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Hands-on Solutions for Teaching Basic Introductory Control Systems Course

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***Abstract* - The Control Systems course is taught in educational electric engineering programs all over the world. The method used for teaching this course is mainly by mathematical representation and software simulation of systems' behavior. In this work the author presents a different approach, which is based on making hands-on experimental applications. The solution presented in this article is based on decomposing and re-arranging the transfer function representation of a dynamic system in order to implement it using electronic circuits. Combining the presented method with a popular simulation software leads to the implementation of practical and effective laboratory classes for this course.**

***Keywords*: transfer function, operational amplifier, summer, integrator, stability**

I. Introduction

The Control Systems course is a topic found in many undergraduate electric engineering educational programs all over the world [1][2][3]. In all Electrical Engineering educational programs in Romania this course is taught as a requirement of the Romanian National Evaluation Agency (ARACIS) [4].

In the context of European Higher Education Area, this course is focused on developing certain skills of understanding [1][5] :

- Of concepts of dynamic behaviour of systems
- Of concepts like: stability, instability, stability limit
- Of concepts of controller design to change the natural behaviour of a system
- How to make connections between different representations and real-life systems

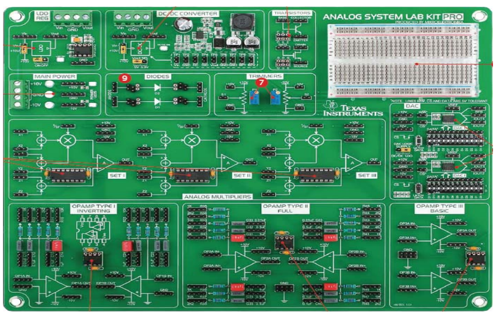


Fig. 1. Hardware board

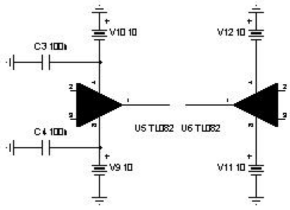


Fig. 2. Open configuration

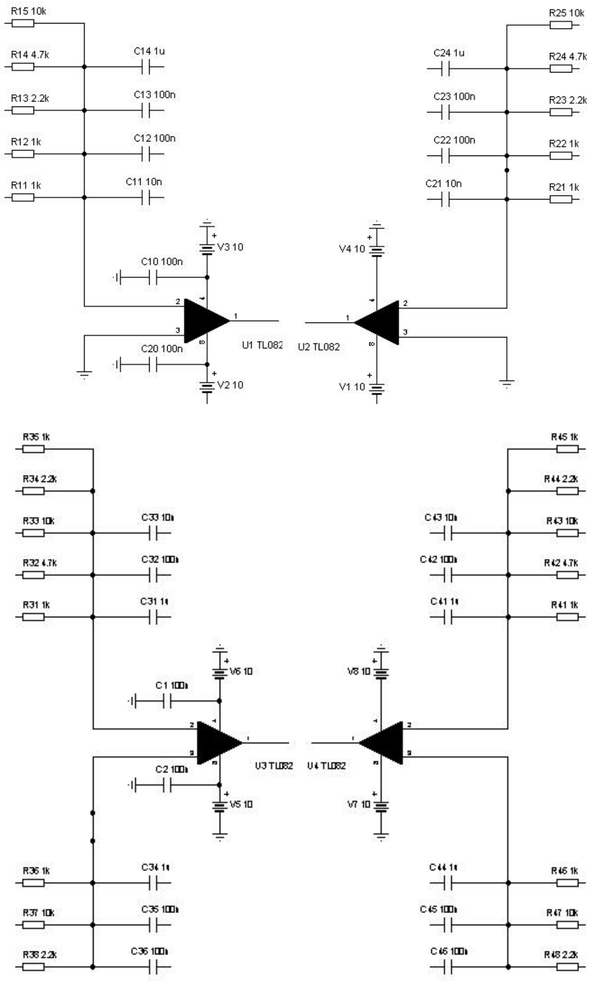


Fig. 4. General configuration

The concepts taught in this course are not always easy for undergraduate students to understand and master [2][6]. In the behaviour analyse of a system is used a high level mathematical algorithm: derivative equations, Laplace transform, stability determination, etc. [7][8].

