2018 26th Mediterranean Conference on Control and Automation (MED)
Zadar, Croatia, June 19-22, 2018

An Introductory Overview About Systems and Control
A Motivation Lecture in Control Education

T. Vámos*, L. Keviczky*, R. Bars **, A. Benedek*, D. Sik****

**Institute of Computer Science and Control, Hungarian Academy of Sciences,
MTA-SZTAKI, Budapest, Hungary (e-mail: vamos@sztaki.hu).
**Dept. of Automation and Applied Informatics,
Budapest University of Technology and Economics, Budapest, Hungary
(e-mail: bars@aut.bme.hu, siktdavid@gmail.com)
***Dept. of Technical Education,
Budapest University of Technology and Economics, Budapest, Hungary
MTA-BME Open Content Development (OCD) Model Research Group (e-mail:benedek.a@eik.bme.hu)*

Abstract: Systems and control are all around us. System view, understanding systems and how they are controlled is important for everyone. By understanding systems and control in different areas of life better decisions could be done influencing our everyday life. Systems and control, control engineering is a basic subject in engineering education. In the paper the main aspects of system view, model building, control objectives, control structures and algorithms, among them YOULA parameterization as an important paradigm are considered. This overview about systems and control can be provided in the first lecture of control giving a motivation for the students for studying systems and control. A multi-layer e-book, Sysbook has been developed which could contribute to understanding the concepts as a supplement to the conventional teaching materials. Students also can contribute to its contents through the Student Area. Interactive learning tools as Java applets and software MATLAB/SIMULINK provide possibilities for active learning.

Keywords: Control education, control systems, systems and control for everyone, control disciplines, YOULA parameterization, sysbook

1. INTRODUCTION

Systems are all around us. These systems are or have to be controlled to reach their required performance. System view, understanding systems and how they are controlled is important for everyone in some extent. System view could be useful also for experts with non-technical background. With this approach systems in different areas of expertise could be better understood contributing to better decisions (e.g. in production, economy, health care, etc.) influencing our everyday life. A deeper insight is required for experts who will design and develop control systems which nowadays become more and more sophisticated.

The authors' idea, dating back for more than a decade, was to present the main principles governing systems and control on different levels, for everyone, for students and also for experts (Vámos, T. et al., Plenary lecture at the IFAC Congress in Beijing, 1999, Vámos, T. and Bokor, J., 1996, Vámos, T. et al., 2016, Benedek and Horváth, 2016). Recently the book of Albertos, P. and Mareels, I. (2010) has gained the best textbook prize at the 20th IFAC World Congress in Toulouse in 2017.

A multi-layer e-book (*Sysbook*) has been developed, which describes the systems and controls around us, addressing readers of different backgrounds and interest. The book is available on web-site http://sysbook.sztaki.hu in Hungarian and in English (under development). Hopefully this book could contribute to understanding the concepts as a supplement to the conventional teaching materials (e.g. for deeper discussion the reader is advised to study control textbooks as e.g. Åström and Murray (2008) or Keviczky at al. (2011), Hetthéssy et al. (2014).

Nowadays the explosion of information technologies changes the ways of our perception of new knowledge. New ways of teaching are required considering this changing environment. Visual learning, microcontent one page materials, dedicated softwares (as e.g. MATLAB/SIMULINK), interactive tools contribute to better understanding of the related topics.

In a basic control course the first lecture should give an introduction and overview about systems and controls. It should give an outlook and also motivate the students in studying the topic. We hope that Sysbook provides a good background for that.

In the sequel the main topics introduced in a first lecture are considered.

2. SYSTEMS AND MODELING

Systems are all around us. Understanding their behavior and the ways of how to control them is important for everyone. System view could influence how we look at the surrounding world and to its parts which we could better influence by our activities equipped with this knowledge.

Figure 1 shows several systems around us. System science does not provide definitive answers but helps to create models that actually work. Systems are connected to the surrounding environment. Variables coming from the environment, affecting the system are the input signals of the system, while the signals obtained as system responses and affecting the environment are the output signals.

