Multivariable Control Systems: An Engineering Approach

P. Albertos
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P. Albertos and A. Sala

Multivariable Control Systems

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With 68 Figures

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Series Editors' Foreword

The topics of control engineering and signal processing continue to flourish and develop. In common with general scientific investigation, new ideas, concepts and interpretations emerge quite spontaneously and these are then discussed, used, discarded or subsumed into the prevailing subject paradigm. Sometimes these innovative concepts coalesce into a new sub-discipline within the broad subject tapestry of control and signal processing. This preliminary battle between old and new usually takes place at conferences, through the Internet and in the journals of the discipline. After a little more maturity has been acquired by the new concepts then archival publication as a scientific or engineering monograph may occur.

A new concept in control and signal processing is known to have arrived when sufficient material has evolved for the topic to be taught as a specialised tutorial workshop or as a course to undergraduate, graduate or industrial engineers. *Advanced Textbooks in Control and Signal Processing* are designed as a vehicle for the systematic presentation of course material for both popular and innovative topics in the discipline. It is hoped that prospective authors will welcome the opportunity to publish a structured and systematic presentation of some of the newer emerging control and signal processing technologies in the textbook series.

There are a considerable number of multivariable industrial processes which are controlled by systems designed using single-input, single-output control design methodologies. One reason for this is that multivariable systems textbooks often incorporate a significant amount of mathematics which tends to obscure the potential benefits that can be obtained from exploiting the multivariable structure and properties of multi-input, multi-output systems. In this new textbook, Pedro Albertos and Antonio Sala have made considerable efforts to discuss and illustrate the inherent meaning and interpretation of the principles within multivariable control system design. This is reflected in a book structure where after several chapters on models and linear system analysis Chapter 4 pauses to review the control roadmap ahead in the second part of the book. This roadmap has chapters devoted to centralised multivariable control methods, optimisation-based methods, robustness and implementation issues. In the presentation there is a clear indication

that the authors are very aware of current industrial control system design practice. This is seen through the choice of industrial and practical examples chosen to illustrate the control system principles presented. These include a paper machine head box control system, a (3×3) distillation column problem, a steam-boiler system and a really interesting ceramic kiln control system problem. The kiln problem is used to show that the industrial multivariable control system design problem has a wealth of associated problems which also have to be considered and solved. Indeed the ceramic kiln problem is similar to other processes like that of plate-glass manufacture, and the reheating of steel slabs in a walking beam furnace in the steel industry.

The discussion of the various issues in multivariable control system design is a particularly attractive feature of the book since this helps to put into context and perspective some difficult theoretical issues. The chapter on robustness (Chapter 8) is a good example of a discussion chapter from which the reader can decide whether to delve further into the supporting technical appendix and references. The book is suitable for final-year undergraduates, and graduate students who will find the valuable insights, and illustrative examples particularly useful to their studies of multivariable control system design and implementation. Lecturers and professionals in the control field will find the industrial context of the examples and discussions a refreshing change from the usual more straightforward academic multivariable systems control textbooks.

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Preface

"'Engineering approach' implies lots of shortcuts and simplifications. Simplification often means telling the truth but not the whole truth. If it were the whole truth, it would not be simple!" (Bob Atkins).

Control engineering is a multidisciplinary subject, useful in a variety of fields. Process control, servosystems, telecommunications, robotics, or social system dynamics, among others, require the concourse of automatic control concepts to better understand the behaviour of the respective processes and to be able to introduce changes in their dynamics or counteract the effect of disturbances.

Recent industrial trends in the implementation of control systems claim a wider perspective in the design, not just a collection of single-loop controllers, coping with a complex system with multiple interrelated variables to be controlled and having the option to manipulate multiple variables. The first step in this direction is to consider the control of multivariable systems.

The aim

Talking about control problems and moving to wonderful mathematical abstractions is very tempting. The complexity and elegance of many control problems have attracted the interest of theorists and mathematicians, developing more or less complex control theories that are not always well connected to the practical problems. However, in this book, the theory is used as a support to better understand the reasons and options of some control design techniques rather than to enter into the details of a given issue, even if this issue can be the matter of dozens of research papers.

The book presents the fundamental principles and challenges encountered in the control of multivariable systems, providing practical solutions but keeping an eye on the complexity of the problem to decide on the validity of the results. We are not interested in control design recipes, although guidelines

are welcome, and always try to analyse the proposed solution and suggest alternatives. The study of some of the control options for multivariable systems, their physical understanding and reasoning, and their tuning in real applications is the main aim of the book, devoting also some effort to the available tools used in their computer-aided design.

