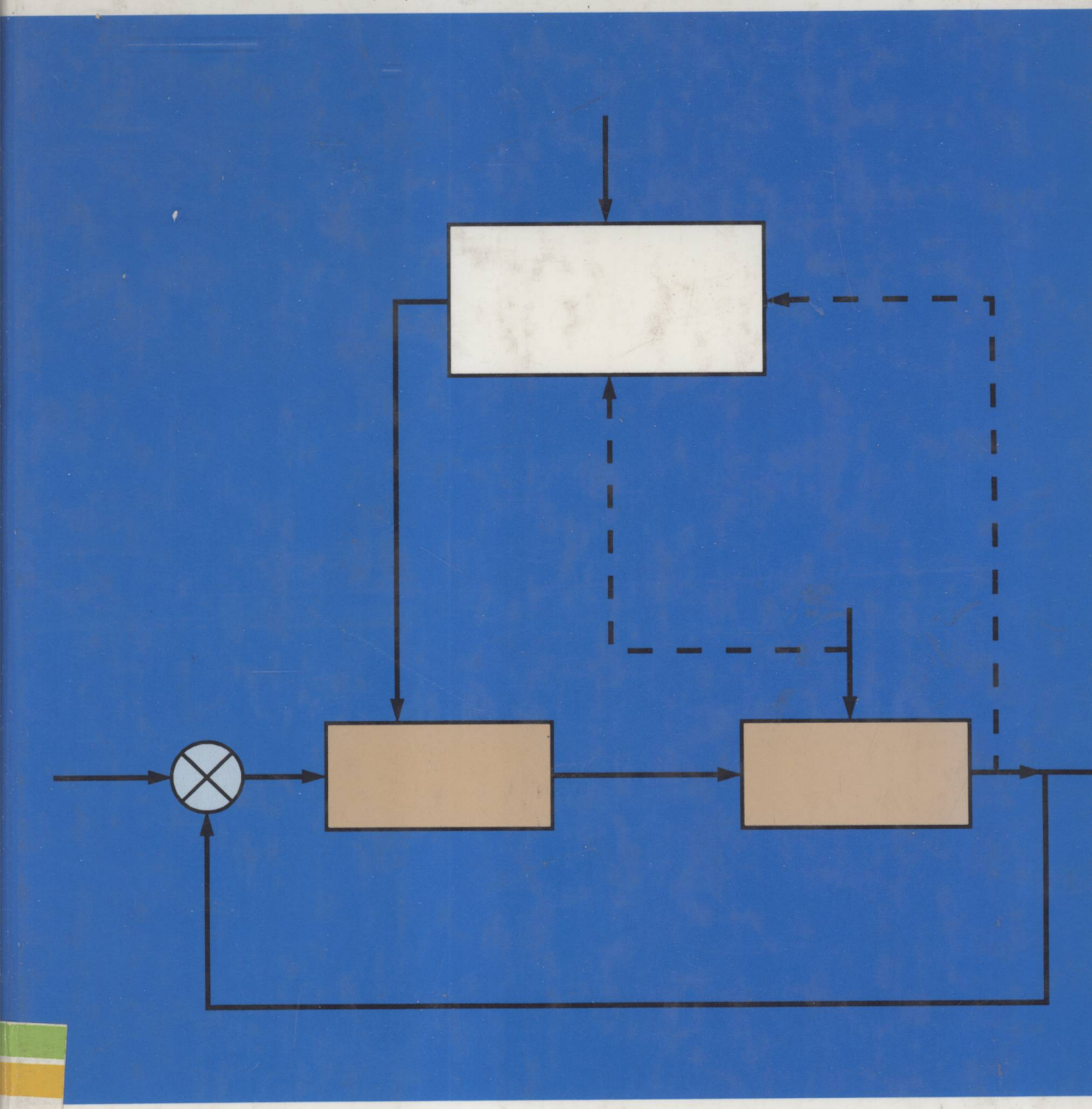
ADAPTIVE CONTROL

By Chang C. Hang, Tong H. Lee, and Weng K. Ho



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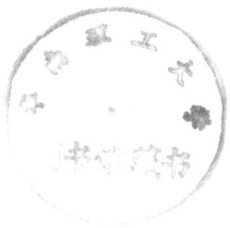

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Adaptive Control

An Independent Learning Module
from the
Instrument Society of America

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PREFACE

ISA's Independent Learning Modules

This book is an Independent Learning Module (ILM) as developed and published by the Instrument Society of America (ISA). The ILMs are the principal components of a major education system designed primarily for independent self-study. This comprehensive learning system has been custom designed and created for ISA to more fully educate people in the basic theories and technologies associated with applied instrumentation and control.

The ILM System is divided into several distinct sets of Modules on closely related topics; such a set of individually related Modules is called a Series. The ILM System is composed of:

- the ISA Series of Modules on Control Principles and Techniques;
- the ISA Series of Modules on Fundamental Instrumentation;
- the ISA Series of Modules on Unit Process and Unit Operation Control;
- the ISA Series of Modules for Professional Development;
- the ISA Series of Modules on Specific Industries; and
- the ISA Series of Modules on Software-Assisted Topics.

