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Book review:

HIGH PERFORMANCE CONTROL

by

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The book is an up-to-date textbook for graduate students readying for a degree in control science or control engineering and having some (modest) background in linear algebra, linear dynamical systems, probability theory and elementary control theory. It will also be useful for engineers working in high-tech industries on nmch demanding control systems. It is complete in itself and for readers with gaps in this background appropriate appendices are enclosed for reference.

It deals with guaranteed stability and performance of control systems for plants subject to a variety of disturbances and modelling uncertainties. Its aim is to answer the question: can high performance be achieved in face of those disturbances and uncertainties? The answer is positive and given by a blend of insight and methods from classical, optimal and adaptive control. The methods are used so that each of them contributes its assets and compensates for the drawbacks of others in order to achieve both robust control and high·performance control. Most of the development refers to the multivariable setting.

The book's predecessors are many. Most important of them are perhaps those by H. Kwakernaak and R. Sivan *(Linear Optimal Control Systems,* Wiley-Interscience, 1972), B. D. 0 Anderson and J.B. Moore (*Optimal Control: Linear Quadratic Methods,* Prentice-Hall, 1989) and J. C. Doyle, B. A. Franics and A. Tannenbaum *(Feedback Control Theory,* MacMillan, 1992).

The book starts with Chapter 1 on "Performance Enhancement", which serves as introduction, outline and guide. The introductory part gives a brief summary of the main topics covered.

The following Chapter 2 on "Stabilizing Controllers" is crucial to the methodology adopted by the authors. It characterises the class of all stabilizing controllers for a linear plant in terms of a stable filter termed Q. It turns out that all the important input/output operators of the closed-loop system are affine in Q. This facilitates optimisation over stable Q. In fact Q may be tuned off-line or on-line to optimise performance.

This chapter is also used to introduce the system matrix notation (dating back to Rosenbrock) which is consistently applied throughout further developments.

Chapter 3 "Design Environment" introduces models of disturbances and uncertainties. It presents also a dual concept to the class of stabilizing controllers, given by the class of plants stabilized by a given stabilizing controller. This class is parameterised in terms of a stable filter S, to be used for representing the unmodeled plant dynamics.

In Chapter 4 "Off-line Controller Design" the optimisation of stabilising controllers via optimal Q filter selection is discussed. The authors are considering a number of performance indices for reference tracking and disturbance rejection.

In Chapter 5 "Iterated and Nested (Q,S) Design" the interaction between control via Q-parameterisation of all stabilising controllers for a nominal plant and identification via S-parameterisation of all plants stabilised by a controller is discussed. This is done using two schemes (the iterated and nested scheme), which differ in the way identification is performed.

Chapter 6 "Direct Adaptive-Q Control" presents direct adaptive-Q methods. The goal of adaptation is to improve performance of the nominal stabilising controller, assumed to be available. In the presented approach, Q is adjusted using a simple gradient algorithm. This adjustment is performed without prior identification of S. Direct adaptive-Q design is thus applicable if reasonably good models for the plant dynamics are available. The direct adaptive-Q control systems are analysed using averaging techniques.

Readers not well versed in the averaging technique may find a good presentation of fundamentals in Appendix C.

Chapter 7 "Indirect (Q,S) Adaptive Control" introduces an indirect adaptive-Q method for handling significant model mismatch. This time an estimate of S is obtained on-line and used in a typical certainty equivalence manner to compute the Q filter. As before, it is assumed that a stabilising controller is available. Because dynamic models cannot be identified without some plant excitation, an external signal is injected into the closed-loop system. The authors are well aware that *it will necessarily frustrate to some extent any control action for as long as it is present.* An analysis is again performed using averaging techniques.

In Chapter 8 "Adaptive-Q Application to Nonlinear Control" the approach from Chapter 7 is extended to on-line adaptive-Q schemes with Q being a parameterised nonlinear function of the state.

Chapter 9 "Real-time Implementation" is a much welcomed departure from the theoretical mainstream of the book. It is setting the stage for practical implementations of high performance control by discussing a number of important issues, which usually are skipped in purely theoretical treatises. The discussion centres on microprocessors (including digital signal processors), issues related to using discrete-time methods for continuous-time plants and issues related to the choice of software platform. Hardware considerations are illustrated by examples of overhead crane control and heat exchanger control systems. A methodology for simplification of the development of a microprocessor based controller system is sketched. This is followed by a dual-processor design approach in case computational resources are required beyond those made available by a single microprocessor. Issues related to the choice of methods are presented by a juxtaposition of the two most common approaches to digital control design: (1) find a continuous-time controller for the continuous-time plant model and discretize the controller, (2) discretize the plant and find a discrete-time controller for the discrete-time plant model. The discussion of software platforms centres on coding in MATLAB and coding in C. The authors are clearly in favour of using high-level m-file functions available in MATLAB toolboxes to be used at the development stage and to be converted later into C sources for stand-alone systems. Other issues discussed in this chapter include integer representation of data and finite word length considerations.

Chapter 10 "Laboratory Case Studies" is also unusual for theoretical treatises. It presents a discussion of three high performance control systems and their real-time implementation: control of a hard-disk drive, control of a heat exchanger and a feasibility study of aerospace resonance suppression. For the hard-disk drive control system, sampling rates must be high and the controller is a result of complicated trade�offs. This is not an issue for the heat exchanger, where speed is not a critical factor, sampling rates may be low and the need to make compromises is less stringent. For the resonance suppression simulation study, a commercial aircraft is modelled to show the potential for performance enhancement using adaptive technique.

The book concludes with three appendices: on linear algebra, on dynamical systems and on averaging analysis for adaptive systems, followed by references to more than a hundred papers and books, an author index and a subject index.

The book is well-written, singularly free of errors and contains a fair number of examples illustrating the development of theory. Each chapter ends with a short summary of the issues discussed and a short guide for all those who would like to read some of the original papers.

Its main strength lies in presenting a unified and consistent approach towards high-performance control: start with a nominal plant and make allowance for its non-ideality, start with a stabilizing controller for the nominal plant and furnish it with additional degrees of freedom to increase performance, and use those additional degrees of freedom, either off-line or on-line in real-time, to boost the performance while making trade-offs for all design consideration, which need them.

The book should find a place on the shelves of any control engineering library.

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