TEACHING AUTOMATIC CONTROL IN NON-SPECIALIST ENGINEERING SCHOOLS

J.A.Somolinos[1], R. Morales[2], T.Leo[1], D.Díaz[1] and M.C. Rodríguez[1]

[1]E.T.S. Ingenieros Navales. Universidad Politécnica de Madrid. Arco de la Victoria 4 28040 Madrid (SPAIN)
[2]E.T.S. Ingenieros Industriales. Universidad de Castilla-La Mancha. Campus Universitario s/n 02071 Albacete (SPAIN)
joseandres.somolinos@upm.es; rafael.morales@uclm.es; teresa.leo@upm.es; david.diaz@upm.es; mariadelcarmen.rodriguez.hidalgo@upm.es

Abstract

Automatic Control Teaching in the new degree syllabus has reduced both, its contents and its implementation course, with regard to traditional engineering careers.

On the other hand, where the qualification is not considered as automatic control specialist, it is required an adapted methodology to provide the minimum contents that the student needs to assimilate, even in the case that students do not perceive these contents as the most important in their future career.

In this paper we present the contents of a small automatic course taught Naval Architecture and Marine Engineering Degrees at the School of Naval Engineering of the Polytechnic University of Madrid.

We have included the contents covered using the proposed methodology which is based on practical work after lectures. Firstly, the students performed exercises by hand. Secondly, they solve the exercises using informatics support tools, and finally, they validate their previous results and their knowledge in the laboratory platforms.

Keywords: Innovation, Technology, Laboratory sessions.

1 INTRODUCTION

When some of the teaching contents are not perceived by the students as the most important for their future profession, or the reduced amount of credits of these teaching contents due to the adaptation to the EEES [1,2,3], does not let to decompose the sylabus into different courses, a great effort needs to be carried out by the teachers to provide the students with the basics contents for the training of future engineers who are not specialist in this field.

Students of both, Naval Architect and Maritime Engineering Degrees in the Technical University of Madrid[4, 5], have their first contact with the automatic control contents in the second course, during the fourth quarter. The subject is entitled “Electronics, Automatic control, Communications and Navigation”, and only 20 hours are invested in the explanation of the basics concepts of the Automatic Control Engineering.

Furthermore, the knowledge of the basics contents of systems dynamics, stability analysis, feed-forward and feedback control enables the students an easy understanding of the higher-level contents related to their degree/degrees. Some examples are “vessel stability”, “vessel dynamics”, “hydrodynamics”, “noise analysis” or “electronics instrumentation”, among others.

This paper presents a novel methodology to improve the learning of the Automatic control contents by the students of Naval Architect and Maritime Engineering Degrees. The proposed methodology is decomposed into four stages (as it was proposed in [6, 7, 8]):

- Direct and theoretical teaching of the most important concepts [9].
- Multiple handmade exercises with easy self-assessment [9].
- Computer sessions using computer based tools, MATLAB (C), the Control Toolbox [10] and the SISOTOOL for easy understanding of the most popular PID synthesis methods. Other computer based tools can be used instead of them (See [11] for details.)
- Laboratory sessions where the students implement the theoretical PID controllers tuned in the previous steps in a real experimental prototype.

In the fourth stage, special Lab equipments based on electronic circuits have been developed for these purposes. Students understand the relation between the different kinds of systems with very different nature after applying the Principle of Analogy which allows the students to synthesize thermal or mechanical systems with simple electronic circuits based on operational amplifiers. PID controllers are easily tuned and the small differences between theoretical and practical results assimilated quickly.

Power and control signals are clearly differentiated allowing the students to follow and to understand the performance of open-loop and closed-loop systems without losing their focus on understanding other connections.

The experimental setup of the special Lab equipment and experimental results with real electronic signals are presented showing excellent learning results and good automatic control contents understanding that are validated when students face later subjects without any appreciated difficulties.

