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Undergraduate Control Education: Theory and Practices

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Abstract:. The paper present control theory courses and laboratory practices which may be useful in reorienting undergraduate course structure. Generally, undergraduate control courses are offered to various disciplines such as electrical,mechanical,electronics,communication,chemical,aerospace and mechatronics. As per the need one, two or three courses are offered at some universities. For a specialized discipline such as instrumentation and control , more courses are offered with inclination towards industrial controls like Programmable Logic Contollers (PLCs) and Distributed Control System (DCS). The work proposes a course structure which represent content useful for all the disciplines. The content may be covered in more than one courses. The paper assumes that, before the first course of control is introduced, students' have cleared courses of physics for basic laws of motion and mathematics which deals with differential equations and its solutions. The work presented also discusses use of computational and simulation tools to support theory as well as laboratory. The paper presents control laboratory practices which may be incorporated as a separate module.

1. INTRODUCTION

The Control theory and technology has seen significant growth in last few years. There has been a remarkable development in the field of computer architecture and industrial computers along with the development in sensor and transducer technology which are used as a feedback elements in closed loop control implementation. The computer and networking technology has made it possible to use interactive simulation tools for control education in theory as well as in laboratory. There is an increasing trend towards computer based simulation and experimentation. Hence, there is a need to review and reorient the control courses being offered at various universities. It is desired that the broad category of process control and motion control systems should be clarified for their different performance requirement and constraint such as process lags and delays. Generally, the control course deals with introduction to systems and its classification, system representation, system reduction,analysis for performance, compensation for desired performance and stability analysis (I.J.Nagrath and M.Gopal,2005). At next level, the course that deals with modern control approach based on state variable modelling, analysis and state variable feedback for continuous time and discrete time, is normally offered (C.T.Chen,2001,K.Ogata, 2001). The digital control system, multivariable control theory, nonlinear control system analysis and design,optimal and robust control, systems theory and modelling of systems are generally offered at graduate level.

The paper proposes course structure for the undergraduate control theory and laboratory practices. The section 2 covers proposed course structure with associated laboratory sessions. The conclusion and discussion is presented in section 3.

2. PROPOSED COURSE FOR UNDERGRADUATE CONTROL

This section presents possible course content which may be considered for undergraduate control teaching. The unit wise presentation style is chosen for easy reference.

2.1 Contents for Undergraduate Control Course

Unit 1:

Introduction to systems such as electrical, mechanical, hydraulics, pneumatic, biological and thermal with their basic elements, interconnections and laws governing dynamics of theses systems. Classification of systems as linear –non linear,continuous time-discrete time, stochastic-deterministic, time varying–time invariant, lumped parameter–distributed parameter, single input single output (SISO) and multi input multi output (MIMO). Illustrative examples of such systems and components with nonlinear and time varying behaviour may be cited. The difficulties in dealing with these elements may be discussed with electronic and computer solution for such systems may be shown at beginner's level (T.Kenjo,1990). Some physical systems which demonstrates stable and unstable behaviour may be cited such as magnetic levitation and inverted pendulum under influence of disturbance in open loop cases.

Unit 2:

Linear systems and their properties, mathematical modelling of system such as spring-mass-damper for quarter car model (Lundberg, Miller et al, 2007), light intensity control model (Techno Instruments manual, 2006), oven (Techno Instruments manual, 2006), dc motor, magnetic levitation of a steel ball, disc drive servo, satellite altitude control (Franklin et al, 2005) and power electronics converters may be considered as case studies. To address nonlinearity problem, linearization process can be elaborated at this stage. Transfer function models with restrictions of initial conditions can be obtained for the systems described above. It may be emphasized that dynamics of actuators and feedback elements may also be taken into account for over all transfer function. The students can get the feel of higher order system in over all transfer functions. The characteristic polynomial and equation with pole-zero map of the transfer function may be explained.

At this point, it may be noted that detailed block diagram reduction and signal flow graph reduction techniques may be avoided. One or two introductory session should be sufficient for these topics.

