PALAS: An Integrated WWW Based Laboratory for Supporting the Teaching of Linear Systems

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Abstract – *For supporting the teaching activities on linear system theory, a WWW based laboratory is being developed. It integrates both simulation and implementation aspects in the same framework. Modules covering the main topics of the linear system analysis are developed using a colloquial language approach in order to attract and retain the attention of the students. The emphasis is on the qualitative aspect of the theory, although various quantitative measurements and exercises are requested on each module. In order to obtain further details or to solve learning difficulties, the students can communicate to a team of instructors by means of electronic mail. Evaluation tests are also available through the Web. The laboratory can be used as an auxiliary tool for a current undergraduate engineering course or as a valuable framework for distance learning projects.*

Introduction

Among the ever-increasing subjects which an engineering student is required to master, very few are more important and fundamental than the linear system theory. The importance of such theory resides in the fact that most engineering situations are linear or can be modeled as such within the specified range. Linear systems are applied in the various fields of engineering and related areas, and disregarding the field to which belongs the problem at hand, the techniques of the linear system analysis remain the same. In fact, the scope of applications of the techniques of the linear system analysis continues to be enlarged as new challenges arise from the studies of complex systems.

In electronics engineering, the theory of linear systems is fundamental to control systems, signal processing, and communication systems, among others [1, 2]. In spite of its importance, the subject of linear systems is not easily assimilated by a significant number of undergraduate students. Subtle concepts and the needs of sophisticated mathematics are the main reasons of such difficulties.

After a 10 year experience in teaching linear systems theory in electronics engineering at the Federal University of Rio de Janeiro (UFRJ), an integrated laboratory on this subject was conceived to act as a supporting tool for the teaching activity. This laboratory would integrate hardware implementation and software simulation techniques of important aspects of the theory of linear systems in a common educational framework. This approach aimed at stressing to the students the fact that modern electronics engineering projects typically comprise integrated hardware and software design phases. Nowadays, not only the circuit designers are spending most of their time using simulation tools in a given computing platform, but also more software oriented designers often face data acquisition and transmission problems that require fundamental knowledge on devices and circuits.

Two essential steps are involved in the analysis of a physical system. The analysis starts by developing a system model and the consequent formulation of the mathematical equations that describe the system. In the sequence, the solution of these equations according to the specific boundary conditions and initial state is addressed. The laboratory under discussion is more oriented to the second step of the analysis, providing discussions on the main aspects of the most powerful techniques, but also investigates some aspects in system modeling.

A Virtual Learning Laboratory

In order to define the framework of such laboratory, the use of the modern tools provided by software engineering techniques on multimedia platforms is of considerable appeal. However, some insights on the educational impacts of new technologies can be derived from the use of audiovisual facilities, which has been receiving a thorough coverage on its educational aspects, possible benefits and misapplications by a number of researchers [3, 4]. It may be derived from such considerations that the use of modern technologies on its own does not assure an immediate gain in educational perception and learning efficiency. The technology should provide the means to improve and optimize the teaching activities. Instead of a technological plaything, the main tool of modern education engineering is the system analysis, in which the input/output transformation can be derived. In this case, the input may be viewed as the student's original raw knowledge that is to be transformed by the application of the educational methodology under consideration, and the output refers to the acquainted knowledge, as a result of such methodology.

It should also be stressed that full exploitation of the benefits introduced by such technologies requires changes and evolution of the overall educational system. Otherwise, the new technology would not transform the usual resources used to expose the subjects and would not contribute significantly as an advance in education (or might even result in a fall back). The main focus of the new integrated educational system should move towards the student as the agent who can make use of the new technology to further explore the target topics.

Having such considerations in mind and in order to have this laboratory easily accessed by students and other interested audiences, the laboratory was built using the World Wide Web (WWW) interface [5]. As the computational power has increased substantially at major universities in Brazil, by means of massive installation of personal computer (PCs) platforms, the use of Internet became very popular among students, which see, in this way, additional attractive features in a WWW based laboratory.