This paper is organized as follows: A scheme of the contents of the subject is summarized in Section 2. In Section 3 denotes an example of a handmade exercise proposed. Section 4 is devoted to the computer sessions and Section 5 depicts the lab sessions proposed. Finally, some conclusions are stated in Section 6.

2 CONTENTS OF THE SUBJECT

Students of both, Naval Architect and Maritime Engineering Degrees, have their first contact with the automatic control contents in the second course, during the fourth quarter. The subject is entitled "*Electronics, Automatic control, Communications and Navigation*". The subject has 4.5 ECTS and 20 hours are invested in the explanation of the basics concepts of the Automatic Control Engineering, 16 hours are devoted to the Introduction to Electronics Systems, and 9 hours are used to present the concepts of Maritime Communications and Support Systems for Navigation.

Next table shows the contents and time schedule of an automatic control course of only 22 hours. It is decomposed into two main parts. The first part is related with systems dynamics representation, and the second part is focused in the synthesis of PID (Proportional Integral and Derivative) controllers using the Root Locus Method and the contanst of errors.

Frequency Response diagrams are included into the contents of this part since it is essential for the contents related with "*Electronics*" and "*Communications*". Due to the limitations in the number of hours, the classical techniques for designing controllers based on the frequency domain are omitted and only the well known technique for designing controllers based on the root locus method and error constants is considered for this course.

<u>Part I. Chapter 1. Introduction to Systems and Signals</u>

1.1.- Concepts of System/Input/Output/Perturbations

1.2.- Linear and time invariant systems (LTI Systems)

1.3.- Causality. Convolution. Temporary Response

1.4.- Transient and Stationary states

Part I. Chapter 2. Complex Transforms and Transfer Function

2.1.- Complex Transformations. Fourier, a reminder

2.2.- Complex Transformations. Laplace, a reminder

2.3.- Transfer Function.

2.4.- Linearization around an operating point

Part I. Chapter 3. Frequency Response

3.1.- Correspondence Complex Plane/Temporary Response. Transient Response

3.2.- Frequency Response. Bode Diagram

Part II. Chapter 4. Introduction to feedback systems

4.1.- Feedback Systems. Elements inside a control loop.

4.2.- Stability

4.3.- Steady State. Errors. Error constants.

4.4.- The controllers P, PI, PID

4.4.- Time response specifications

4.5.- The root locus plot.

4.6.- Controller design using root locus and error constants method

The rest of the contents are resumed next:

Part III. Chapters 5, 6 and 7. Introduction to Electronic Systems (16 hours)

Part IV. Chapters 8 and 9. Introduction to Maritime Communications and Support Systems to Navigation (9 hours)

