

Teaching Process Control in the 21st Century: What has Changed?

D.E. Seborg, T.F. Edgar, and D.A. Mellichamp

Department of Chemical Engineering
University of California, Santa Barbara
University of Texas, Austin

Abstract

The process control course should continue to be a required course for chemical engineering undergraduates because of its fundamental importance and because a large number of graduates are employed in manufacturing or fields connected to manufacturing. Process control technology has changed considerably during the past 15 years, requiring that textbooks be updated accordingly. In this paper, we discuss some of these changes in the context of revising one of the leading textbooks in process control, "Process Dynamics and Control". Trends that influence how process control will be taught in the future are identified.

1. Introduction

Process control has become increasingly important in the process industries as a consequence of global competition, rapidly changing economic conditions, and more stringent environmental and safety regulations. Process control is also a critical concern in the development of more flexible and more complex processes for manufacturing high value-added products. Furthermore, the rapidly declining cost of digital devices and increased computer speed (doubling every 18 months, according to Moore's law) have enabled high-performance measurement and control systems to become an essential part of industrial plants.

It is clear that the scope and importance of process control technology will continue to expand during the 21st century. Consequently, chemical engineers need to master this subject to be able to design and operate modern plants. An introductory course should provide an appropriate balance of process control theory and practice. In particular, the course should emphasize dynamic behavior, physical and empirical modeling, computer simulation, measurement and control technology, basic control concepts, and advanced control strategies. The process industries have generally embraced digital hardware, and enhanced/advanced control algorithms are widely used, although the PID controller remains the basic building block for feedback control.

Indicative of the changing nature of process control is the plethora of textbooks for process control introduced over the past 20 years (Bequette and Ogunnaike, 2001):

1980's - Stephanopoulos (1984); Seborg, Edgar and Mellichamp (1989).

1990's - Luyben (1990); Coughanowr (1991); Ogunnaike and Ray (1995); Smith and Corripio (1997); Luyben and Luyben (1997), Erickson and Hedrick (1999).

2000's - Marlin (2000); Riggs (2001); Bequette (2003); Seborg, Edgar and Mellichamp (2003); Srvcek, Mahoney, and Young (2000); Chau (2002).

Compared to other core courses in chemical engineering, the textbook market for process control is very fragmented with many competing books. Most core courses such as reaction engineering and thermodynamics have only about four or five textbooks in use at the current time (vs. 13 books for process control).

The authors' textbook (SEM-1), "Process Dynamics and Control", was a reflection of control practice roughly 15 years ago. The first edition was adopted by over 80 universities worldwide and translated into Korean and Japanese. A major revision of this book (SEM-2) will be available in November, 2003. The process of writing the second edition has caused us to re-evaluate in some depth how both control education and control methodology and technology have changed since the mid-1980s. We have added a large amount of new material and removed a number of topics from SEM-1 in order to keep the length of the book about the same, a desirable result.

2. Structure of the Second Edition

The book is divided into four parts, as shown in Table 1. Part I provides an introduction to process control and an in-depth discussion of process modeling. Control system design and analysis increasingly rely on the availability of a process model. Consequently, the second edition includes additional material on process modeling based on first principles such as conservation equations and thermodynamics. A stirred-tank blending system is used as an illustrative example throughout the book, replacing the stirred-tank heating system in SEM-1. The development of dynamic models for other representative processes is also illustrated.

Part II (Chapters 3 through 7) is concerned with the analysis of the dynamic (unsteady-state) behavior of processes. A key issue is the determination of the transient response that occurs after a process disturbance occurs, a grade change is initiated, or a process is started-up or shut down. The Laplace transform and the transfer function are important tools that can be used to characterize the dynamic behavior of linear systems. For many practical control applications, it is not feasible to develop a physically-based, dynamic model. Thus, the important topics of empirical models and their development from plant data are presented. The development of both continuous-time and discrete-time models are considered.

