e-book readers and web browsers. A LaTeX expression is recreated from XML markup and converted to MathML with the same parser as the one used to typeset equations in Sysquake figures. Going back to LaTeX markup and throw a parser specific to mathematical equations permits to better take into account mathematic semantics. Yet LaTeX is more focused on the visual appearance where, for instance, spacing can mean products or function application, and operators do not have a definitive precedence priority; while in MathML, all relationships are defined explicitly. The parer attempts to produce correct results, but eventually the main goal is to produce a visually satisfactory result, so encoding errors without impact on the rendering are not deemed as a major issue. Conversion from MathML to SVG is more straightforward.

(7) Finally, XHTML and JS files are combined into an EPUB file with `ne`, a member of the open-source text processing suite NME.

The whole process may seem complicated, but it is supervised with a single makefile, i.e. a set of rules for the `make` program which describes how to convert a file type to another one with which tools and which arguments, and a list of dependencies. All the intermediate files are preserved; they provide useful and clear information in case the e-book does not match the expectations. They can be inspected with text editors for text and XML files, with graphic applications for PDF and PNG files, and with web browsers for XHTML files.

4. INTERACTIVE BOOK EXAMPLE

This section presents a short example to show how a book chapter and an individual standalone application are modified and converted into a web-based resource and also embedded into an epub file. The selected book chapter is dedicated to understand second-order systems and its temporal response. It is a book chapter extracted from the project (Guzmán et al., 2016). In that project, a static book was written in LaTeX, where each chapter had associated an interactive tool coded in Sysquake to explain the different concepts interactively. Figures 3 and 4 show the original interactive tool and the book chapter that are used here to create the e-book. The main concepts included in this chapter are:

- 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.
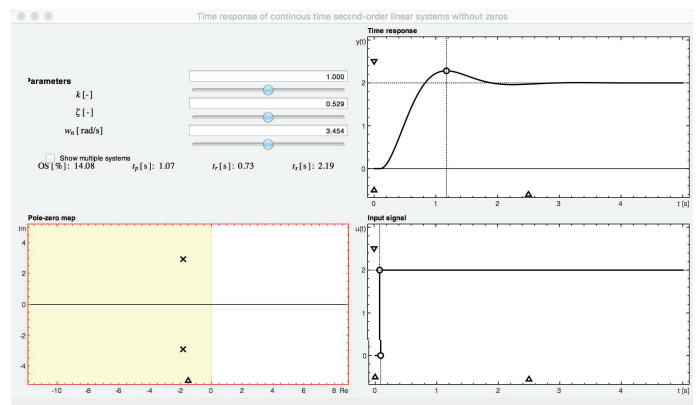- Concept of static gain and its effect on the system time response for a step input.

Fig. 3. Original second-order tool coded in Sysquake

```
t = linspace(0, 20, 200);
s = sqrt(1 - zeta^2);

$t = this.$linspace([0,20,200])[0];
$s = this.$sqrt([this.$minus([1,
this.$mpower([arg[1],2])[0]])[0]])[0];
```

Fig. 2. Example snippets of conversion from Sysquake's programming language (top) to JavaScript (bottom).
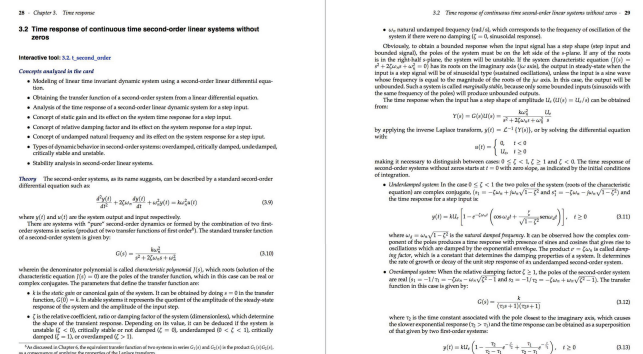

Fig. 4. Original book chapter written in LaTeX

- 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.