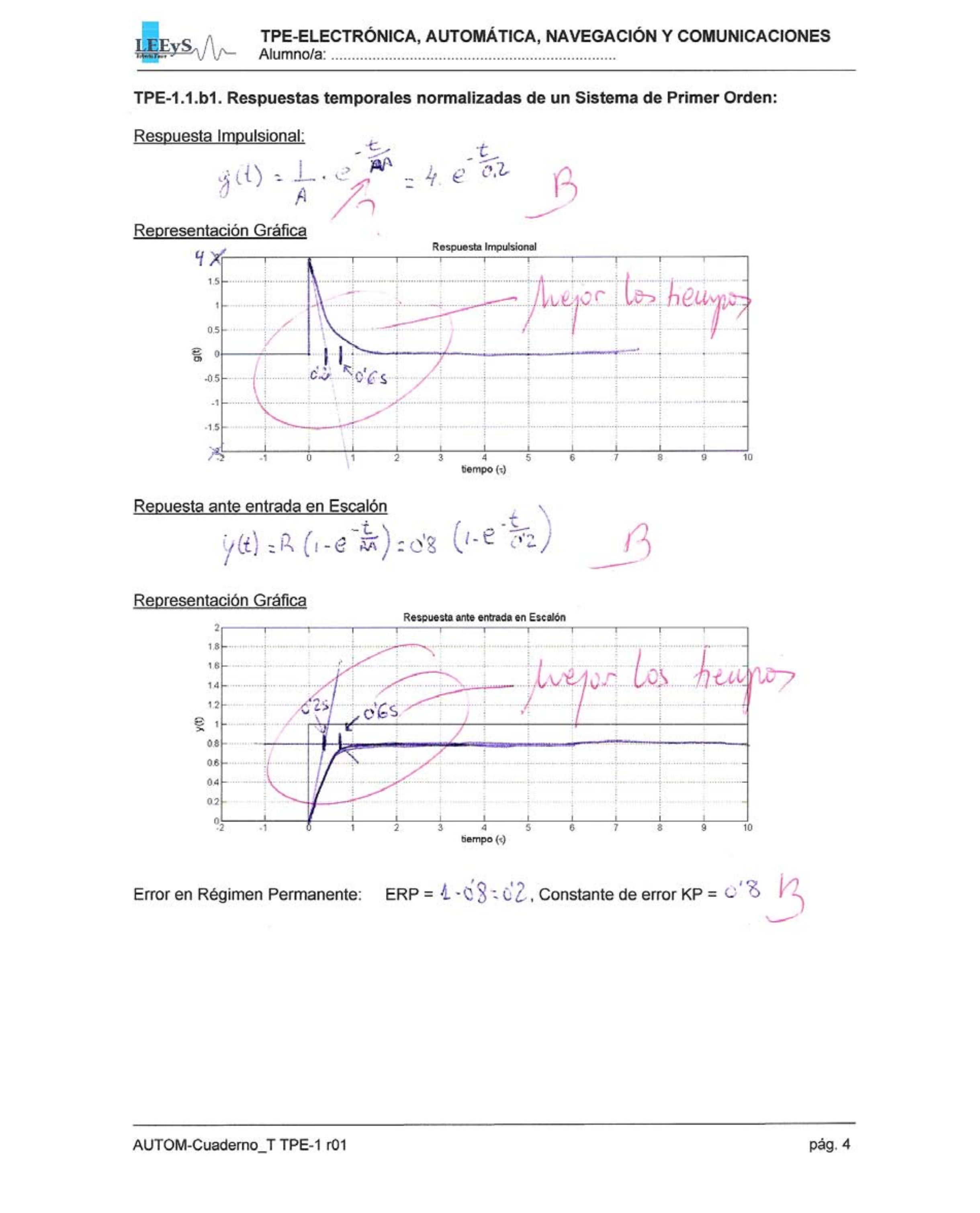
3 HANDMADE EXERCISES

Students have to perform various exercises related to the subject previously explained. The sequence of these exercises is the following:

- Obtain the dynamic model of a proposed system. (first or second order)
- Calculate the transfer function of the linearized system.
- Obtain the open loop responses to standardized input signals (Impulse, Unit step, etc.)
- Plot the Bode Diagram and calculate the Bandwidth, the DC gain and the phase and gain margins.
- Obtain the root locus of the system.
- Select the appropriate type of the controller. P, PI, PID, PD.
- Obtain the root locus of the controller-system for designing the controller
- Adjust the gain.
- Validate temporal responses of the closed loop according to the given time response specifications.

Figure 1 shows one of the pages from a given exercise by a student after being revised by the teacher.

In this case, the student had to draw output response signals to impulse or step signals for a first order system on a bounded template that is included in the job script. This work is made in an individual way. Data for each of the students are personal and related to their identity number.


LEEyS

TPE-ELECTRÓNICA, AUTOMÁTICA, NAVEGACIÓN Y COMUNICACIONES

Alumno/a: ....

