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ADVANCES AND CHALLENGES IN CONTROL EDUCATION

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Abstract- Control Engineering is the engineering field that deals with the modeling of dynamic systems and the design of controller or regulatory set-ups that will cause those systems to behave according to some desired specifications. The advancements in technology, the development of sensors, activators and suitable IT tools are the main factors that made autonomous systems possible. In view of these developments control education must be revised and reshaped to meet these requirements and also must be adapted to meet the challenges posed by new fields which require application of control.

Keywords: Classical Control, Modern Control, Project Based Learning, Subspecialties in Control Applications.

I. INTRODUCTION

Control systems are used almost everywhere in our modern society, in homes, in cars, in electrical and electronic appliances, in transportation systems, in industry, in manufacturing processes, in power generation, in computer systems, in telecommunications, and many other emerging application areas but in general those control systems are invisible to the user and the general public.

To give a few examples electrical home appliances like the refrigerator, the dishwasher, the clothes washer and dryer, the hot water heater operate with automatic control principles. Similarly electronic devices like the television set, the radio, the CD and DVD players contain automatic controllers in their circuitry. We do not see the control systems in those home appliances but we observe the results of automation in their functioning.

Our cars are equipped with a variety of automatic controllers the most familiar one to the general public being ABS brakes. Speed controllers, fuel and exhaust controllers, vibration controllers in the car are known but usually not seen by the user unless the user wants to act like an amateur mechanic.

If we examine living organisms we can realize that there are many biological control systems that regulate the movement of limbs, the circulatory system, the metabolism, the respiratory system, the body temperature and various other bodily functions. Almost all diseases are the result of failure of those automatic biological controllers.

These few examples justify the need to include control education in the curriculum of electrical & electronic engineering, of mechanical, mechatronic and automotive engineering, manufacturing engineering, chemical engineering, aviation and aerospace engineering as well as in life sciences programs like biomedical engineering, biotechnology and bioengineering, and lately in financial engineering and some social sciences like economics, psychology and sociology.

II. HISTORICAL DEVELOPMENTS

Although some primitive but ingenious automatic controllers, like the water clock, date back to antique eras perhaps the first feedback controller was the temperature regulator of an oven designed by Cornelius Drebell around 1620, while the first industrial automatic feedback controller was Watt's speed governor, designed in 1788 for the speed regulation of the steam engine. It was a mechanical controller operating with the principle of centrifugal force thus opening or closing the valve that fed steam to the engine. Later in 1868 Maxwell published his book "On Governors" which presented a formal analysis of dynamic systems. In 1878 independently Ruth and Hurwitz analyzed the stability of control systems and their work is now known as the Routh-Hurwitz stability theorem.

It was during the World War II that control theory found important applications in fire-control systems, guidance systems, aviation and electronics. Immediately after the war, "Servomechanisms" was introduced as a compulsory course in electrical and mechanical engineering programs. In Turkey the "Servomechanisms" course was first introduced in 1951 at the Istanbul Technical University in the electrical and mechanical engineering programs, while a year later a similar course was included in the electrical engineering program at the American University in Istanbul known as Robert College, which later was nationalized and is now called Bogazici University, Istanbul, Turkey.

In the 1950's almost every university had developed at least one or two courses under the titles "Control Theory", or "Control Systems", "Feedback Control", "Automatic Control Systems" and even "Stability of Control Systems" a course based on Lyapunov stability theorem, the Nyquist stability criterion and the Bode plots for feedback systems. Also in electronics and communication courses the Wiener-Kolmogorov filter developed in 1941 was included in the course materials. All those courses were in the category of "Classical Control".

Later a course on "Linear Control Systems" was the standard introductory course which dealt with time and complex s-domain analysis of systems and required a thorough background in mathematics and Laplace transforms and frequency domain interpretations. Usually those courses were confined with the analysis of single input-single output (SISO) linear systems.

In September 1957 the International Federation of Automatic Control (IFAC) was founded as a multinational federation of National Member Organizations (NMOs), each one representing engineering and scientific societies concerned with automatic control in its own country. Turkey joined IFAC in 1958 its NMO being TOK (Turk Otomatik Kontrol = Turkish Automatic Control), which is very active in organizing the yearly National Conference on Automatic Control, as well as several IFAC workshops, regional conferences and international symposia.