The principal components of the series are the individual ILMs (or Modules) such as this one. They are especially designed for independent self-study; no other text or references are required. The unique format, style, and teaching techniques employed in the ILMs make them a powerful addition to any library.

The published ILMs are as follows:

Fundamental of Process Control Theory, Second Edition—Paul W. Murrill—1991

Controlling Multivariable Processes—F. G. Shinskey—1981

Measurement and Control of Liquid Level—Chun H. Cho—1982

Control Valve Selection and Sizing—Les Dreskell—1983

Fundamentals of Flow Measurement—Joseph P. DeCarlo—1984

Intrinsic Safety—E. C. Magison—1984

pH Control—Gregory K. McMillan—1985

Fundamentals of Programming with FORTRAN 77—James M. Pruett—1986

Introduction to Telemetry—O. J. Strock—1987

Application Concepts in Process Control—Paul W. Murrill—1988

Control of Centrifugal Compressors—Ralph L. Moore—1989

CIM in the Process Industries—John W. Bernard—1989

Continuous Control Techniques for Distributed Control Systems—Gregory K. McMillan—1989

Temperature Measurement in Industry—E. C. Magison—1990

Simulating Process Control Loops Using BASIC—F. G. Shinskey—1990

Tuning of Industrial Control Systems—Armando B. Corripio—1990

Computer Control Strategies for the Fluid Process Industries—Albert A. Gunkler and John W. Bernard—1990

Environmental Control Systems—Randy D. Down—1992

The Management of Control Systems—Justification and Technical Auditing—N. E. (Bill) Battikha—1992

Measurement Uncertainty—Methods and Applications—Ronald H. Dieck—1992

Essentials of SPC in the Process Industries—James M. Pruett and Helmut Schneider—1993

SCADA—Supervisory Control and Data Acquisition—
Stuart A. Boyer—1993

Most of the original ILMs were envisioned to be the more traditional or fundamental subjects in instrumentation and process control. With the publications planned over the next few years, the ILM Series will become much more involved in emerging technologies.

ISA has increased its commitment to the ILM Series and has set for itself a goal of publishing four ILMs each year. Obviously, this growing Series is part of a foundation for any professional library in instrumentation and control. The individual practitioner will find them of value, of course, and they are a necessity in any institutional or corporate library.

There is obvious value in maintaining continuity within your personal set of ILMs; place a standing purchase order with ISA.

Paul W. Murrill
Consulting Editor, ILM Series
May, 1993

Comments about This Volume

This ILM is designed to introduce you to the techniques of adaptive control that are applicable to industrial process control problems. Although it is written from a practical rather than a theoretical point of view, the material is organized in each unit in a logical sequence so that you can easily see the reasons for the techniques that are presented. A complete guide to the ILM is given in Unit 1.

Since adaptive control is an advanced control topic, it is assumed that the student has basic knowledge of automatic control. Mathematical treatment is minimized whenever possible since this is meant to be an introductory text for an industrial audience and the emphasis is on the principles, properties, merits, and limitations of the various practical adaptive control techniques.

Acknowledgment

This book would not have been written without the kind invitation and encouragement of Dr. Paul W. Murrill, the ILM

Consulting Editor. It was a challenge, but it also presented the opportunity to make a contribution to the industrial community.

Over the years of active teaching, research and consulting, we have come into close contact with many academic and industrial experts in the field of adaptive control. Consciously or unconsciously, we have picked up material from pleasurable interaction with many of them throughout the world. We wish to thank especially Prof. Karl Johan Åström of Lund University, Sweden, who has pioneered the development of adaptive control theories and applications over the last 20 years, for his inspiration, encouragement, and collaboration in recent research work in adaptive and intelligent control. The first author would also like to thank his former employer, the Shell Eastern Petroleum Co., from which he has learned much of the process control expertise and has gained a solid foundation for applied research. He is also very grateful to many of his postgraduate students, particularly Kok K. Sin, Li S. Cao, Eng K. Koh, Vinod Vasnani, Pik K. Yue, and S. Nungam for their contributions in his research work on practical adaptive control.

We want to express our gratitude to those who have read different versions of the manuscript and thereby removed many of the errors and gave us good suggestions for improvement: P. B. Desphande; Graham Goodwin; Tore Hägglund; and Qing G. Wang.

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Unit 1:
Introduction and Overview

UNIT 1

Introduction and Overview

Welcome to this ISA's Independent Learning Module (ILM) *Adaptive Control*. The first unit of this self-study program provides the information needed to proceed through the course.

Learning Objectives — When you have completed this unit, you should:

A. Understand the general organization of the course.

B. Know the course objectives.

C. Know how to proceed through the course.

1-1. Course Coverage

This ILM on the fundamental techniques of adaptive control as applied to industrial process control problems covers the following:

A. A definition of adaptive control, its merits, and the limitations of its applications.

B. The common techniques for auto-tuning, self-tuning, and gain-scheduling of PID controllers.

C. The common techniques for adaptive advanced control, including the Smith predictor, feedforward, pole-placement, minimum-variance, generalized predictive control, and multivariable control.

