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INDUSTRIAL DIGITAL CONTROL SYSTEMS

Edited by
K. Warwick and D. Rees

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Preface

The purpose of this book is to provide an introduction to the techniques involved in the design and application of digital control systems. The book is intended for Engineers, Managers and Engineering students who have a basic knowledge of mathematics, computers and control systems and who wish to become widely informed about using the latest advances in digital control technology. It must be emphasised that what follows is concerned neither with the proferring of highly abstract theoretical ideas nor with detailed descriptions of specialised industrial plant. Indeed the book is based on a continuingly successful series of annual IEE vacation schools which are extremely well supported by industrialists, academics and students alike. The book provides an overall balanced perspective of the theme of digital control and may be used as reference articles, either forming the main text or providing introductory supplementary material for courses on real-time control, digital control and industrial control systems.

Digital hardware has become a widely accepted basis for controller implementation during recent years. The revolution has been due to the availability of low cost computing power in the form of the microprocessor, which has allowed the gap between control theory and practice to be dramatically reduced, permitting the application of many control algorithms to real processes. This technological development has resulted in the theory of digital control systems taking on a more realistic and usable format in order to meet practically imposed discrete time requirements, resulting in the real-time implementation of modern control concepts such as system identification, optimal and multivariable control. The object of this book is to present these advances in digital control systems theory in a readily digestible way by linking the theoretical developments with practical implementations of adaptive and self tuning control, computer aided control system design and expert systems. An unique feature of the book is the presentation of case studies given in the later chapters. These concern themselves solely with the implementation of the techniques described, an approach which is entirely in character with the rest of the book. The tutorial nature of the case studies serves as a general introduction to the application of digital control schemes for industrial purposes.

The several contributions which constitute this book give a representative account of the different aspects involved in the design of Industrial Digital Control Systems and allow the reader to either

consider the book as a whole for the purpose of a taught course or to use it as an introductory reference text to particular topics by consulting the relevant chapters.

The book commences with a brief overview and historical account of the background behind the use, in terms of both theory and practice, of digital control schemes for systems. Modelling of systems in a discrete time framework is discussed and various design methods are summarised, in particular classical, adaptive, optimal and state-space approaches are considered. The theoretical basis of the book and therefore the knowledge required can be gauged from Chapter 2 in which the foundations of digital signals and systems are put forward. The relationships between continuous time s-plane representations and discrete time z-plane representations are looked at from the point of view of system input/output transfer functions with special attention given to the position of both open and closed loop transfer function poles and zeros.

Chapters 3 and 4 then concern themselves with laying the foundation for the design of digital controllers. In Chapter 3 the main emphasis is placed on the three term (P+I+D) controller and its application in the process control environment. This popular and widely encountered control structure retains a relatively simple and hence readily understandable relationship with the system signals, each of the three terms having a straightforward affect on the signals under control. The PID controller is developed here stage by stage and various pointers are given as to the methods available for the selection of the controller settings. A highlight of this chapter is the consideration given to implementation problems encountered with the controller, such as choice of sampling rate and numerical accuracy. Chapter 4 however concentrates on various digital control schemes seen either as alternatives to the PID method, or as a necessary approach for some more commonly encountered variations on the basic feedback control requirement. Hence Dahlin, Kalman and predictive control algorithms are discussed whilst the use of feedforward compensation is also considered.

A frequently encountered problem in the implementation of controllers in general is the occurence of time delays in the system characteristics, indeed requirements for the remote control of manipulators in space or in hazardous environments ensures that problems with time delays will have to be overcome for many years hence. In Chapter 5 several examples are considered in which inherent time delays are apparent, and the control of these systems is looked at by means of the Smith predictor method. Alternatives to the Smith predictor are also considered and the effects of mismatch and disturbances on the closed loop system response are discussed.