There is a wide practice to use software tools both online as well as offline to study the concepts of Control Systems course [9][10][11][12]. Most of them are commercial like MATLAB, LabView. Other tools, like SCILAB, Octave are free.

There are many voices among engineering educators that emphasis the benefits of software simulation tools in various fields like robotics [13], chemistry [14][15], hydraulic [16], process control [17], electric machines [18], etc. All the authors mention benefits like: the price and the accessibility of the experiments, also the results are easy to be shared, the ease of repetitiveness, etc. [19].

However, the hands-on experiments should be the purpose of any Engineering teaching program [20][21]. The future engineering specialists should do as much as possible experiments with real life elements. Software simulation tools should not replace entirely the hands-on experiments [22].

There are companies like Lukas-Nuelle, Alecop, Feedbackplc, etc. that produce educational materials. The ready made equipment often times are not flexible enough to allow the exemplification the teacher might want to underline at a certain point of his/her class development [3]. Another problem of these products is that they are quite expensive. Due to the cost, it is not common that one laboratory could have several equal stands so that various groups of students could do the same experiment in the same time.

The solution proposed in this article is the use of a hardware board [23] indicated in Fig.1. This solution could be used as inspiration. Different boards could be constructed both at the university laboratory as well as by students with their own resources.

The solution used in this article allows the configuration of three possibilities as indicated in figures 2, 3 and 4. Based on these configurations, different implementation of basic mathematical operations used in the Control Systems course [7] can be obtained:

- Summation/differentiation
- Multiplication/division with a constant
- Integration/derivation
- Inverting/non-inverting

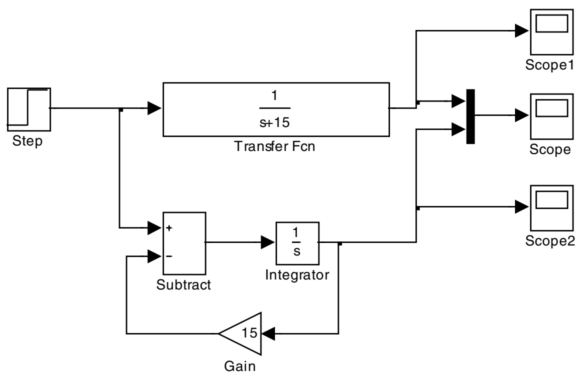
In this article is presented a hands-on method of teaching the introductory course of Control Systems in Electrical Engineering Educational Programs. The teaching/learning the concepts of the course are not limited only to software, mathematical and/or block representations of systems. By implementing systems using "real life" devices, it is easier for the undergraduate students to make necessary connections between different types of representations and real systems.

The novelty of this approach is that by using basic Operation Amplifier (OA) in different configurations is obtained a hands-on model of transfer function representation of systems. Even though this is also a model representation, from the educational perspective is a plus because students could easier make the required connections between mathematical and transfer function representation and 'real life' devices. Also by using this method of teaching basic introduction Control Systems course, students could experiment the practical construction of systems starting from their mathematical representation.

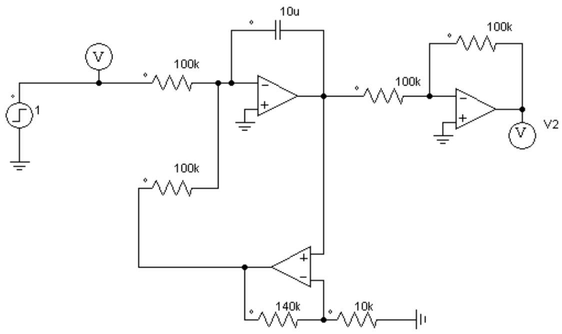
The fact that there are available different programmable modules, makes it easy to implement signal generators and data acquisition inexpensive boards [24][25]. Thus the implementation of this methodology combines and develops knowledge of Control Systems Theory, Electronics, Programming, Data Acquisition, etc. This makes it be a multidisciplinary approach.