The course will focus on the adaptive algorithms as well as the associated heuristics that ensure robustness and easy use by plant operators. Such heuristics actually take the software designer longer to incorporate because their computer codes are usually many times longer than the algorithms themselves.

No attempt is made in this ILM to be exhaustive in the presentation of adaptive control techniques. In fact, certain techniques have been specifically omitted; an example is model reference adaptive control, which is more suitable for low order, well structured servomechanisms as used in robotic and

aerospace systems. The unknown nonlinear nature, high order, and nonminimum phase dynamics, the presence of significant dead time, the possibly low signal-to-noise ratio, and the frequent occurrence of load disturbances are what characterize difficult industrial process control problems. We shall focus on practical adaptive control techniques for these problems.

1-2. Purpose

The purpose of this ILM is to present, in easily understood terms, the principles and practices of adaptive process control techniques. Although the course cannot substitute for actual field experience, it is designed to speed up the learning process during field training.

1-3. Audience and Prerequisites

The material in this ILM will be useful to control and instrument engineers who are concerned with the design, installation, and operation of modern process control systems. The course will also be useful to undergraduate and postgraduate students in universities who wish to gain some insight into the practical aspects of adaptive process control.

The prerequisite to this course is a basic knowledge of automatic control, which has been covered by an earlier ILM, *Fundamentals of Process Control Theory*. It would be useful to have some familiarity with the basic concepts of controller tuning and advanced control, especially when the student studies the material on adaptive advanced control. If necessary, the student can refer to another earlier ILM, *Tuning of Industrial Control Systems*. In terms of mathematical skills, it is not absolutely necessary for the student to be intimately familiar with the mathematics used in the presentation in order to understand the fundamentals of adaptive control. It is hoped that the barrier that extensive mathematics usually presents to the understanding of automatic control concepts will be kept to a minimum in this ILM.

1-4. Study Materials

This textbook is the only study material required in this course; it is one of ISA's ILM system. It is an independent, stand-alone textbook that is uniquely and specifically designed for self-study.

Contained in Appendix A is a list of suggested reading to provide additional reference and study materials for the student. The student will find it useful to study other ILMs available from ISA that present a broad range of specific applications of instrumentation and process control techniques.

1-5. Organization and Sequence

This ILM is organized into 10 separate units. The next unit presents the functions, classification, and appropriate applications of adaptive control. Unit 3 presents the general structure of a self-tuning controller, which gives the student a macro view of the major components of an adaptive controller and an introduction to the need for supervision for robust adaptive control. Units 4 and 5 are devoted to the principles, properties, and applications of auto-tuning and self-tuning techniques for PID controllers, namely, the relay feedback, pattern recognition, and correlation methods. Relevant controller tuning formulas and their improvement, process modeling from relay feedback, and a design to achieve specified gain margin and phase margin design are presented. Unit 6 is devoted entirely to the adaptive Smith predictor control of processes with long dead time. More details of on-line recursive parameter estimation methods are presented in Unit 7 to prepare the necessary background for understanding the adaptive techniques for model-based advanced control of single-loop, multi-loop, and multivariable systems in Units 8 and 9. The last unit presents recent developments in knowledge-based control as an extension of adaptive control, neural networks, and adaptive fuzzy control towards the realization of an intelligent control system.

As with all ILMs, the method of instruction is self-study. You select the pace at which you learn best. You may completely skip or browse through some units with which you feel you are intimately familiar and devote more time to other units that contain material new to you.

Each unit is designed in a consistent format with a set of specific learning objectives stated at the very beginning of the unit. Note these learning objectives carefully; the material in the unit will teach to these objectives. Each unit contains examples to illustrate specific concepts and exercises to test your understanding of these concepts. All of these exercises

have solutions contained in Appendix B, against which you should check your solution.

1-6. Course Objectives

When you have completed this entire ILM, you should:

- Know when to apply adaptive control to compensate for significant process or disturbance parameter variations.
- Be able to decide whether the simpler auto-tuning method or the (open-loop) gain-scheduling technique should be used instead of the more sophisticated, continuous (closed-loop) adaptive control technique.
- Be able to select different adaptive control techniques for PID controllers.
- Be more confident in applying the adaptive Smith predictor for tighter control of a process with long dead time.
- Know when and how to apply adaptive techniques for other advanced control techniques, including cascade, feedforward, pole-placement, minimum variance, and generalized predictive control.
- Appreciate the difficulty of and possible solutions for adaptive multivariable control.
- Be familiar with new possibilities and developments in intelligent control.

1-7. Course Length

The basic premise of ISA's ILM system is that students learn best when they progress at their own pace. As a result, there will be a significant variation in the amount of time taken by individual students to complete this ILM. On the average, most students will complete this course in 50 to 60 hours.

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