The content

The book is structured to cover the main steps in the design of multivariable control systems, providing a complete view of the multivariable control design methodology, with case studies, without detailing all aspects of the theory. An introductory chapter presents in some extent the general issues in designing control systems, guiding the reader through the subjects to be treated later on. As most control systems are conceived to be digitally implemented in a computer-based system, the use of process models is generalised and the control design approach is based on a model of the process. This is the subject of Chapter 2, where the representation of linear systems, in continuous and discrete time, is dealt with in some detail. Although there is an introduction to the modelling of non-linear processes, approximation techniques move the problem to the linear "arena", where the theory is simpler and well known and the concepts can be acquired more easily.

Chapter 3 deals with the tools for extracting properties from the models, including models of the process, the controller and the whole controlled system. This is a key chapter that provides the basis of analysing the behaviour of a system and its possibilities of being controlled. Emphasis is placed on the structural properties of multivariable systems and issues such as directionality and interaction, not relevant in single-input-single-output (SISO) systems, are discussed. Using the analysis results, model reduction techniques are introduced.

The general options in designing a control system are the subject of Chapter 4, where an analysis of the advantages and drawbacks of different control structures is presented. This is an introduction to the rest of chapters, where different design and implementation control techniques are developed. Decentralised and decoupled control is the subject of Chapter 5. Here, most of the ideas of SISO control system design are useful, being complemented with the analysis of the loops' interaction and the crucial issue of variables selection and pairing. Some guidelines for the setting of a multi-loop control system are discussed.

Full advantage of the internal representation is taken in Chapter 6 to introduce the centralised control structure. All the ideas presented in the previous chapters are used here to present a methodology for the integrated design of a control system with multiple controlled variables. The classical state feedback strategy, complemented with the use of state observers, provides a solution that is easily implemented in a digital computer and reduces the cost of instru-

mentation. Virtual sensors are a step further in the construction of observers and present an attractive solution from an engineering viewpoint.

One of the characteristics a control user demands is the interpretability of the tuning parameters of a control system. Cost or performance indices are a suitable way of expressing some requirements, even using limited options such as norms of variables, and optimal control provides an effective approach to controller design. In Chapter 7, the assumption of linear models simplifies the treatment and allows us to find a closed solution that can be implemented as a linear controller.

The treatment of uncertainty in the models (and even in the requirements) is fundamental from an engineering viewpoint, as the models are always partial representations of the process behaviour. An introduction to robust control design techniques, as a variation of optimal control, is presented in Chapter 8, complemented with additional readings and material presented in an appendix.

Implementation of the designed control is a key factor in the success of a control system. Many issues are application-dependent, but a number of general guidelines and warnings are the subject of Chapter 9. The integrated treatment of the control design and its implementation, in resource-constrained environments, is a matter of research interest and should be always kept in mind by a control design engineer.

The use of the internal representation provides a good framework for reviewing the control concepts in a general way, with validity not only for multivariable systems but also for SISO. The introduction of tools for analysing and designing robust control systems is also an added value of the book and a motivation to enter into this control design methodology.

As previously mentioned, all the relevant concepts are illustrated with examples, and programming code and simulation diagrams are provided to make the validation of the results easy as well as the grasping of the concepts. A number of case studies present a joint treatment of a number of issues. Unfortunately, there is no room to describe in full detail the practical design and implementation of a complete application. This is something that the reader could try to carry on in his/her own control problem.

A number of appendices include some reminders and new ideas to help in the reading of the main body of the book, giving a self-contained feature, always desirable in a book with a large audience. Of course, the analysis and representation tools are also developed, but they are always considered as a way of achieving the final control system design and evaluation. Examples with high-level simulation packages, mainly MATLAB®, are provided. The case studies and the chapter examples lead the reader into a practical perspective of the control solution. Usually, a full design completing additional issues of the case studies could be attempted as an exercise. Additionally, a large list of references will provide alternative reading to those interested in more rigorous treatment of the topic or more detailed specific applications.

The audience

This is not an ambitious book either from the theoretical perspective or from the end-user viewpoint, but it is trying to bridge the gap between these two extremes. The main goal is to present in an easy-to-read way the challenging control problems involving subsystems, interactions and multiple control objectives, introducing some tools for designing advanced control systems.

There is a wide audience of engineers and engineering students with a background of basic control ideas grasped in their previous studies or in their practical experience in designing systems. This is a heterogeneous audience coming from different fields, such as instrumentation in the process industry, the design of electronic devices, the study of vibrations and dynamics in mechanical systems or the monitoring of process units.

The book can be helpful in introducing the basic concepts in multivariable linear control systems to practical engineers. The control problems may be familiar to them and the presented tools will open their mind to find appropriated solutions.

For senior undergraduate students that previously had grounding in SISO control (PID, root locus, discretisation of regulators), the challenge is to convey the basic heuristic ideas regarding multivariable control design in a one-semester course, presenting the necessary mathematical tools as they are needed and putting emphasis on their use and intuition, leaving the details of the theory for more advanced texts.

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Valencia,
August 2003

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