II. EXPERIMENTAL IMPLEMENTATIONS

The block schematic representation of a system needs to be expanded so that the mathematical operations are separated. Generally speaking in system approach, it is intended to obtain a minimized block schematic or transfer function. In order to obtain the physical electronic representation of a system, this needs to be expanded in such a way that in the direct loop remains mainly the integration operation, as displayed in Fig. 5 and Fig. 6. By combining nested loops is obtained the implementation of any system regardless of the order of its transfer function.



a. Block representation a 1st order system



b. Electronic implementation of a 1st order system

Fig. 5 Representation of a 1st order system

In order to obtain the desired form of the block schematic, it is required to have some transformation of the transfer function as indicated in (1):

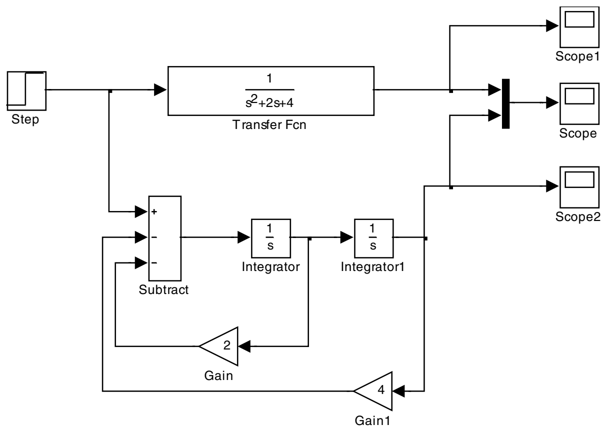
$$G_1(s) = \frac{1}{s+15} = \frac{\frac{1}{s}}{1+\frac{1}{s}\cdot 15} \qquad (1)$$

Equation (1) contains the expressions of transfer functions for the feed-forward and the feed-back as indicated in equation (2):

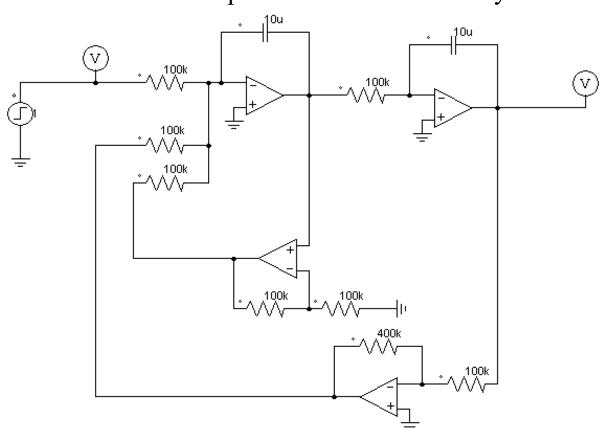
$$\begin{cases} G_{1d}(s) = \frac{1}{s} \\ H_{1f}(s) = 15 \end{cases} \qquad (2)$$

The equation (2) can be implemented by the system structure indicated in Fig. 5a. Following this representation and using integration, summation and gain OA circuit operations, it is obtained the electronic schematic displayed Fig. 5b.

For a 2nd order system, there are several similar operations to be made.



a. Block representation a 2nd order system



b. Electronic representation a 2nd order system

Fig. 6 Representation of a 2nd degree system

The transfer function of a 2nd order system is indicated in (3), and its transformations in (4) and (5):

$$G_2(s) = \frac{1}{s^2+2\cdot s+4} \qquad (3)$$

$$G_2(s) = \frac{\frac{1}{s^2+2\cdot s}}{1+\frac{1}{s^2+2\cdot s}\cdot 4} \qquad (4)$$

$$G_2(s) = \frac{\frac{1}{s\cdot(s+2)}}{1+\frac{1}{s\cdot(s+2)}\cdot 4} \qquad (5)$$

The equation (5) indicates that the transfer function of the 2nd order system was transformed in two nested 1st order systems in which the fee-forward and the feed-back transfer functions are:

$$\begin{cases} G_{2d}(s) = \frac{1}{s\cdot(s+2)} \\ H_{2f}(s) = 4 \end{cases} \qquad (6)$$