Part III (Chapters 8 through 15) addresses the fundamental concepts of feedback and feedforward control. The topics include the ubiquitous PID controller and an overview of the process instrumentation and control hardware and software that

are necessary to implement process control (Chapter 9 and Appendix A). The important relationship between process design and process control is emphasized, and a new section on process safety has been added. The design and analysis of feedback control systems receive considerable attention, with emphasis on new methods for controller design, tuning, and troubleshooting. The frequency response approach is utilized for the stability and robustness analysis of feedback control systems. Part III concludes with a chapter on feedforward and ratio control. Because interactive computer software allows many calculations to be performed routinely and “what-if” variations (such as controller tuning) to be explored, MATLAB[®] and Simulink[®] are extensively used in examples and exercises.

Part IV (Chapters 16 through 24) is concerned with advanced process control techniques. The topics include digital control, multivariable control, and enhancements of PID control such as cascade control, selective control, and gain scheduling. Up-to-date chapters on real-time optimization and model predictive control (MPC) emphasize the significant impact these powerful techniques have had on industrial practice. New chapters have been added on process monitoring, batch process control, and plantwide control.

3. What Has Changed in Process Control?

There are a number of notable trends that have occurred since the mid-1980s that are relevant for process control education. It is interesting to compare these trends with predictions made by Edgar (1990), which included contributions by 11 other educators and practitioners.

- (1) A modern multi-level view of process control incorporates a variety of activities at different time scales, as shown in Figure 1.
- (2) Increased utilization of simulation software such as Aspen Custom Modeler, HYSYS, or gPROMS makes development of physically-based dynamic models much easier than in the past. Software is also available for developing empirical linear or nonlinear dynamic models from experimental data, e.g., neural nets.

Table 1

Chapter Outline for “Process Dynamics and Control” (SEM-2)

- I. INTRODUCTION TO PROCESS CONTROL
 1. Introduction to Process Control
 2. Theoretical Model of Chemical Processes
- II. DYNAMIC BEHAVIOR OF PROCESSES
 3. Laplace Transforms
 4. Transfer Function and State-Space Models
 5. Dynamic Behavior of First-Order and Second-Order Systems
 6. Dynamic Response Characteristics of More Complicated Systems
 7. Development of Empirical Dynamic Models from Process Data

III. FEEDBACK AND FEEDFORWARD CONTROL

8. Feedback Controllers
9. Control System Instrumentation
10. Overview of Control System Design
11. Dynamic Behavior and Stability of Closed-Loop Control Systems
12. PID Controller Design, Tuning, and Troubleshooting
13. Frequency Response Analysis
14. Control System Design Based on Frequency Response Analysis
15. Feedforward and Ratio Control

IV. ADVANCED PROCESS CONTROL

16. Enhanced Single-Loop Control Strategies
17. Digital Sampling, Filtering, and Control
18. Multiloop and Multivariable Control
19. Real-Time Optimization
20. Model Predictive Control
21. Process Monitoring
22. Batch Process Control
23. Introduction to Plantwide Control
24. Plantwide Control Design Procedures

- (3) Professional software such as MATLAB (especially Simulink) and Excel makes control calculations easy to perform. This advantage has greatly reduced the historical dependence on Laplace transforms as a simulation tool, although such transforms are valuable for analyzing certain properties of control systems.
- (4) Discrete-time models are increasingly used for multivariable control and process monitoring, while continuous-time models are used for PID controller design. Ultimately all control and simulation tasks must be represented in discrete-time form in order to be implemented with digital computers. On the other hand, most control loops are sampled at a high frequency relative to the process dynamics, which allows use of continuous-time control system design procedures.
- (5) Use of time-domain analysis instead of z-transforms has become more attractive for discrete-time systems. Twenty years ago it was deemed necessary to cover many aspects of z-transforms for process control (e.g., five chapters in SEM-1), whereas that material has been condensed to one chapter in SEM-2. The rise in popularity of discrete-time approaches such as model predictive control has largely driven this development.
- (6) Model predictive control is now the multivariable control method of choice. Alternative techniques such as decoupling are still valuable for small problem sizes (e.g., 3x3), but the software for MPC is so powerful and fast for handling problems of large dimension (e.g., 100 manipulated and controlled variables), there is no meaningful alternative.
- (7) Advances in digital hardware and telecommunications are changing how instrumentation is employed in process plants. New technologies such as fieldbus, smart sensors, and wireless transmission have radically changed the economics of measurement and communication in the field. New sensors such as “lab

on a chip” are answering the need for in-situ measurements for new biochemical processes.

