Educating Undergraduate Chemical Engineers in Process Control Using a Real-time Approach

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Summary

This article describes the successful and revolutionary real-time approach to the education of undergraduate chemical engineers in the fundamentals of process control, i.e. teaching process control in the same way that process control is practised/implemented in the chemical and processing industries.

Introduction

The classical approach to process control education of chemical engineers has been to employ the frequency response methods of process control that were originally developed as pen and paper methods for the modeling of process systems. It has been evident for some time that the way process control is taught to chemical engineers needs to be updated.

There is an academic requirement that the fundamentals of process control be taught in a more practical and concrete way than afforded by the traditional classical approaches. It has been recognised for some time that chemical engineers trained in process control by a strict classical approach require almost complete re-education in process control when they are employed by industry. Brisk and Newell [1] recommended training students "in how to utilise process control systems with just enough theory that they can understand what they are using and maintaining". And they went on to lament that "unfortunately most of our institutions are teaching too much theory, very little on utilisation and maintenance". Doss [2] comments that "students tend not to retain the mathematical theory but to remember the experiences from control laboratory experiments and simulations". Ramaker et al. [3], point out that "an undergraduate in a chemical engineering curriculum [studying] process control should be taught using concepts that fit with the rest of chemical engineering education … maintaining the undergraduate curriculum as closely tied as possible to the time domain".

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There is also an industrial imperative to teach material that is of use to the practising engineer. Downs and Doss [4] note that “what the [graduating engineer] needs is a base level understanding of differential equations, process dynamics, dynamic modelling of basic unit operations, basic control algorithms (such as PID), cascade structures and feed forward structures. With these basic tools and an understanding of how to apply them he can solve most of his control problems himself. What he does not need is the theory and mathematics that usually surround process control”. The industrial imperative is further reinforced by the comments such as the following that arise from practising Chemical Engineers working in process control or process operations [5]:

- “I never made use of Bode plots or root-locus when I was designing a control loop”
- “There are no transfer functions out there in the real plant”
- “The material I had been taught was of no use in commissioning a control loop”

Process control education clearly needs to do better.

The Classical Approach

Classical Control methods were developed between the 1940’s and the 1960’s in the mechanical and electromechanical engineering disciplines. Given the limitation of computer hardware and software at that time, it was impractical to solve large numbers of higher-order differential equations. Furthermore, since mechanical and electromechanical systems are typically linear and possess little dead time, they lend themselves to analytical and graphical techniques. Hence the development and popularization of analytical and graphical such techniques as:

- Transform methods (Laplace and Fourier Transforms)
- Graphical frequency domain methods (Bode, Nichols and Nyquist)
- Root locus analysis.

Given the fit to their purpose, classical control techniques still prevail and remain relevant in these engineering disciplines today.

Although these methods make up almost half the content of standard control texts, these methods all share a number of deleterious characteristics. They all require a substantial amount of applied mathematics. In spite of the high level of mathematics required, in order to apply the analysis, the system must first be made linear and the methods have a transfer function basis, focus on individual units and are generally good only for single loops and PID control. Limited multivariable and no plant-wide controls are possible.

Beyond the engineering deficiencies of classical techniques, there are implications from a teaching and learning perspective. The abstraction of classical methods makes a difficult subject more difficult, and the methods lack physical meaning, obscuring the central problem of how to modify the system in order to achieve control [5]. These methods are also not suited to "what if" studies such as determining loop performance with parameter variation.

The ready availability of hardware and software now has called into question the relevance of these classical methods for a primary course on process control. A number of previous workers have also identified this need for change. Many workers in the past decade have incorporated simulation software into the syllabus and deleted previous graphical procedures, but retained the classical methods. However, Brauner et al. [6], and then Stillman [5], Bissell [7] and Ramaker et al. [3], almost simultaneously, all proposed the more radical solution of complete replacement of classical methods with computer simulation, i.e. not as an add on, but as an integral part of the teaching and learning of process control. Ramaker et al. [3], possibly say it best when they say "this doesn't mean that the Laplace transform cannot be used as a tool to solve differential equations in the undergraduate course. Neither does it mean that frequency domain analysis and design are not useful in chemical engineering. It only means that we feel that frequency domain analysis and design should be taught at a graduate level, maintaining the undergraduate curriculum as closely tied as possible to the time domain". In this article we outline and evaluate the actual implementation of such a complete real-time approach to process control education [8].