TPE-1.1.b1. Respuestas temporales normalizadas de un Sistema de Primer Orden:

Respuesta Impulsional:

Representación Gráfica

Repuesta ante entrada en Escalón

Representación Gráfica

Error en Régimen Permanente: ERP = 1 - 0'8 = 0'2, Constante de error KP = 0'8

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Figure 1. Example of a handmade part of a proposed exercise

4 COMPUTER SESSIONS

After passing the first part of their practical work, students are invited to use MATLAB (C) and the Control Toolbox (sisotool tool) to perform the same tasks described above. After a brief presentation of the main commands of the Control Toolbox (30 minutes), students repeat all the previous steps they did at home, verify their handmade results and give the corrections to the teacher. During this session, the teacher only monitors work in a computer room, solves the student questions and helps to understand some theoretical concepts. Finally, results are delivered at the end of the session.

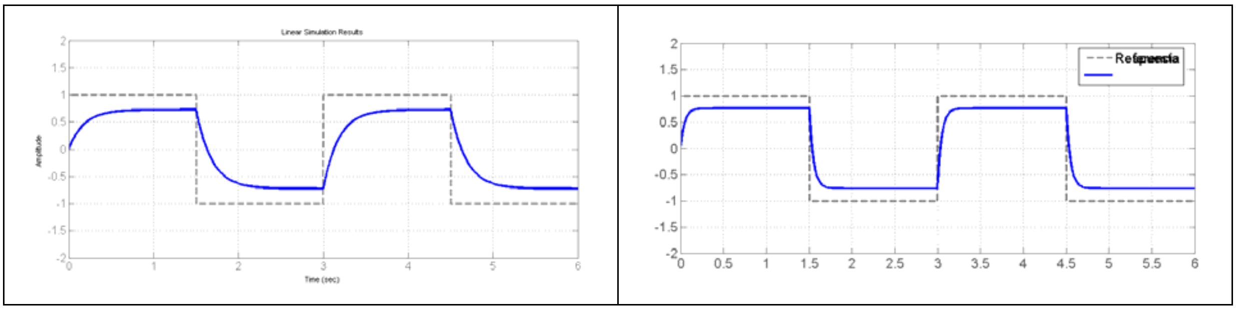
The Mathworks Control Toolbox provides facilities to achieve time responses, frequency responses and system properties for both, open and closed loop systems. Bode diagrams or root locus diagram are very easy displayed by only using a single command, "*bode*" or "*rlocus*" respectively.

Figure 2 shows four different graphs from the complete design process of the controller. Figure 2a shows the open loop response of a first order system to a rectangular signal. Figure 2b depicts the closed loop response with a proportional controller when the transient response design specifications are satisfied. A null steady state error is desired and it can be observed that the steady state system response does not fulfill the design specifications. Then, a PI (Proportional-Integral) controller has to be designed.

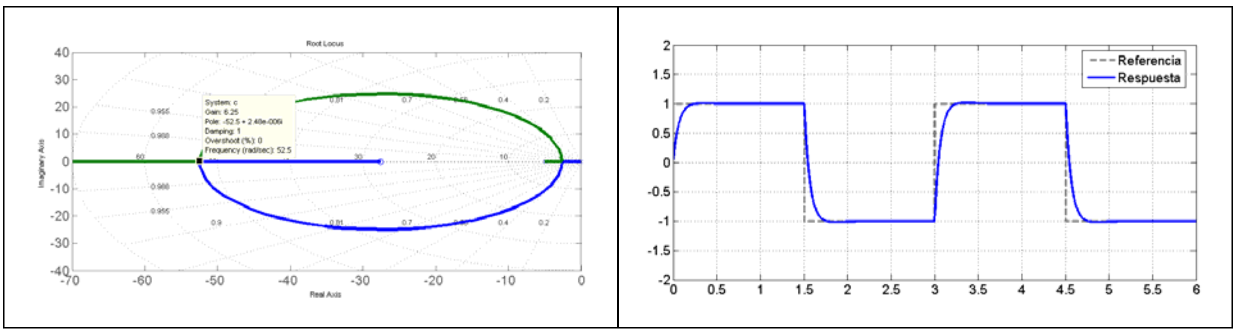
Figure 2c illustrates the root locus of the set controller-system. The student has to place a pole in the origin and to design a real cero. By this way, steady state errors become zero and the transient response can be modified by placing the cero in different positions of the real axis and by choosing diverse gains.