Further on, the transfer function G_{2d} from equation (6) can be expanded as a nested 1st degree system as indicated in equation (7) and fig. 6.a.

$$G_{2d}(s) = \frac{1}{s\cdot(s+2)} = \frac{1}{s}\cdot\frac{\frac{1}{s}}{1+\frac{1}{s}\cdot 2} \qquad (7)$$

In order to obtain the systems' structure displayed in fig. 6b it is used the mathematical expression (7). One aspect that should be noted in the implementation of a 2nd order system is to take into consideration the signals' signs (±) after the implementation of each operation. Taking this into consideration, the feed-back implementation differs for the nested loops: the exterior one is implemented with an inverting structure, while the nested one is implemented with a non-inverting structure.

For the implementation of superior order systems with OA networks, it has to be followed the same algorithm.

III. System Stability Exemplification

By using real experiments and simulation tools students observe the behavior for the analyzed system: transient and stable regimes. Often times, stability concept is not easy for to be understood. Therefore, besides the theoretical presentation and software simulation, when working with real circuits, it is easy to observe how a change of certain parameters could translate a system from stability to instability.

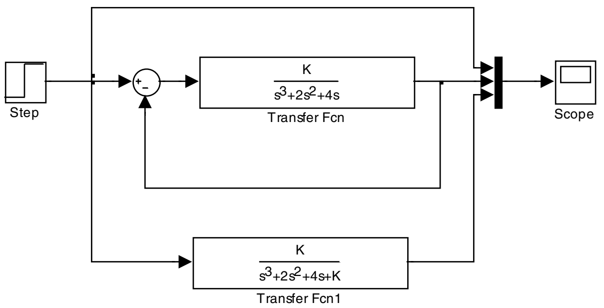
For a system with a given characteristic equation, such as $s^3 + 2 \cdot s^2 + 4 \cdot s + K = 0$, applying the Routh stability criteria, it is found the stability variation domain for $K \in (0,8)$.

The root-locus of the system displayed in fig.7 is obtained through the use of basic knowledge of Control System Theory course. The stability of the system depends on the values of the gain *K*. In fig. 7.b are indicated the stable and unstable domains. Sometimes it is difficult for the students to understand the concept of variation for the gain K and its reflection in the system stability.

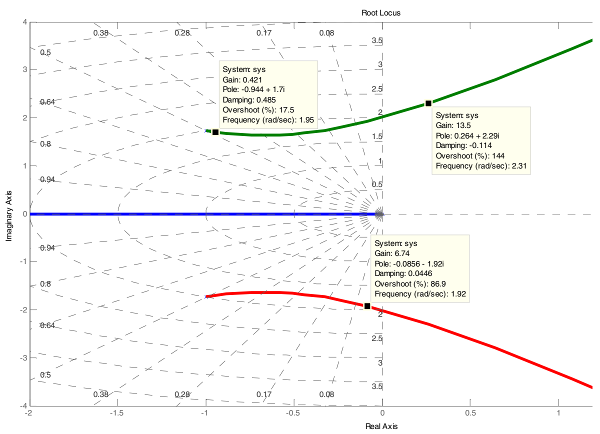
If the analyzed system from fig. 7 is implemented with an electronic OA configuration, as indicated in fig. 8, then it is easier to observe the immediate way of changing the gain and the modifications in the output waveform.

With the change of values of the output and the outer feed-back loop, it can be obtained the behavior of the system as displayed in fig. 8.

From the data acquisition results of the schematic displayed in fig. 8 students can observe different behaviors of the analyzed system for gain variation. A concept that is difficult to be seen and studied is the saturation in case of an unstable system. By using the proposed method of approaching the Control System Course, it is not difficult to present stability, limit of stability and instability associated with saturation for an analyzed system.