Then came the 1960's when the space exploration race between the United States and the then Soviet Union – which in October 1957 had already placed Sputnik in an orbit around the World- fueled the developments in control theory giving rise to approaches which make up the "Modern Control Theory" which utilizes the time-domain state-space representation of control systems where the mathematical model of the physical system, with the inputs, the outputs and the state variables of the plant are related with a set of first order differential equations. The state space method is suitable for the analysis of multiple input-multiple output (MIMO) systems as well as for (MISO) and (SIMO) systems.

In this period we have impressive developments in control theory: the work on Optimal Control by Hamilton, Jacobi and Bellman in 1957, the theoretical contributions on the calculus of variations by Euler. Lagrange and Pontryagin in 1962 for minimal energy optimal system design and of course the Kalman filter introduced in 1961 which gave rise to new controller structure as well as new state feedback and feed forward generators. In the same decade we have the contribution of Ragazzini who introduced digital control and the use of the z-transform for the analysis of discrete time control systems.

From the early 1960's the theoretical works mentioned above were formulated as formal courses in the curricula primarily of electrical & electronic engineering and mechanical engineering programs. Courses entitled "Modern Control Theory", "State Space Analysis of Dynamic Systems", "Optimal Control", "Digital Control", "Multivariable Control", "Discrete Time Control Systems", "Design of Linear Control Systems" and surprisingly courses on "Analysis and Design of Nonlinear Control Systems" were taught in many universities both in the United States and in Europe. Turkey introduced those courses in the early 1970's with a delay of a few years only.

The following years in the 1970's and the 1980's a variety of subspecialties like nonlinear control, fuzzy control, stochastic control, computer based control, intelligent control, adaptive control, Model Predictive Control (MPC), Linear-Quadratic-Gaussian (LQG) control, machine learning, application of evolutionary and genetic algorithms to control dynamic systems had tremendous impact on the design of control systems.

Universities took the challenge and started courses related with those specialties and developed research programs for application of these new approaches and techniques to power plants, robotics, aerospace and aviation, process control, building automation, computer systems, computer games, mobile phones, biomedical prostheses and devices and even global enterprise and finance control.

III. DILEMMAS IN TEACHING CONTROL

The historical development of control systems resulted in a transition from teaching the theory of servomechanisms to the theory of automatic control, which basically consisted of converting experience into fundamental principles. The control courses abandoned the engineering descriptions of practical methods of analysis and design in favor of mathematical presentations of formal system models which, using some necessary simplifying assumptions, are obtained based on the physical characteristics and the input-output relationships of the individual system components, taking into account the loading effects resulting from the particular interconnections in the system structure.

This transformation in the teaching of control engineering using the available technologies can be summarized as follows: control theory requires a solid background in mathematics, must take advantage of computing and communication facilities and apply the developed control methods to the plant whose behavior is desired to comply with some given specifications.

With such sophisticated theoretical and technological demands the dilemma facing control educators is "what to teach" and "how to teach it".

Experience shows that students learn most readily by proceeding from the specific to the general; by analyzing, solving and designing simple control systems before tackling more complicated and more complex problems. It is with this understanding that a logical control teaching strategy will be to start perhaps in the second year of the university program with control system analysis and design methodologies using classical control. The scope of classical control is limited to SISO systems. The system is represented by a simple differential equation which is readily transformed to the complex s-domain by Laplace transformation and by the substitution $s = j\omega$ can also be expressed in the frequency domain. The entire control system can be represented by a block diagram where the feedback and the feed forward braches are shown and blocks are used to show the plant, the controller, the transducers and other possible physical devices.

The performance specifications are usually given in time domain and/or frequency domain, which certainly have physical meaning and can be easily understood by the students. Time specifications for the unit step response like delay time, rising time, peak time and settling time as well as amplitude specification expressed as the maximum overshoot, are easy to visualize and to simulate using MATLAB or SIMULINK.

The stability analysis is performed in the frequency domain using Bode plots utilizing the concepts of gain margin and phase margin, or by the Nyquist plots. In the complex s-domain stability can be checked using the Routh-Hurwitz method. The change of the location of the closed loop poles as a system parameter varies can be tracked using the root-locus method again by making use of MATLAB.

All these methods and tools render easier physical implementation of classical controller designs as compared to systems designed using modern control methods. Although classical controllers require in general on-site tuning due to modeling and design approximations nonetheless they are preferred in industrial application, the most common controllers being the PID controllers and the lead and lag compensators.