The state-space approach to system modelling and controller design is seen as an important complementary procedure which can often reveal characteristics of both the system and controller which are not obvious from a straightforward polynomial construction. The fundamental aspects involved in state space design are given in Chapter

6 within which the ideas of system controllability and observability are subsequently introduced. By the end of Chapter 6 the main building blocks of digital control theory have been considered, and in the next three chapters 7, 8, and 9, the major problems in digital system modelling and control are considered from a more theoretical perspective. In the first of these, the question tackled is once the system to be controlled has been decided upon, how can a mathematical representation of the system be obtained?' Within the chapter techniques such as least squares model fitting and maximum likelihood estimation are discussed along with recursive methods which are mostly suitable for use on slowly time varying systems. Once a suitable model of the system has been obtained the next question to be faced is 'what objective do we wish to aim for in the design of a controller for the system. In Chapter 8 the basis for an optimal controller is considered. The primary dependance rests on the function that is to be optimized by maximizing)or minimizing if appropriate) its value over a period of time. Choice of functions, methods of optimisation and their implementation procedures are all covered.

Only too frequently the system under consideration does not simply consist of one input and one output, but has several inputs affecting each output and any one input will actually affect several outputs. The features and approaches apparent in the control of multivariable systems are put forward in Chapter 9, in which the topic is introduced by means of a case study from the aerospace industry. Subsequently the design of robust multivariable controllers is considered via a framework of various possible feedback configurations.

Over the last 15-20 years the need for controllers, which can adapt themselves to changes in both system and environment, has become more widespread. Use of an adaptive control scheme can often result in improved control action over a period of time and/or a controller which remains in operation despite significant alterations or system modifications. Alternative adaptive control methods with descriptions of the presented types of system for which they are suitable, are in Chapter 10. Chapter 11 meanwhile is concerned with a description of the use of Computer Aided Design (CAD) as a tool in the development and study of control systems. It is in fact preferable for the types of controllers considered in the preceeding three chapters to be investigated in terms of simulation and further CAD work before actual implementation takes place.

The next three chapters, 12, 13 and 14 are concerned primarily with various aspects of applying digital controllers in an industrial setting. In Chapter 12 reliability, fault tolerance and detection and types of error encountered with microprocessor based controllers are discussed. Further, two case studies are included in order to highlight the methods described for error minimization. The idea of microcomputer or computer implementation is continued in Chapter 13 in which software design procedures are considered along with hardware and interfacing techniques. Chapter 14 concentrates on applications of digital control in the electrical supply industry. This brings together many of the theoretical ideas put forward in some of the earlier chapters, for example the use of multiloop feedforward and

adaptive control. The main chapters are concluded with Chapter 15 in which the employment of an expert system architecture around an adaptive control shell is discussed. Examples are given of the overall scheme in operation and features in the development of the expert system are highlighted.

In conjunction with the main set of chapters just reviewed, a set of case studies are presented in Chapters 16 to 21, and are intended to demonstrate the implementation of both the more conventional and modern control ideas. These chapters should therefore be regarded as a supplement to the main text and an aid to understanding the techniques presented. In all cases it is felt that the case study chapter headings are self explanatory and the intention here is merely to point to where they most appropriately tie in with the main text, which is as follows:

a) Chapter 16, Case Study I: follows Chapter 3.

b) Chapter 17, Case Study II: follows Chapter 4 and 6.

c) Chapter 18, Case Study III: follows Chapter 4 and 5.

d) Chapter 19, Case Study IV: follows Chapter 8.

e) Chapter 20, Case STudy V: follows Chapter 10.

f) Chapter 21, Case Study VI: follows Chapter 11.

Finally it must be emphasised that in addition to the case studies, almost all chapters, even the most theoretical, contain practical or worked examples as a tutorial aid.

In conclusion the editors would like to thank all of the authors for their contributions and their promptness in forwarding the chapters for final preparations. The editors would like to give a special mention to P.A. Witting for his organisation of the course in recent years and his predecessors as Chairman of the organising committee Dr. G.K. Steel, Dr. D. Sandoz, Dr. A.J. Morris and Prof. J.P. Stuart, who nurtured the vacation school through its formative years. Also on behalf of all of the authors the editors would like to thank those at Peter Peregrinus and in the IEE who were responsible for the production of this book, in particular John St. Aubyn at the former and Andrew Wilson and Sarah Morrall of the latter.

May 1986

K. Warwick
D. Rees

Contents

Chapter 1

Introduction to digital control

P.A. Witting and Dr C.G. Proudfoot

1.1 INTRODUCTION

This introduction to 'Industrial Digital Control Systems' serves two purposes. Firstly it gives a history of computers in Control and discusses the advantages of using them. Secondly it gives an overview of the digital control systems theory to be presented in the later chapters.