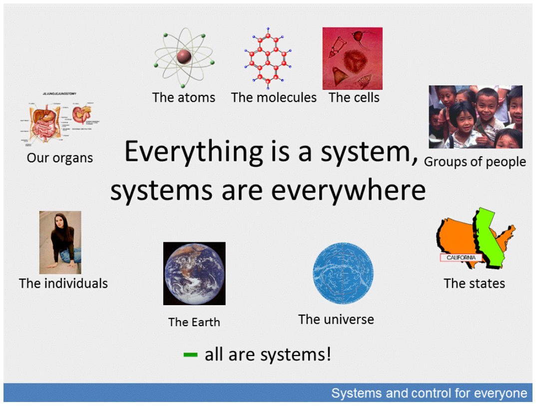

Fig. 1. Systems everywhere

Between them the model of the system provides the relationship between the input and the output signals. Successful decisions, control of systems are based on the models which are the reflections of what we perceive and think of the reality. Imperfect as they are, the models actually work. The models show how the system transfers the inputs into the outputs.

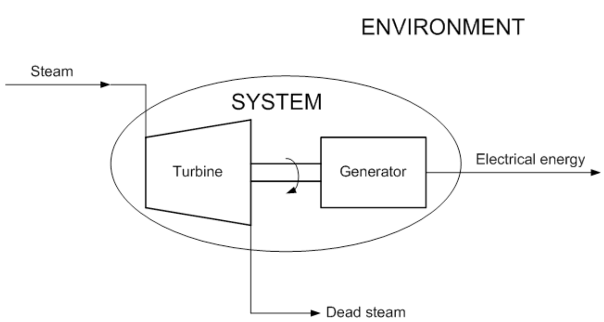

Fig. 2. System and its environment

Figure 2 demonstrates the structural model of a system consisting of a turbine and a synchronous generator producing electrical energy. The input signal is the amount of steam flow into the turbine, which is converted to the speed of the turbine shaft, connected to the rotor of the generator, rotating in the magnetic field of the stator of the generator, producing electrical energy, the output signal. These processes can be described mathematically, generally by differential equations. The relationship between the output and the input, the transfer property of the input signal into the output signal can be written in a box, which is considered as the model of the system. Modeling always emphasizes some properties of a system while neglecting other ones. In this aspect the considered aspect are signal transfer properties of the system. Models can be linear or nonlinear, continuous or discrete time, single or multivariable, etc. The models can be built through deep understanding and mathematical description of the behavior of the system (physical modeling) and analyzing the input/output data. Generally the two methods are combined to get a reliable model of the system (Fig. 3).

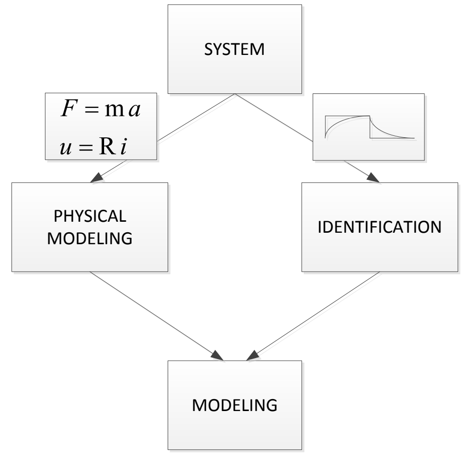

Fig. 3. Physical modeling and identification are used together to build the model of the system

When determining the model of the system the following questions are considered: What is our system, how is it connected to the environment? What are the input signals, what are the output signals? What happens between them? How can this be described mathematically? How can the physical modelling and data based modelling combined to create the model? How can the a priori knowledge and the measurement data converted into reliable knowledge about the system? Several case studies show the application of system view (see also CSS IEEE, 2014). On the basis of system models the behavior of the systems can be analyzed and control system can be designed to ensure the required system performance.

3. CONTROL SPECIFICATIONS

Systems should be controlled to ensure the fulfilment of quality specifications.

The produced electrical energy has to be available at given voltage and frequency in spite of the changing load. The temperature under the shower has to be approximately constant at a pleasant value, the juggler has to balance the rod ensuring its stable position (Fig. 4).

The requirement set for a control system are stability, prescribed static and dynamic behaviour, reference signal tracking and disturbance rejection, attenuating the effect of measurement noise, insensitivity for parameter variations (robustness), consideration of constraints. Also ensuring appropriate start and shut down of the process have a primary importance. Energy, economical and aspects also have to be taken into account. In formulation of the requirements the possibilities of the system have to be taken into account, they have to be realistic.