After placing the cero and adjusting the gain, the closed loop system response is achieved using the same input signal as it can be observed in Figure 2d. From this figure, it can be clearly noticed how all the specifications have been satisfied. (No overshooting and a setting time smaller than 0.2 s).

It can be clearly seen how the signals are plotted easily and how the students can check their design progress as well as their goodness.



a) Open loop response b) Closed loop response with a P controller



c) Root Locus of the controller-system d) Closed loop response with a PI controller

Figure 2. Some graphical results from the MATLAB-Control Toolbox

In this last case, the input signal is not a normalized signal. The use of a single step signal is avoided, and a rectangular pulse signal with a 50% duty cycle has been used instead. The reason for the selection of this input signal is that: (a) it is very easy to generate using a frequency generator; (b) it is very similar to the real signal that the students will use in the laboratory sessions; and (c) the processing of this kind of signal requires a more advanced software tool management.

Students can understand the sense of the system response to an input signal, not as a repetitive process of calculating the step responses, but analyzing the response to a non normalized input signal and comparing both signals.

5 LABORATORY SESSIONS

During the last step of the proposed methodology, students identify the system dynamics from time responses; they design a controller for satisfying time specifications and, finally, they implement the controller by adjusting the three gains of the PID (Proportional, Integral and Derivative) controller which is based on the parallel topology.

After doing this step, students verify that all the theoretical contents are applied in a real system and how the proposed methods based on the classical control theory let design controllers in a simple manner, instead of processing time dependant signals or differential equations.

Figure 3 shows the proposed schemes for connecting both the open and the closed loop systems. Two systems –first of them being a first order system and the second one, a lightly damped second order system– are implemented into a “black box” with easily connectable terminals.

The proposed lab setup was built with operational amplifiers that require differential DC power source that are easily accessible in the Lab. All the connections are clearly differentiated by using small and discrete pins for power connections with different colors.

Input signals are generated with a simple function generator while both, input and output signals, are displayed using a two channel oscilloscope. All these signals are connected with BNC based wires that are easily connectable. Students do not invest too much time on system connections according with the schemes illustrated in Figure 3 and Figure 4.

Figure 3 shows the connections for visualizing into an oscilloscope both, the input and output signals, from the open loop first order system while Figure 4 depicts the complete set of BNC connections for visualizing into the oscilloscope both, the input and the output signals, from the closed loop system.