The WWW interface is also a quite interesting manner to implement a virtual learning laboratory [4]. Such concept relies on the following up to date statements:

- The learning process mainly depends on student activity, instead of the speech abilities or knowledge transmission skills of the instructor;
- The information technology is the ideal support, as it allows enough flexibility for the learning development. In this way, the student can determine the speed, the style and the outlines of the learning process;
- As a parallel action to the standard curriculum, the educational system should envisage to form autonomous students who become able to adapt themselves to methods and to distinguish what are the methods that will allow them to acquire new information.

The WWW merges the techniques of networked information and hypertext to make an easy-to-use and powerful information system. It provides an attractive way to visualize and explore interactively the information stored in remote nodes. Moreover, the WWW interface inherently establishes links to other nodes, so that the laboratory can be part of a network chain WWW based laboratories of related subjects. In this way, linear system theory can be linked to basic calculus, mathematical analysis and physics principles, or to more advanced subjects that apply the linear system analysis as an important tool (as it is the case of classical and modern control theory, continuous and discrete-time signal processing and communication systems).

Computing all these aspects, the student gains in motivation and mobility in such framework, which allows navigation on updated and state-of-art information. The WWW also allows worldwide access to the linear system laboratory and consequently it paves the way to support distance learning programmes, where the communication link between students and instructors is established by the network. Besides this, the laboratory to be described has been enlarged and maintained efficiently by using the WWW as the main information repository system.

Basic Structure and Module Descriptions

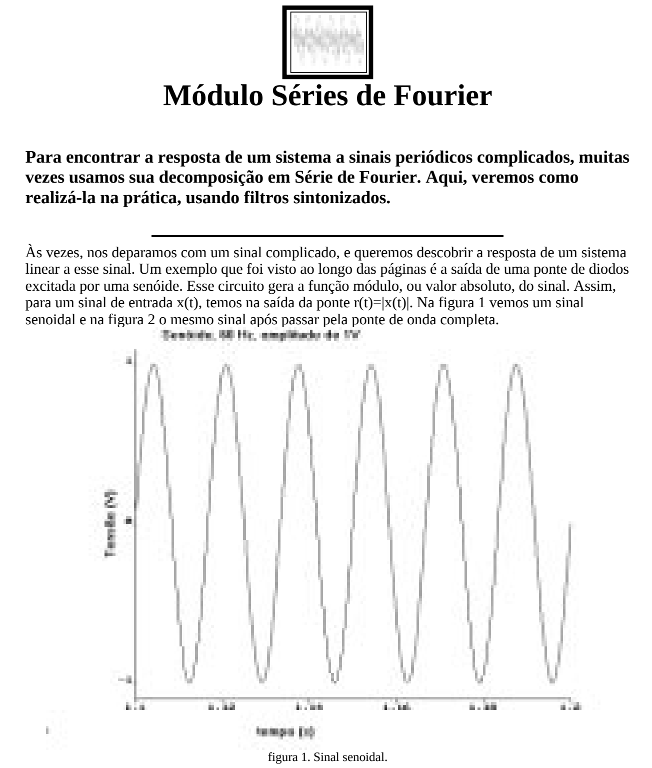
The laboratory (known as PALAS) [1] was built in a modular structure [6]. As an example, Figure 1 shows the first page of the Fourier Series Module.

Each module has its own page, which may be linked to other modules (pages) according to the development of the topic. Among others, modules discuss topics like system identification, differential equation modeling, step and impulse responses, Fourier series, filtering, discrete-time systems and Bode diagrams. A supporting module is also provided to introduce students to the main tools used for circuit caption, simulation and analysis. The development platform was a standard IBM PC running Windows 95.

For the simulation tasks on each module, a set of commercial and widely used software packages was used. This selection aims to integrate the laboratory environment to the student's universe of tools, so that the student does not have to learn extra features from specific software packages but can carry his current experience with everyday software to the framework of PALAS. Therefore, Circuit Maker and PSPICE (MicroSims, USA) are used for circuit simulation. For system simulation based on differential equations, SimNon (SSPA System, Sweden) was the choice. For state space analysis, convolution and transfer function computations, MatLab (MathWorks Co., USA) was selected. For this, control systems, signal and image processing toolboxes were used.