4. CONTROL IS BASED ON NEGATIVE FEEDBACK

These requirements can be fulfilled by control systems, which are based mainly on the evaluation of the difference between the reference, required value and the measured actual value of the system output. This realizes a negative feedback.

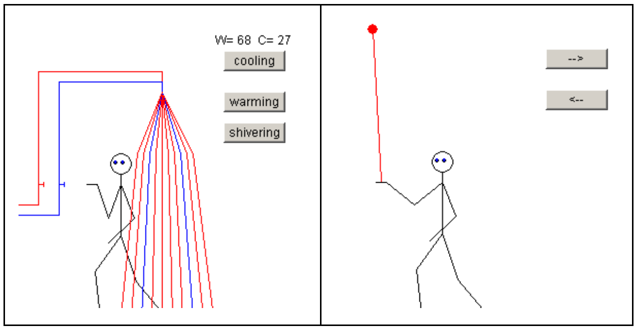

Fig. 4. Showering and balancing a rod are difficult processes

Negative feedback is an old idea used already by the ancient Greeks (e.g. water clocks). It is applied in different areas of life (Fig. 5). Getting feedback and using that to control the process is of primary significance in all areas of activities.

Fig. 5. Feedback in different areas of life

Measuring the weight and comparing it with the desired value one can modify the eating habits. Feedback in financial investments: after the end of the investment profit/loss can be determined then start a new investment with conditions depending on the feedback. In the industry: the experts can see whether the process satisfies the needs in the specific domain and change the input if necessary. In politics: the politicians can analyse their performance, popularity index etc. and react to them in the future.

In control of technical processes on the basis of the difference between the reference and the output signal (the error signal) a controller unit modifies the input of the process. Thus a control system is built around the process using measuring, reference signal producing, comparison, control and actuator equipment. The latter provides the input of the process. The structural diagram, showing the units with boxes is shown in Fig. 6. When giving the signal transfer relations of the individual boxes by mathematical relationships the block diagram of the control system is obtained (Fig. 7.). The letters written within the boxes are the mathematical functions characterising signal transfer of the individual blocks. The block diagram is the model of the control system which makes possible the analysis and the design of the control system to meet the quality specifications.

Negative feedback has amazing properties. It adjusts the output to the required value, it eliminates the error even if it has been caused by the input or the output disturbance or affected by the measurement noise. It decreases the effect of nonlinearity or of parameter uncertainties. But because of the time delays in the elements of the control system the correction effect emerges in a delayed manner what may cause oscillations, unstable behavior. Therefore this issue has to be always analyzed. There are mathematical and simulation methods for checking stability and other performances of a control system.

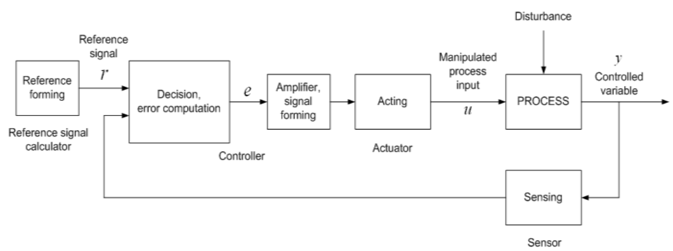

Fig. 6. Structural diagram of a control system

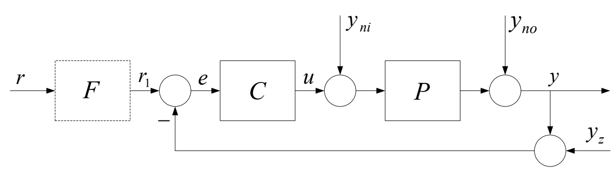

Fig. 7. Block diagram of a control system

In the controller block denoted by C in industrial applications the most frequently used control algorithms are the so called *PID* algorithms, which combine proportional (*P*), integral (*I*) and differentiating (*D*) effects on the error signal. With these effects the control requirements can be fulfilled, moreover their technical realization is easy with operational amplifiers. Nevertheless if the process contains significant transport delay (dead time) the settling process will be slow.