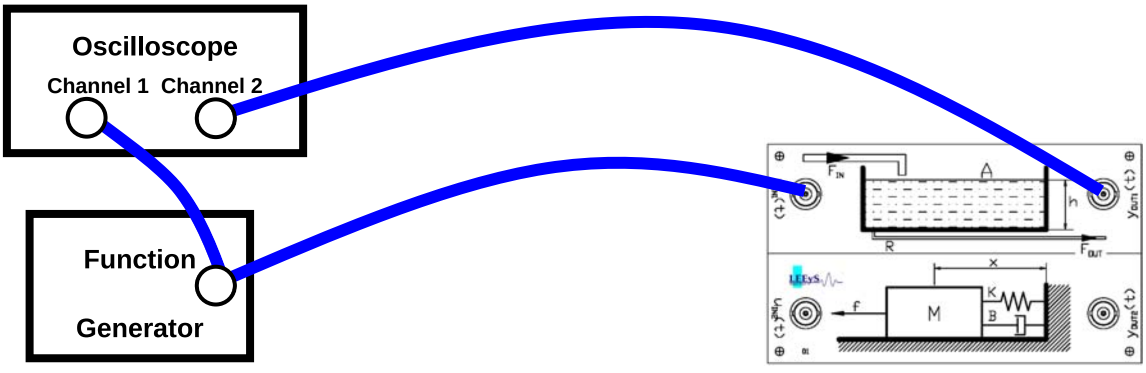


Figure 3. Signal connections for an open loop system

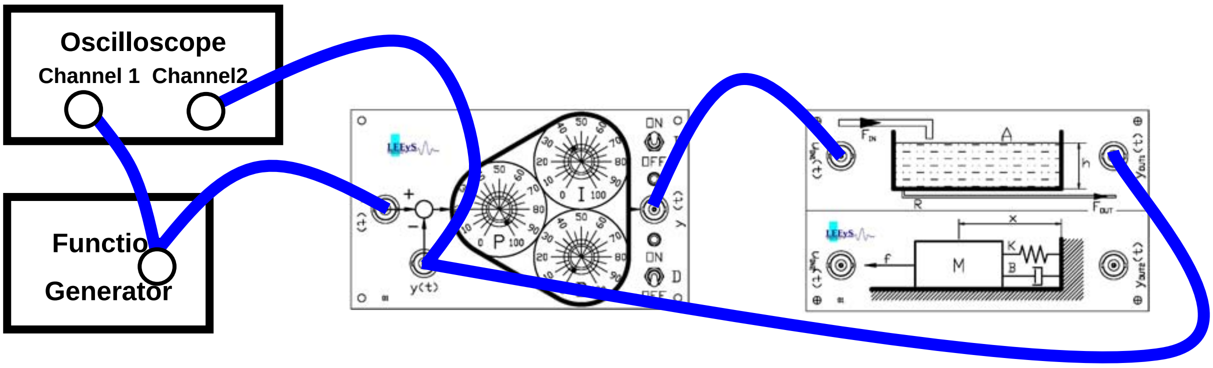


Figure 4. Signal connections for a closed loop system

The connection procedure illustrated in Figure 3 and Figure 4 let the students a better understanding of the meaning of the feedback control and the main differences between open and closed loops. The comparison between the output signal and the input signal to obtain the error signal is easily interpretable and understandable by the student. In a similar manner they understand how the controller signal is handled by the original system.

Figure 5 illustrate the laboratory platform setup showing the power and signal connections and the input and output signals from the first order system. Two oscilloscopes with very different performance have been connected to the laboratory platform to demonstrate that it is not necessary a high performance oscilloscope. A cheap analog oscilloscope is valid for the purpose of this lab session.

Additionally, it is observed the good agreement between the experimental system responses achieved in Figure 5 and the theoretical system responses depicted in Figures 1 and 2a.