Figure 2 displays a summary of the main modules of

[1] **http://www.del.ufrj.br/~palas**


Módulo Séries de Fourier

Para encontrar a resposta de um sistema a sinais periódicos complicados, muitas vezes usamos sua decomposição em Série de Fourier. Aqui, veremos como realizá-la na prática, usando filtros sintonizados.

Às vezes, nos deparamos com um sinal complicado, e queremos descobrir a resposta de um sistema linear a esse sinal. Um exemplo que foi visto ao longo das páginas é a saída de uma ponte de diodos excitada por uma senóide. Esse circuito gera a função módulo, ou valor absoluto, do sinal. Assim, para um sinal de entrada x(t), temos na saída da ponte r(t)=|x(t)|. Na figura 1 vemos um sinal senoidal e na figura 2 o mesmo sinal após passar pela ponte de onda completa.

figura 1. Sinal senoidal.

Figure 1. The first page of the Fourier series module in PALAS (in Portuguese).

the laboratory, the supporting tools needed to run the experiences and their main didactic objectives.

The hardware implementation of simple but significant circuits is suggested wherever it is relevant. For local students (at UFRJ), experimental measurements on such circuits can readily be performed as prototypes are available in the labs. For distance learning programmes, the circuit modules can be sent on demand by mail. PALAS also provides simulation of the circuit modules and virtual measurement equipment facilities to enable the user to perform the main tasks of the experimental setup from a remote node.

Both experimental measurements or simulation analysis are performed according to instructions and motivations given in each module. Modules also include a specific challenging topic, in which students are requested to discuss a more advanced application of the module's main theory.

The evaluation of the evolvement of students as they proceed from one module to another is performed by means of virtual tests applicable to students for each module. Students can also communicate with the staff that maintains the laboratory by means of electronic mail. This structure is also ready to be applied to distance learning programmes.

Educational Impact and Perspective

The first attempts to use the laboratory as an auxiliary tool for teaching a regular undergraduate course in linear system confirmed the potential interest that such initiative produces in students.

During the development period of PALAS, students were asked to comment on modules under development and finished modules were used as an optional tool that students could use during course attendance. These feedbacks and first contacts with completed material helped a lot in defining the right language approach (colloquial) and module contents.

The WWW based laboratory here discussed is perfectly aligned with other initiatives committed to the application of information technology in engineering education and which are being carried out by a number of researchers at UFRJ. Presently, this trend is supported by institutional programmes and it is spread around the different engineering departments.

Within the electronics department, PALAS received a considerable attention as it concerns the teaching of a very important subject in the graduate engineering course. Moreover, as linear system theory has strong links to basic science (specifically mathematics and physics) and more advanced topics in electronics, such laboratory can help students to establish connecting bridges between what was learnt in the early semesters of the course and the specialized topics learnt in the professional segment of the course. In this way, PALAS also has a contribution to multidisciplinary approaches in engineering education and collaborative learning.

Taking advantage of such educational links, the laboratory is also serving to establish collaborative work with other (non-electronics) engineering departments and the physics and mathematics institutes. One possibility is to adapt the experience of developing PALAS to other domains, so that a corresponding laboratory on a fundamental subject with similar tree of links can be designed. For instance, PALAS could be adapted to accommodate ocean engineering needs, as linear systems are extensively used in this domain despite differences in terminology and approach. Going even further, a full virtual environment can be constructed from links with similar laboratories designed for physics (mainly electricity and mechanics), mathematics (with emphasis in linear algebra, analysis of complex functions and differential equations), and