- (8) The emphasis on product quality in manufacturing (e.g., six sigma) has increased the reliance on monitoring techniques such as statistical process control.

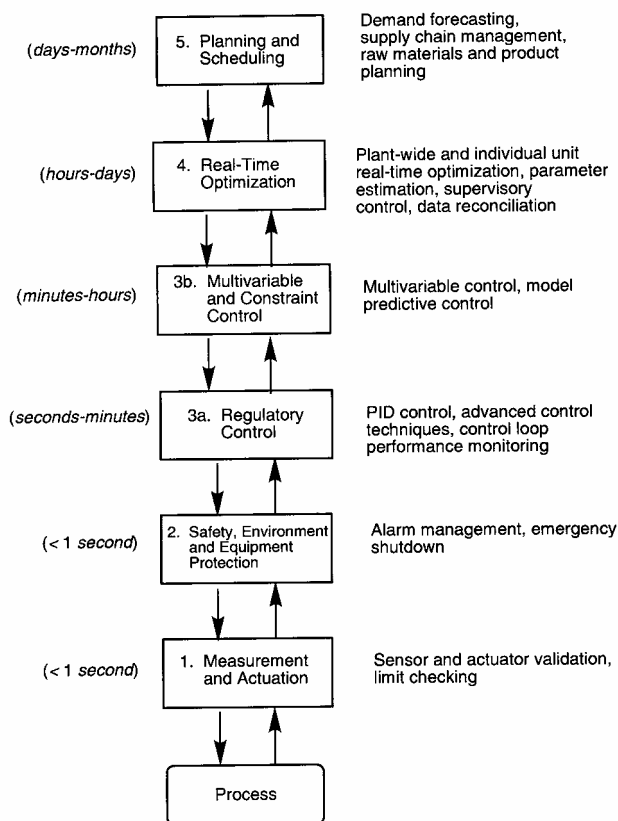


Figure 1. The five levels of process control and optimization. Time scales are shown for each level (Seborg et al., 2003).

- (9) Process safety concerns tend not to fit in the analytic framework that is typical of many process control topics, which means that it may not receive much coverage by process control instructors. The role of safety in process control should be mentioned frequently so that students are aware of its importance vis-à-vis process dynamics and control.
- (10) Batch process control is another under-emphasized topic, much in the same way that batch processing is not emphasized in most core courses in chemical engineering. Discrete logic is heavily employed in batch process control, and it has direct connections to analysis of safety systems and abnormal situations. Current and future manufacturing technologies in semiconductors, nanomaterials, and biochemicals make extensive use of batch processing.
- (11) Plantwide control is another subject that is not covered in many textbooks, and new methodologies for analyzing complex plants are being developed.

Traditional techniques such as RGA (relative gain array), singular value analysis, and MPC are important tools for plantwide control analysis, as are simulation tools to test various hypotheses.

- (12) Within chemical engineering, there is a national movement to incorporate biological science and bioengineering subjects in addition to chemistry and physics into the standard curriculum. As a result, the process control course could place a greater emphasis on modeling biosystems and their dynamic behavior, understanding the natural occurrence of feedback in such systems, and perhaps de-emphasizing of some standard control material, such as tuning PID loops (although feedback and feedforward control will be important).

Relevant to item (12) above, modifying the content in other courses in the chemical engineering curriculum can better build the foundation of process control education. Relevant content could be added as follows:

- (1) More dynamic modeling and operations emphasis in the design course
- (2) Exposure to optimization tools, perhaps in the numerical analysis course
- (3) Covering Laplace transforms and matrix algebra in required mathematics courses
- (4) Adding digital control/data acquisition experiments in junior/senior laboratories
- (5) Requiring statistics coverage in other courses (useful for process monitoring/diagnosis, statistical process control).

These suggestions should not be interpreted as a way to dilute process control as a separate core course but rather to strengthen the background of undergraduate students in the control and systems areas.

5. Conclusions

Process control is an important, rapidly changing field, thus it requires periodic review and updating as a core undergraduate course. In the future, there will be more use of simulation, interactive graphics, optimization, and less emphasis on simple examples with analytical solutions. As a result of growing competitive pressures, all sectors of the process industries will employ better models, sensors, and monitoring and control strategies. Such trends should be reflected in future undergraduate textbooks.

References

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