Unit 3:

Transient response and steady state response of the system of the first, second and third order systems for peak overshoot, rise time, peak time and settling time along with steady state error. Here, the system may be analysed for various test inputs such as impulse, pulse train, step and ramp. The limitations in removing steady state errors may be highlighted in some cases. The limiting value of the gain for transient performance and stability trade off should be demonstrated with suitable examples. Effect of dominant poles may be covered for higher order systems. Computer simulations using MATLAB® where impulse, step, and lsim command may be used which provide better visual effects while obtaining transient and steady state behaviour. (MATLAB® user manual 2002, Control System Toolbox user manual 2002). The sensitivity analysis can be carried out next.

The above mentioned process may not need R-H criteria but still as an analytical technique for finding absolute stability and range of K, it may be mentioned for information only.

Unit 4:

Analysis and compensation using root locus method. Introduction with rules may be given and few case studies may be taken. If computational tools are available roots can be computed using single command roots(p) where p represents characteristics polynomial, in MATLAB®. Entire root locus can ploted using a rlocus command and gain values corresponding to root locations can be readily obtained with corresponding transient response specifications But, it is essential that the student do learn analytical process of computing roots, numerical techniques and limitation there in. This method of analysis provides guideline on gain values for stability as well as for transient performance graphically; it may be presented rigorously covering all points.

Unit 5:

Frequency response analysis can be covered in this unit with emaphasis on correlation between time response and frequency response, polar plots, Nyquist plots, Bode plots for relative stability analysis and Nichol's plot for closed loop analysis from open loop response data. Additionally, bode plots may be exclusively used for compensator design to meet the performance specification. These topics may be covered along with emphasis on design for given specifications. Here, graphical simulations and interactive performance analyser with the help of computer can be very useful for quick results on obtaining values of performance specifications.

Unit 6:

Structure of the various controllers can be discussed starting with on-off, proportional, proportional-integral, proportional, integral and derivative controller with anitwind up strategies can be covered. The effects on transient performance, steady state response, relative stability and suitable case for each controller may be discussed. Variants of these controllers and tuning methods may be covererd with emphasis on auto tuning.

Unit 7:

This unit may briefly introduces an alternate approach of modern control that deals with concept of states, state variables and state variable modelling with notions of controllability and observability. Limitations of classical control can be discussed with reference to modern control approach. Solutions of the state equations and State variable feedback may be introduced with basic pole placement algorithm. This concept can extended for discrete time and digital system.

Unit 8:

This unit may briefly introduces concept of discrete time systems and digital systems, difference equation models and solutions. Mapping from s plane to z plane, z-transform, modified z-transform and inverse z-transform may be covered. Stability of the discrete time and digital systems may be analyzed using bilinear transformation.

Hence, the proposed content may be divided in to three courses which may provide complete background for graduate study in controls. It may become essential to provide the proposed minimum content to all discipline as applicable.

2.2 Laboratory Session

In this subsection, laboratory experiments related to the course is being proposed. It may include demonstration of the system and performance on laboratory type system model.

Lab 1:

Examples of systems with open loop and closed loop configurations may be exposed to the students. Demonstration of dc motor speed control system, dc motor shaft position control system (Techno Instruments manual, 2006), temperature control of a small oven, light intensity control system and stepper motor controls in open loop with fixed set of pulses under load and no load conditions with encoder feedback in closed loop may be useful examples for undergraduate course. In this session, students may be asked to study the complete system architecture with all interconnect components, both electrical and mechanical. The frictional and inertial parts may be separated for understanding purpose. The need for rapid acceleration and deceleration, hence for servo system may be emphasized.

The feedback elements along with their transfer functions can be clearly demonstrated for these systems. Light intensity control system demonstrates relatively faster response for obvious reasons which may be discussed. The dynamic response of its sensors, i.e. light dependent resistor, can also be observed as function of distance from the source. The lag is generally negelected. Semiconductor temperature transducers provide linear and fast dynamic response when used as a feedback element in temperature control of small laboratory type oven.

The potentiometers as feedback element does not show any lag for position information when coupled to the shaft of the motor. It does provide friction and reflects gradual change in system parameters over a period of time. It also exhibits jumps in output voltage or no response for some inputs , due to weared contacts. For motor systems, dead zone can be obtained as inherenrt nonlinearity in the closed loop which may be compensated electronically.