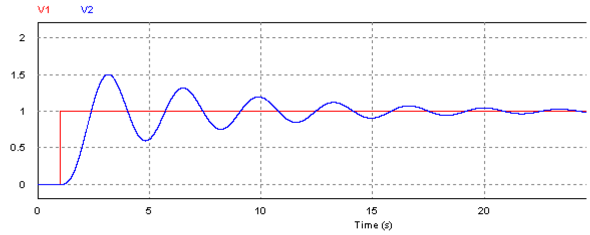


a. Analysed system

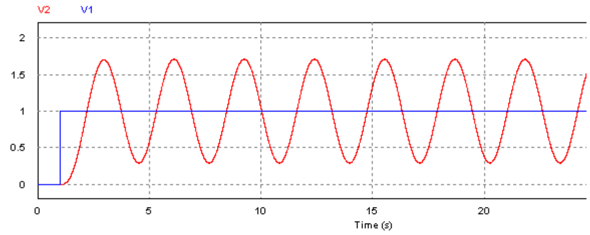


b. Root locus representation for stability analysis

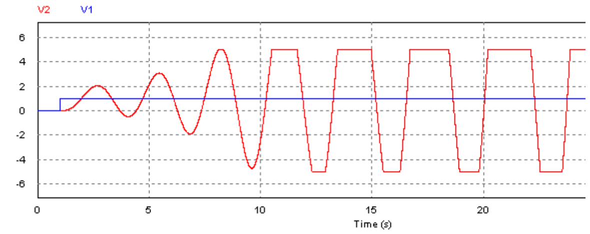
Fig. 7 Stability representation



a. Stable system for K=6



b. Stability limit for K=8



c. Instability and saturation for K=13

Fig. 8. System behavior according gain *K* values

IV. CONCLUSION

The purpose of this article was to present a 'hands-on' methodology of teaching a basic Control System Course.

The concept of the proposed method was to make a direct transformation of the transfer function representation to OA network representations.

There are several benefits of this method:

- Ease of electronic implementation
- Possibility to observe different behavior of the implemented systems
- Possibility to observe the direct influence of parameter changes in the response waveform of the system
- A direct connection between mathematical representations and 'real life' systems

Taking into consideration the real success of programmable systems like Arduino, or TI's MSP 430, a signal generator and an oscilloscope are frequent applications hobbyists do and share on the Internet.

Combining the presented methodology with these programmable systems for signal generation and data acquisition it is expected that for a quite arid and difficult course like Control Systems will be easier to implement experimental laboratory practices in universities. Otherwise, the experiments that are needed to study systems behavior become quite expensive and many times unaffordable.

Also, if the implementation of both system representation and data acquisition system is obtained at a reasonable price, students can do it as 'do it yourself' experiments. If students are getting the interest and curiosity of developing and observing the experiments by themselves, the understanding of the theoretical concepts is more successful than if they focus only on computer simulations.

REFERENCES

[1] J. A. Méndez and E. J. González, "A reactive blended learning proposal for an introductory control engineering course," *Comput. Educ.*, vol. 54, no. 4, pp. 856–865, May 2010.

[2] S. S. Nudehi, P. E. Johnson, and G. S. Duncan, "A control systems laboratory for undergraduate mechanical engineering education," *Int. J. Mech. Eng. Educ.*, vol. 39, no. 4, pp. 334–345, Oct. 2011.

[3] A. Cruz-Martín, J. A. Fernández-Madrigal, C. Galindo, J. González-Jiménez, C. Stockmans-Daou, and J. L. Blanco-Claraco, "A LEGO Mindstorms NXT approach for teaching at Data Acquisition, Control Systems Engineering and Real-Time Systems undergraduate courses," *Comput. Educ.*, vol. 59, no. 3, pp. 974–988, Nov. 2012.

[4] *Standarde specifice de evaluare academică pentru programele de studiu din domeniul fundamental - Ştiinţe inginereşti*. Romania: Ministry of Education.

[5] D. Isoc, "Adaptive mechanisms and structures in engineering education," in *Advanced Topics in Electrical Engineering (ATEE), 2011 7th International Symposium on*, 2011, pp. 1–6.

[6] R. Beloiu, "A practical approach for an introductory control engineering course," 2013, pp. 1–4.

[7] K. Ogata, *Ingenieria de control moderna, 3rd ed.* Mexico: Prentice-Hall Hispanoamerica, 1998.