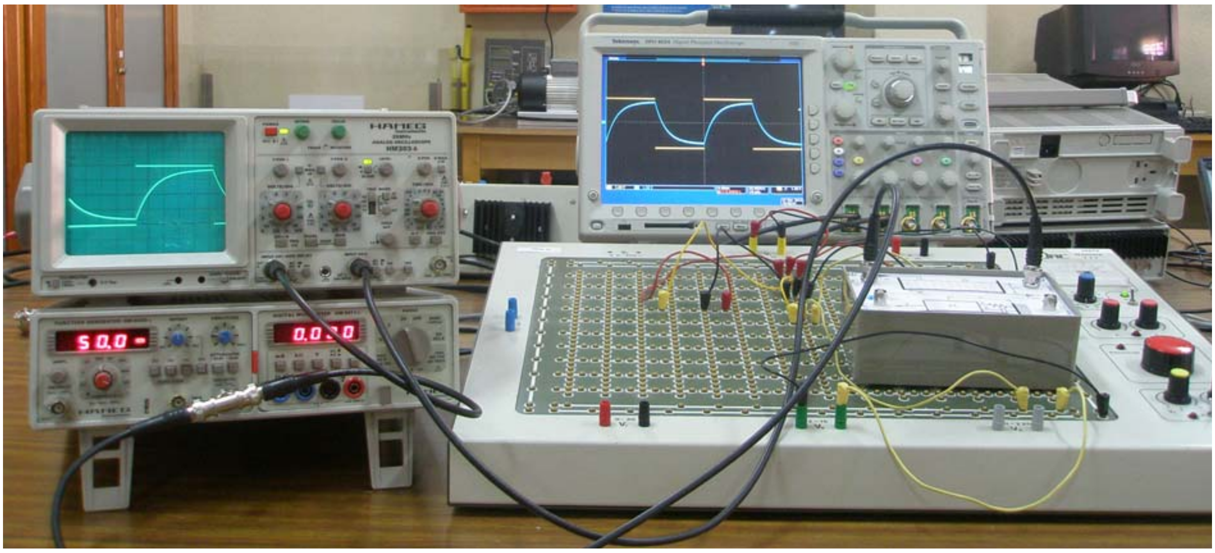


Figure 5. Overview of the lab setup. Open loop response of a first order system

Figures 6 and 7 illustrate the experimental platform when the closed loop system is analyzed. Figure 6 shows both input and output signals when a simple P (proportional) controller is used.

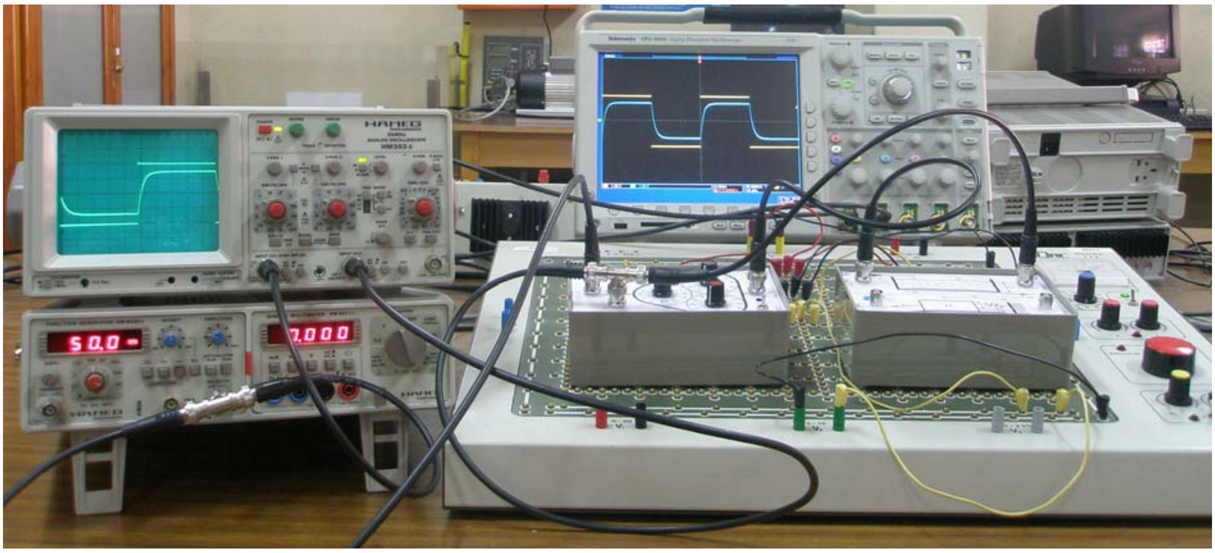


Figure 6. Closed loop response of a first order system with P controller

Students verify how an increase of the proportional controller gain gives a faster system response and reduces the steady state error. Of course, it is not possible to obtain null steady state error, and a PI (proportional integral) controller must be designed.