Figure 8 shows the output signals of a control system for a unit step reference signal applying the above control effects for a system containing time delays. It is seen that the settling process needs time. Applying differentiating effect accelerates the control process. Integrating effect is required to ensure accurate settling in steady state, without steady error.

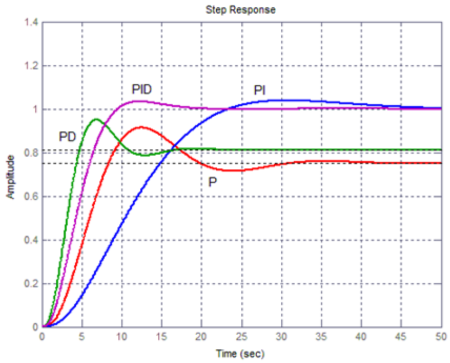

Fig. 8. Output signals of a control system with *P*, *PI*, *PD* and *PID* controllers

The performance of the control system can be improved using additional information about the system or the disturbances. If e.g. the disturbance acting on the output of the system is measurable, then this information can be used to influence the actuating signal to improve the disturbance rejection (feedforward). If inner signals (states) within the plant *P* are measurable, they can be also fed back to improve the properties of the control system (cascade control, state feedback).

The control system can be continuous, when the signals are available through the whole time course. Nowadays computers are used to control technological processes. The process is connected to the computer (or to PLC) via analog/digital and digital/analog converters. The output signal is sampled, thus it is available only in the discrete sampling instants. It is then quantized and digitalized to be interpretable for the computer. The basic tasks of control are executed in real time by the computer and the calculated control signal is forwarded to the process. Thus the controller is realized by a computer program running in real time. Discretized PID algorithms are mostly applied, but there is a possibility to use other algorithms easily as well. Especially those algorithms are searched which could ensure faster settling process in case of big dead time.

5. YOULA PARAMETERIZATION

For stable processes the control structure and control algorithm of YOULA parameterization provides very effective control paradigm (Keviczky, L. and Bányász, Cs., (2015)). According to Fig. 9 the controller *Q*, the so called YOULA parameter is designed in open loop (in the forward path) to ensure the best reachable reference signal tracking, which can be ensured if *Q* realizes the inverse of the process transfer function *P*. In open loop then the reference signal tracking would be optimal, but this structure will not operate to reject the effect of the disturbance. Therefore the structure is enhanced with the so called IMC, internal model control according to the Figure. The process and the model outputs are compared and the difference is fed back to the reference signal. If there is no disturbance or no plant/model mismatch, then the ε feedback signal is zero, otherwise the deviation creates an error signal which works to eliminate the effect of the disturbance in the output signal.

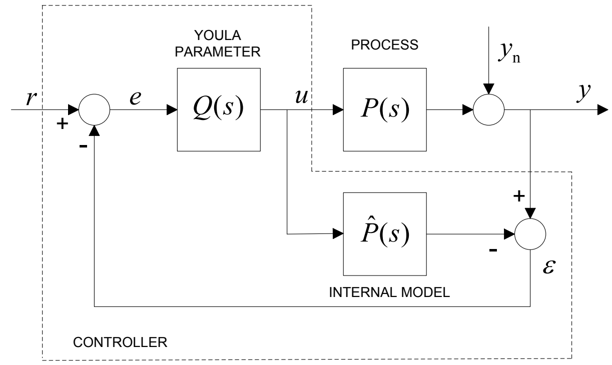

Fig. 9. YOULA parameterized control structure

Unfortunately generally the inverse of the process transfer function is not realizable. Therefore it is separated to the product of the invertible P_+ and the non-invertible $\overline{P}_-$ parts (where the upper line indicates that it includes the dead time as well), and the beat control is achieved if the controller *Q* is set to the inverse of the realizable part (Fig. 10.). The control structure is completed with the appropriately designed reference signal filter R_r and the disturbance filter R_n, which ensure difference in the dynamics of reference signal tracking and disturbance rejection, set the control signal *u* within the required limited range and may ensure robust performance in case of plant/model mismatch.