After this introductory course, in the third year of the program, a course on modern control theory can be taught provided the student has taken a linear algebra course in mathematics. In modern control formulation any MIMO plant is represented by the system matrix, the state variable vector, the input and output matrices and the vectors of inputs and outputs. In general it is a set of first order differential equations in matrix-vector form where usually the state variables may not correspond to the physical variables. However this formulation is perfectly suitable for computer implementation and computer simulations for design purposes. Again the course must be supplemented with design assignments for which MATLAB provides a rich alternative of tools.

Next a course on digital control can be included in the curriculum which can be treated both in the z-transform domain using classical methods and in parallel in modern control formulation where the mathematical model of the control system is given as a set of first difference equations. The analysis and design methodologies of discrete time systems are conceptually quite similar to those for continuous time systems but they differ due to the time discretization. Programmable Logic Controllers (PLC) are extremely suitable for digital control studies.

Finally in the fourth year a course on optimal control may be included in the curriculum. More specialized courses can be incorporated to the curriculum of a particular program according to the requirements of the field. In the aeronautics program flight control, in the mechatronics program robot manipulator control, in the biomedical program biological control systems are examples of specialized control courses directly relevant to the field of study.

Whichever courses are chosen for undergraduate students in control programs, those courses must be supplemented with either a laboratory component emphasizing design experiments or directly by a design project assignment. The aim of the project is to bridge the gap between the scientific knowledge and the solution of practical industrial problems that the students may face during their careers. The ultimate project should be a realistic design problem which may present difficulties and give rise to delays and frustrations like in real life.

IV. THE CHALLENGE OF THE SUBSPECIALTIES

The remarkable advances in control theory until ten years ago appeared to be far beyond any practical application. However in the past few years we have witnessed the application of many theoretical findings in a variety of subspecialty fields like physics, biology, ocean engineering, transportation systems, computer systems, mobile communication, medication dosimetry, olfactory applications, food control, psychology and economics to name a few.

These emerging fields for control application obviously require deep knowledge in the specific area, broad knowledge of neighboring fields but most important they require special courses in control engineering which will address the control problems using notations appropriate to the field and which will present the necessary theoretical knowledge through examples relevant to that field. In a joint control course offered to electrical and mechanical engineering students the instructor will certainly notice the dissatisfaction of one group of students when the example treated in class is from the discipline of the other group, in spite of the fact that no specialized knowledge is necessary to relate to the concepts, the notation, the models and the physical rules of the other field.

Another challenge is that many applications in those emerging fields require the design of complex networked systems or embedded systems which use different sensors and actuators. As a matter of fact the variety of sensors developed lately is truly remarkable: electrical, electronic, mechanical, optical, chemical, thermal, biological, gas, taste and odor sensors and wearable sensors. Every new field and every new application has now commercially available sensors and actuators. The whole process of educating control engineers in those areas has changed dramatically from the traditional way of teaching control theory and engineering.

V. CONCLUSIONS

The advances in control theory, the needs of automation in various applications and the availability of advanced technological tools like computational facilities, appropriate software and simulation programs, networked embedded systems, suitable sensors and activators are the factors that keep control engineering among the vital, dynamic and expanding fields of engineering.

In particular the need for autonomous systems has driven control engineering to develop more advanced adaptation algorithms and learning mechanisms, to incorporate reasoning, to accommodate cognition facilities and take precautions for safety by creating back-up systems, diagnostics and reconfiguration capabilities.

Many manufacturers of control system components and instruments realizing the need for specialized training have started online certificate courses for their control systems and instrumentation. This kind of auxiliary inputs and training courses will certainly help in educating the future control engineers.

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BIOGRAPHY

Yorgo Istefanopulos was born in Istanbul, Turkey, on February 28, 1944. He received the B.Sc. degree from Robert College (Istanbul, Turkey), the M.Sc. and the Ph.D. degrees from Massachusetts Institute of Technology (MIT, MA, U.S.A.), all in Electrical Engineering, in 1967, 1969, and 1972, respectively. He was a faculty member of Bogazici University (Istanbul, Turkey) from 1972 to 2005, where he was for many years the Chairman of the Electrical and Electronic Engineering Department, from 1985 to 2005 the Head of the interdisciplinary Graduate Program of Systems and Control Engineering and from 1994 to 2005 the Director of the Graduate School of Biomedical Engineering. He was then appointed Dean of the School of Engineering at Isik University (Istanbul, Turkey) where he served from 2005 to 2012 and presently he is the Senior Advisor to the Rector.