Figure 7 depicts the input and output signals of the closed loop system using a PI controller design. All the given time specifications are fulfilled after a good controller tuning.

Additionally, it is observed the good agreement between the experimental system responses achieved in Figure 7 and the theoretical system response depicted in Figure 2d.

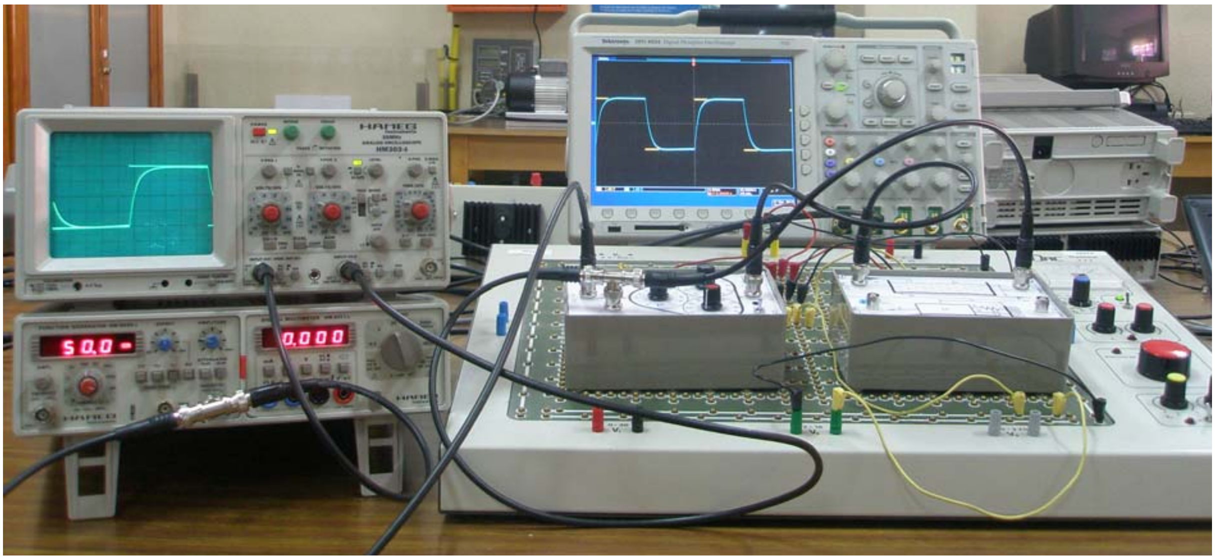


Figure 7. Closed loop response of a first order system with PI controller

If students have completed both, the tuning and implementation tasks of the controller, and they have a little amount of time in the laboratory session, they can modify the controller gain values and verify the different output signals as well as the effects of each of the individual gains: (a) K_P for the proportional gain modifies the damping of the obtained second order system; (b) K_I for the Integral gain modifies the natural frequency and; (c) K_D for the derivative gain that is fitted to cero in this case.

6 CONCLUSIONS

This paper presents a novel methodology to improve the learning of the Automatic control contents by the students of Naval Architect and Maritime Engineering Degrees. The proposed methodology is decomposed into four stages: (a) Direct and theoretical teaching of the most important concepts; (b) Multiple handmade exercises with easy self-assessment; (c) Computer sessions using computer based tools, MATLAB (C), the Control Toolbox and the SISOTOOL for easy understanding of the most popular PID synthesis methods; and (d) Laboratory sessions. The results obtained let us conclude that academic results are satisfactory, in order to the achievement of those who were the initial objectives:

- Students accessing to the laboratory have previously solved related contents problems.
- Students validate the laboratory results against the previous theoretical and computer aided results.
- Not too much teacher resources are spent for these tasks.
- Groups of students can validate and compare their results preventing massive copy of results and encouraging teamwork (during first and second stages).
- Teachers invest a relative small amount of time during the correction and marking phases, and he/she may fill the marks at the same time completing the lab sessions.

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