[8] A. Whitworth, *The Wikibook of automatic Control Systems And Control Systems Engineering With Classical and Modern Techniques And Advanced Concepts*. Free Software Foundation, Inc.

[9] A. Barrios, S. Panche, M. Duque, V. H. Grisales, F. Prieto, J. L. Villa, P. Chevrel, and M. Canu, "A multi-user remote academic laboratory system," *Comput. Educ.*, vol. 62, pp. 111–122, Mar. 2013.

[10] D. Muñoz de la Peña, F. Gómez-Estern, and S. Dormido, "A new Internet tool for automatic evaluation in Control Systems and Programming," *Comput. Educ.*, vol. 59, no. 2, pp. 535–550, Sep. 2012.

[11] L. Domingues, I. Rocha, F. Dourado, M. Alves, and E. C. Ferreira, "Virtual laboratories in (bio)chemical engineering education," *Educ. Chem. Eng.*, vol. 5, no. 2, pp. e22–e27, May 2010.

[12] G.-R. Gillich, D. Frunzaverde, N. Gillich, and D. Amariei, "The use of virtual instruments in engineering education," *Procedia - Soc. Behav. Sci.*, vol. 2, no. 2, pp. 3806–3810, 2010.

[13] R. Kumar, P. Kalra, and N. R. Prakash, "A virtual RV-M1 robot system," *Robot. Comput.-Integr. Manuf.*, vol. 27, no. 6, pp. 994–1000, Dec. 2011.

[14] C. Martin-Villalba, A. Urquia, and S. Dormido, "Development of virtual-labs for education in chemical process control using Modelica," *Comput. Chem. Eng.*, vol. 39, pp. 170–178, Apr. 2012.

[15] C. Martin-Villalba, A. Urquia, and S. Dormido, "Object-oriented modelling of virtual-labs for education in chemical process control," *Comput. Chem. Eng.*, vol. 32, no. 12, pp. 3176–3186, Dec. 2008.

[16] E. Yılmaz and S. Katrancıoğlu, "Distance Control of Hydraulic Experiment Set with Different Algorithms and Software Simulation," *Procedia - Soc. Behav. Sci.*, vol. 83, pp. 318–322, Jul. 2013.

[17] D. Muñoz de la Peña, F. Gómez-Estern, and S. Dormido, "A new Internet tool for automatic evaluation in Control Systems and Programming," *Comput. Educ.*, vol. 59, no. 2, pp. 535–550, Sep. 2012.

[18] G. E. Subtirelu and M. Dobriceanu, "Virtual instruments (VIs) for study of asynchronous motor functional characteristics," in *Advanced Topics in Electrical Engineering (ATEE), 2011 7th International Symposium on*, 2011, pp. 1–6.

[19] D. Ibrahim, "Engineering simulation with MATLAB: improving teaching and learning effectiveness," *Procedia Comput. Sci.*, vol. 3, pp. 853–858, Jan. 2011.

[20] R. Beloiu, "A practical approach for an introductory control engineering course," in *Proceedings of the International Conference on ELECTRONICS, COMPUTERS and ARTIFICIAL INTELLIGENCE – ECAI-2011*, Pitesti, Romania, 2013, vol. 4, pp. 1–4.

[21] C. Sigogne, G. Berger, T. Rees, and A. De Ferron, "May laboratory experiments explain how a lightning protection system works?," in *Advanced Topics in Electrical Engineering (ATEE), 2013 8th International Symposium on*, 2013, pp. 1–4.

[22] M. Iorgulescu, "Study of three-phase bridge rectifier diagnosis based on output voltage and current analysis," 2013, pp. 1–6.

[23] K. R. K. Rao and C. P. Ravikuma, *Analog System Lab Kit Pro. Manual.* Belgrade: Microelectronika Ltd, 2012.

[24] "A Simple LaunchPad DAC, http://www.msp430launchpad.com/2011/06/simple-launchpad-dac.html, accessed January 2015" .

[25] "Arduino - Multi-Channel Oscilloscope (Poor Man's Oscilloscope).", http://www.instructables.com/id/Arduino-Multi-Channel-Oscilloscope-Poor-Mans-O/, accessed January 2015 .