In the 1950s and 1960s a Control Engineer had to master analogue technology as the major tool for computations in control systems implementation, and also for simulation purposes. Due to rapid developments in digital computers, however, the scene has changed dramatically. As well as being used for control system implementation computers are increasingly being used for design and analysis.

Because of these developments the approach to analysis, design and implementation of control systems is changing drastically. Originally it was only a matter of translating the earlier analogue designs into the new technology. As such, digital, or computer-controlled systems can be viewed as an approximation of analogue control systems. This approach does not always achieve the best performance however, because the full potential of computer control is not used. As an alternative approach it is possible to make full use of modern digital design and analysis methods, as discussed in the following chapters of this book,and briefly outlined in section 5 of this chapter.

Control engineering went through a considerable period of transition in the 1960s and 1970s with the development of 'modern' control theory. In essence the movement looked at control engineering from a somewhat different viewpoint to that of conventional frequency response/transfer function methods. The drive was for a better understanding of control systems and an improved quality of control. To achieve this much use was made of digital computers for the processing of data and this led to a move away from the Laplace transform/calcus approach and towards those techniques that could be readily programmed onto a computer.

The sheer unfamiliarity of the resulting mathematics (rather than its intrinsic difficulty) drove a wedge between the theoreticians and most practising control engineers. This rift was (and still is) rationalised by asserting that 'modern control is impractical'. Originally there may have been some truth in this, the early theories could not cope with the imperfections found in real plant,and the analogue controllers were not suited to their implementation. However,the advent of inexpensive and virtually limitless computing power means that it is possible to implement even quite complex calculations cheaply and quickly. The techniques of 'modern' control may now be put into practice. It is the purpose of the remaining two major sections of the introduction to show how the various aspects of digital control are related to each other and to show how they relate to modern industrial practice.

Figure 1.1 provides a 'road map' of the book. It will be seen that there are three classes of material: introductory, theoretical and applications.

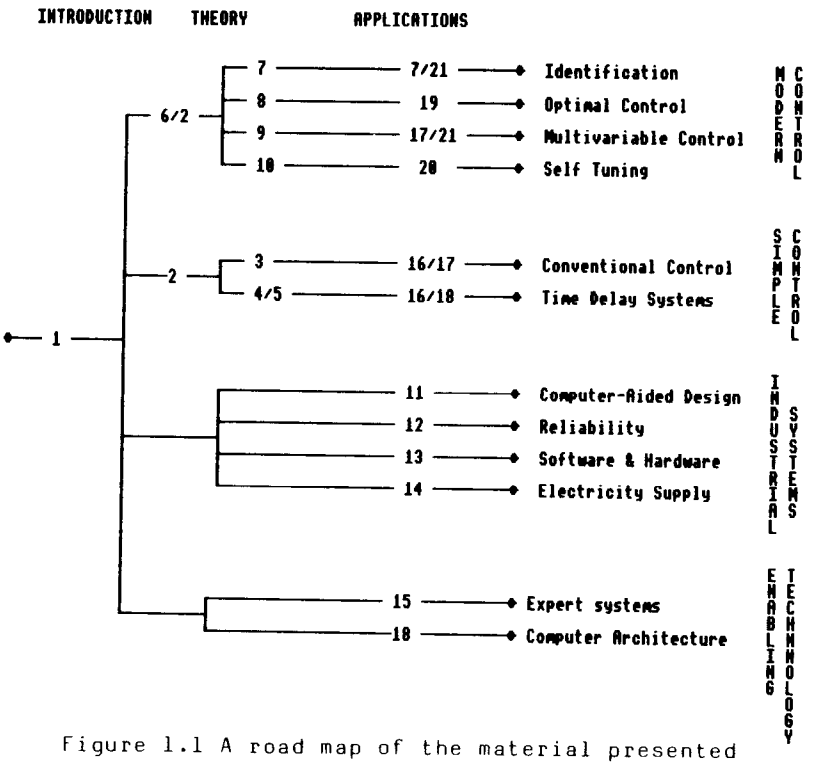

Figure 1.1 A road map of the material presented

These are applied to the four 'threads' of the school namely 'modern control' (the largest single one), 'conventional (simple?) control' where digital computers can offer