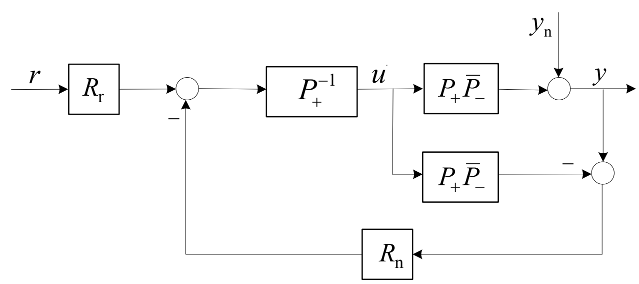

Fig. 10. The realizable YOULA parameterized control system

With this control structure the behaviour of the control system can be better than with *PID* control especially if the process contains big dead time (transport delay). Different other control algorithms (as. e.g. dead beat control, Smith predictor and even PID control can be considered as special cases of YOULA parameterization.

6. INTERACTIVITY: USING JAVA APPLETS

In education interactivity is a very important issue. Besides the detailed discussion of the topics it is important to provide the possibility of active participation of the students in experimenting the different ideas and the properties of the systems and of the different control algorithms. For dynamic, interactive approach we refer to Guzmán et al., (2014).

In *Sysbook*, but also separately available there are some Java files, where dynamic behaviour of processes or of control systems can be investigated actively by the user. E.g. Fig. 11 shows the surface of the Java applet analysing the behaviour of YOULA parameterized control. The reader can set the process, its model (which may differ a bit from the process), the separation of the process to cancellable and non-cancellable parts, can give the filters, and then running the program can analyse the dynamics of step reference tracking and disturbance rejection of the control system.

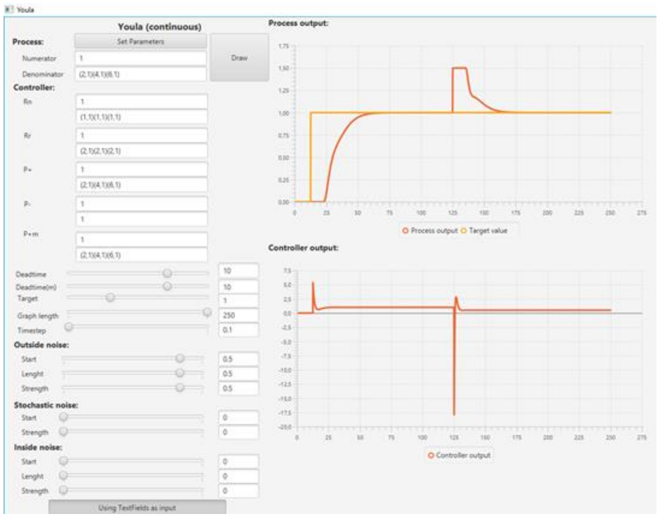

Fig. 11. Interactive analysis of YOULA parameterized control running a Java applet

7. SIMULATIONS IN MATLAB/SIMULINK

MATLAB is an interactive environment for scientific and engineering calculations, simulations and data visualization. MATLAB provides strong background to solve mathematical and engineering problems related to matrix algebra, differential equations, etc. The basic set of MATLAB operations can be extended by powerful *toolboxes*, such as *Control Systems Toolbox*. The graphical surface of SIMULINK provides possibilities to modelling and simulating of processes. MATLAB computer laboratory exercises provide better understanding of systems and control topics. As an example Fig. 12 shows the SIMULINK block diagram of YOULA parameterization. Running it the behaviour of this control can be evaluated.

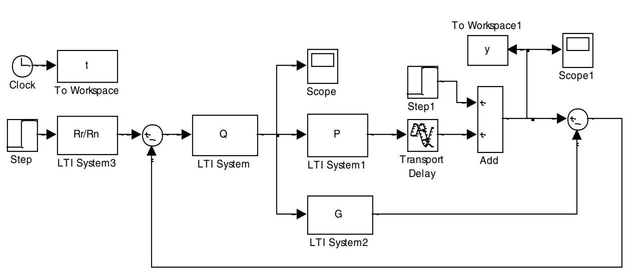

Fig. 12. SIMULINK diagram to analyse YOULA parameterized control

8. CASE STUDIES

In *Sysbook* several case studies show the application of system view (see also CSS IEEE, 2014). In the different examples it is investigated, what is considered a system, how is the system connected to its environment, what are the input signals and what are the output signals? How can the model of the system be built? What are the requirements set for the system? Which balance and energy considerations have to be applied? Can we control the system? How to control the system?