The Real-Time Approach

Unlike mechanical and electromechanical systems, chemical processes are characterized by high degrees of non-linearity, process interactions, and substantial dead time. Additionally, due to these non-idealities, chemical process control demands to be addressed with a multivariable and plant-wide view. As such, applying classical techniques to chemical process control is a bit like using a wrench to do a hammer's work. In an ideal world, the chemical engineer would have a "virtual plant" on which to experiment. This plant would capture most of the important non-idealities the real world imposes, and would allow the engineer to readily test even the most outlandish of control structures with impunity.

Early attempts to realize this "ideal world" date back to the 1970's and 1980's when dynamic simulators such as DYFLO, DYNSYS or SPEEDUP first became available for the solution of the non-linear differential equations describing process dynamics. However, the hardware was slow at this time, and the software was impractical for students to learn and implement in a reasonable time frame. There was effectively no user interface in that the graphics were poor and the programs were run batch-wise.

However, in today's "simulation-rich" environment, the right combination of hardware and software is available to implement a "real-time" approach to process control education. The hardware and software, such as HYSYS, Aspen Dynamics or MATLAB, is now fast and easy to use. Simple, complex and/or user defined process modules are available and it is now easy to do "what-if" studies, multi-loop and plant-wide control simulations. The software user interface is now graphical and interactive and the software can be painlessly run on a PC. In short, the "virtual plant" has arrived.

This real-time approach also quite naturally lends itself to active, "hands-on" or resource based learning. In our undergraduate course we use of a small number lectures at the beginning of the course to motivate students and provide a fundamental understanding rather than to transmit information and a majority of "hands-on" simulation tutorial sessions on case study projects facilitated by the instructors that we call workshops [8]. The syllabus covers the development of mathematical models to describe the transient real-time response characteristics of basic process elements, capacity and dead time; fundamentals of single input, single output systems; use of a dynamic process simulator; block flow diagram of a feedback control loop; process control hardware; basic control modes; tuning feedback controllers; cascade control; feedforward control; common control loops; distillation column control; design of multiple single loop controllers; plant-wide modelling and control.

We also note that while computer simulations provide generally favorable experiences, real experiments are still necessary and desirable for undergraduates. Therefore we employ in our undergraduate course a cascade of tanks and a heat exchanger in a pilot plant laboratory that allows students to perform process identification exercises on real plant and tune real controllers. So that the undergraduate student understands the underlying "physics" of process control, modeling exercises that require the student to write the describing differential equations and solve them numerically using MATLAB are associated with these laboratory plant experiences.

Student Evaluation

This real-time approach to process education was first developed in 1996 as a text and an associated set of workshops. This version was used at the University of Calgary during the 1997 academic year as a pilot course for nine students as their senior year controls course. Their comments were used and motivated a revised second version of the notes and workshops. This second version was used as a basis for the classes of 1998, 1999 and 2000 at the University of Calgary, totaling forty-five, sixty and eighty students, respectively. A further revision has just been published [8] and was used for the 2001 class of 46 students.

As a means of generating feedback, the students were asked to complete a questionnaire. Overall, the overwhelming majority of undergraduate students preferred the "hands-on real-time approach" to learning process control. More than 80% of the undergraduate students said the approach was clear, concise, useful and applicable. The major complaints, but from a minority of undergraduate students, were that they did not like "hands-on" self directed learning, found the workshops too involved and time consuming and would have preferred a standard course consisting of standard lectures, assignments, quizzes and a written final exam. Our feedback from former students in industry is also overwhelming enthusiastic.

Conclusions

The need for change to conventional process control education was identified. The change that is required is from a classical frequency domain methodology to instruction using concepts that fit with the rest of chemical engineering education, i.e. a real-time approach.

A real-time simulation approach to undergraduate process control education in chemical engineering with the aid of realistic "hands-on" workshops involving real-time simulation of chemical processes was outlined. The workshops are based on fundamental process models of industrial unit operations using educationally affordable and readily available commercial process simulation software.

Student feedback from four years of implementation at the undergraduate level in the University of Calgary evaluated the new "hands-on" real-time simulation workshop approach as effective, useful and applicable.

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