Module	Summary of the guide	tools	Didactic objectives (desired performance)
Tools	Introducts the simulation and numerical computation tools, with a set of exercises involving their use.	ML, SN, CM	To use the tools to simulate a given circuit or system.
System identification	Presents black boxes to be characterized according to classical criteria.	AC or stand-alone routines	To characterize a physical system according to classical criteria, like linearity, stationarity, dynamicity, causality, continuity and so on.
Differential Equations	Shows some examples of numeric solution methods for differential equations, pointing out the occurrence of errors and suggesting their evaluation.	SN	To solve differential equations, which model dynamic linear systems, using numeric computational methods.
Step input response	Suggests experiments with the step input response of simple systems, with real and complex poles and zeros; proposes exercises with various pole-zero configurations of classical filters; requests a system with conjugated complex poles to match the desired step input response characteristics.	ML with additional routines	To describe qualitative and quantitatively the response to a step input of a generic linear system, given the locations of the singularities.
Fourier series	Proposes experiments with tuned filters using non-sinusoidal periodic inputs, for identifications of the Fourier components; requests the synthesis of a rectifier, given the ripple characteristics.	AC or CM	To decompose periodic signals into their Fourier components. To show the cases in which it may not be achieved.
Tuned filters	Presents the description of tuned filters by their Q parameters and tuning frequencies; asks to identify the integrating and differentiating operating regions of the filter.	AC or CM	To foresee the effect of parameter changes in the tuned filters; to identify regions of validity of real approximations of ideal filters.
Matched filters	Describes briefly the applications of matched filters for detection; suggests the evaluation of the discrimination of the filters with signal contamination.	ML	To synthesize simple filters for the detection of corrupted signals; to execute and to foresee the behaviour of graphical convolutions.
Discrete systems	Exposes briefly the representation of discrete systems in the frequency domain, and the sampling effects; suggests subsampling experiments and introduces digital filtering.	ML	To foresee the effects of sampling rates; to identify the effect of the parameters of a simple digital filter, implemented by difference equations.
Bode plots	Concerns the Bode diagrams of the same systems shown in the module Step Input Response.	ML	To plot the approximate frequency response of a linear system, using the technique of Bode plots.

Acronyms: ML: MatLab; SN: SimNon; CM: Circuit Maker; AC: analog circuits implemented with physical analog components.

Figure 2. Summary of main modules in PALAS.

specialized topics of the professional segment. This educational environment is under development.

It should also be stressed that a WWW based laboratory exhibits an extraordinary flexibility that can be exploited to accommodate the different educational approaches of instructors. In this way, the material developed can be modified according to the desired methodology. This adds a potential enlargement of the laboratory as it looses its paternity and can be considered as a result of many interactions that involved various collaborators. Moreover, this development history can be stored and maintained easily and efficiently in such environment.

For the next phase of project development, a course on linear systems theory is being designed around the laboratory modules. The students will be interacting extensively with the laboratory that will serve as the main complementary didactic material. Therefore, the existent material is being considerably enlarged to include other important modules (pulse response, approximations of the impulse response, generalized Fourier Series, Nyquist theorem on sampled signals, etc) [7]. Evaluation of student progresses will also be using the laboratory support, including the challenging topics of each module and the proposed evaluating tests. Additional WWW based educational tools [8] will also be included in this programme.

The application of the laboratory in distance learning projects is being updated by recent national discussions on policies for such activity, stimulated by the Brazilian federal government. As UFRJ has been established as a national excellence center in engineering, these discussions will be receiving a considerable importance among university researchers along the incoming months.

Conclusions

A WWW based laboratory was developed to support teaching activities in the field of linear system theory. The modular structure of such lab allows students to navigate through the most challenging topics of the field. Emphasis is placed on the main concepts of the theory but computational efforts are also requested to allow students to gain insights in the operational techniques used to solve practical applications. Both simulation and hardware implementation aspects are covered by such lab.

The development of a such laboratory provokes an avalanche of educational ideas that may follow this initiative. As the needs of modern information technology to improve engineering education efficiency is becoming more clear to most engineers and researchers, various projects have been launched at UFRJ to restructure engineering education and the enlargement of the developed laboratory is clearly aligned to such trend. New tools and techniques become available to researchers at high rates and more sophisticated supporting material can be developed and linked to the laboratory to form a new environment for teaching and learning engineering. On its own, the laboratory can be extended both ways, by connections with other similar laboratories and by adding modules to the existent structure. Moreover, these educational activities are putting together instructors and researchers of different fields and as a consequence different experiences can be merged into a common framework. All these ideas are under development at UFRJ.

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