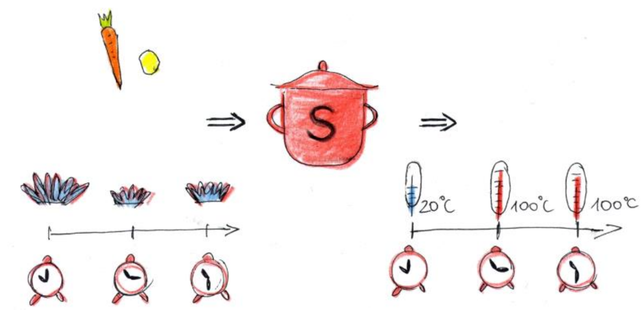

Fig. 13. Input-output model of the pot used for cooking soup in the cooking case study

Two case studies are dedicated for everybody, about *driving a car* and *cooking* (Fig. 13.). Systems and controls in technological processes as energy production and distribution, oil refinery are discussed. System view is shown considering the living body and health control. Some aspects of system view in economical systems and the importance of feedback in education are also analyzed.

9. STUDENT AREA IN SYSBOOK

Considering the OCD Open Content Development approach the students can contribute to the content of *Sysbook*. They can develop their own contents related to systems and controls they are familiar with. After a review this area can be supplemented with new materials. Till now some examples are temperature control of a terrarium, speed control, model of the blood circulation and the respiratory system, the model of building a house, etc. (Fig. 14).

Fig. 14. Systems appearing in the student area

Acknowlegment

This work was supported partly by the Open Content Development Research Group of Hungarian Academy of Sciences at Budapest University of Technology and Economy

References

Albertos, P., Mareels, I. (2010). *Feedback and Control for Everyone.* Springer.

Åström, K.J., Murray, R.M. (2008). *Feedback Systems: An Introduction for Scientists and Engineers.* Princeton University Press, http://www.cds.caltech.edu/~murray/books/AM05/pdf/am08-complete_22Feb09.pdf

Benedek, A., Horváth, J. Cz. (2016). Case Studies in Teaching System's Thinking. *11th IFAC Symp. on Advances in Control Education, ACE'2016*, Bratislava, Slovakia, Preprints, (ed. M. Huba and A. Rossiter), IFAC-PapersOnline, Vol. 49 Issue 6, pp. 286-290.

CSS IEEE *Control Systems Society*, The Impact of Control Technology (2014). ISBN: 978-0-692-24262-9 http://ieeecss.org/general/IoCT2-report

Guzmán, J. Luis, Hägglund, T., Åström, K. J., Dormido, S., Berenguel, M. and Piquet, Y. (2014). *Understanding PID design through interactive tools*. 19th IFAC World Congress, Cape Town.

Hetthéssy, J., Bars, R., Barta, A. (2014). *Szabályozástechnika, MATLAB Gyakorlatok* (in Hungarian) (*Control Engineering: MATLAB Exercises*) Viking Zrt.,VI 201-040

Keviczky, L., Bányász, Cs. (2015). *Two-Degree of Freedom Control Systems, The Youla Parameterization Approach*. Elsevier, Academic Press

Keviczky, L., Bars, R., Hetthéssy, J., Barta, A., Bányász, Cs.: *Control Engineering*. Széchenyi University Press, 2011.

Vámos, T., Bokor J. (1996). Bird's eye view on control theory - motion, spaces, transformations. *13th IFAC World Congress*, San Francisco, USA, pp. 105-115.

Vámos, T., Bokor J. and Hangos, K. (1999). Systems - governing principles and multimedia /CD/. *14th IFAC World Congress*, Beijing, China, PT-5, p. 79. Plenary lecture.

Vámos, T., Bars, R. and Sik, D. (2016). Bird's Eye View on Systems and Control – General View and Case Studies. *11th IFAC Symp. on Advances in Control Education, ACE'2016*, Bratislava, Slovakia, IFAC-PapersOnline Vol. 49, Issue 6, pp. 274-279.