Thus, the different steps described in the previous section were followed to transform the tool and the chapter and to combine them. As a result, the web-based solution presented in Figure 5 was obtained, where now the interactive tool is embedded in a web page with all the interactive capabilities. Moreover, the resulting html and JS files were combined to create the final epub book. Figure 6 shows an example of the book running on the iBook App of an iPad device.

The resulting teaching resources for this example are available at the following website:

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

5. CONCLUSIONS

A new paradigm to develop interactive books for control education has been presented in this paper. The core idea relies on the conversion of LaTeX text and Sysquake-based interactive tools into html and js files. Then, the resulting files are adapted to provide interactive books in web-based and epub versions. The conversion of a book chapter has been presented as example to show the full procedure.
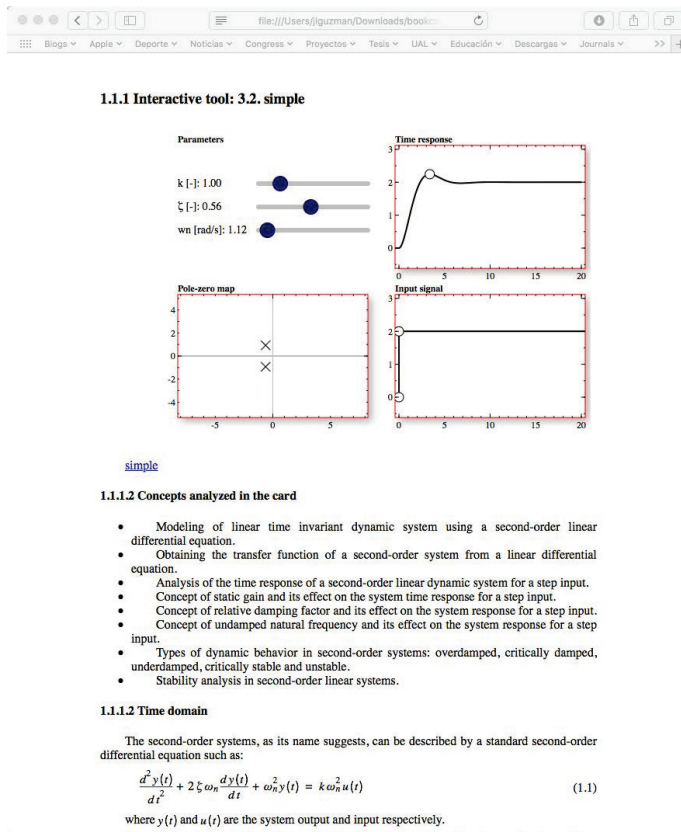
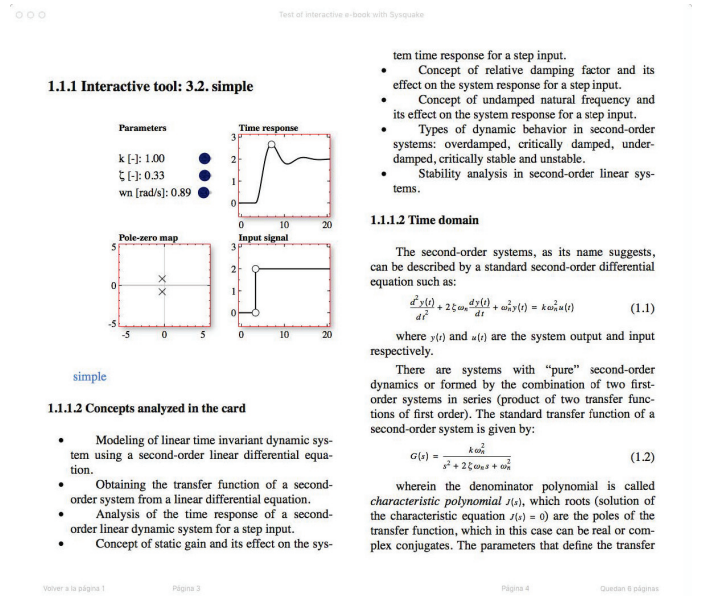Fig. 5. Interactive book in web-based format running on a web browser

Fig. 6. Interactive book in epub format running on an iPad device

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