Some times, it is useful to demonstrate the method for separating two time constant in case of motors. By removal of applied known voltage motor stops due to friction and inertia which contribute to the mechanical time constant of the motor. The electrical constants can be measured from the electronic meters or may be obtained by subtracting mechanical time constant from averall time constant (P.C.Sen, 1989). The tachogenerator speed v/s output voltage characteristics may also be obtained for design of speed controller for dc motor.

Lab 2:

Second session in laboratory may generally deal with control components. In such experiments, potentiometers and synchros are studied as positional error detectors for servo systems. The linearity of the components may be used in selection of analog controller gain and for digital algorithms if digital controllers need to be implemented. Some times speed-torque curves for dc servomotor and ac servomotors are obtained and information thus obtained may be used for further computations of motor constants and experimental plant model.

Lab 3:

An electronically simulated system with operational amplifiers of first order, second order, type 0 and type 1 can be analysed for impulse, step and ramp response as well as for steady state errors. Results obtained here can be confirmed with theory. At the same time, it may be demonstrated that, plant model may be obtained from the captured transient response data using storage scope.

Lab 4:

Transient performance of dc servomotor speed control, dc servomotor position control , temperature control of an oven, light intensity control system can be obtained by changing controller gain and feedback path gain. Effect of proportional, PI controleller and PID controller can be observed on output of the system. Effects of load disturbance can be observed with and without feedback in these cases. These experiments can be extremely useful in understanding the concepts of the feedback control system.

Lab 5:

Transfer function of all the plants are obtained experimentally from captured dynamic response. A beginners' level system identification may be explored to get the plant parameter and compared with analytically obtained model. Validating the model may be significant contribution in the laboratory sessions. The performance of low inertia and high inertia systems may be compared for the interesting exercise.

Lab 6:

During this unit, Digital transducers such as encoders (E.O.Doebelin et al,2007) and proximity sensors can be studied for their characteristics. These may have a characteristics with ideal on-off or with hysteresis which may compensated for in hardware and software. The Digital implementation of the control algorithms, converter interfaces and their limitations may be elaborated. The implementation may use microprocessors, computers with capability of real time interfaces. Specifcally, switching type controllers (B.Bandyopadhyay and V.K.Thakar,2004) may be implemented and effectiveness can be demonstrated with an example of stepper motor control (Kenjo and Akira, 2000). This lab module can also incorporate separate experiments on existing analog to digital and digital to analog conversion techniques for comparision of sample and hold effects and conversion time. This may help them in chosing appropriate converters for fast process and slow process.

The small stand alone laboratory type hardware setups are strongly recommended. There exist several computational software for example MATLAB® from Mathworks and LAB view® from NI a which can offer complete package for block level and code level simulations for most of the control related problem along with interface to small system models. It ranges from modelling to design and interactive results with analysis. It is also possible to develop custom make experimentation set up with these and other tools those may exist. Computational and conversion delay effects can not be ignored for fast processes. They may be used at graduate level for research and development. These tools may be used at undergraduate level for introduction of the theory and practices in an interactive way.

3. *DISCUSSION AND CONCLUSION*

In the above sections the details of the course content for undergraduate control course for theory and practices have been presented. With the existing computers having tremendous computational power, interactive graphical simulation tools with real time capability, theory and laboratory can be easily correlated. The earlier days time consuming methods for calculating roots, ploting root locus on graph, bode plots may be carried out quickly with few sets of commands. At the same time use of simulation tools forces to understand the numerical computation methods involved while command is executed and result is obtained. Of course, performance specifications are more readily and accurately obtained. This may further lead to online computation and reconfiguration of control law in general.

Hence, the paper suggest undergraduate course in control with extensive laboratory support. It has been proposed that the basic control philosophy can be made clear with careful design of the courses. The extensive use of computers can help in making the conventional methods, during class room teaching, concise such as Transient response analysis, R-H criteria, Root locus, Bode plots and Nichol's plot and design methods. It has also been pointed out that exhaustive sessions on block diagram reduction and signal flow graph reduction methods may be overlooked. Additionally, it is observed that discrete state space modelling; analysis and design are obvious choice for computer implementation of controllers. Hence, when plant is continuous, analysis, design and comparison of digital controller should be carefully carried out in theory as well as in practice.

Thus, it may be noted that all the units need to be covered; it requires at least three courses along with two exhaustive laboratory sessions for complete understanding of control philosophy at undergraduate level.

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