Loop Transfer Recovery: Analysis and Design

Stoustrup, Jakob

Published in:
IEEE Transactions on Automatic Control

Publication date:
1996

Document Version
Tidlig version også kaldet pre-print

Book Reviews

Loop Transfer Recovery: Analysis and Design—A. Saberi, B. M. Chen, and P. Sannuti (Berlin: Springer-Verlag, 1993). *Reviewed by Jakob Stoustrup.*

I. Introduction

Loop transfer recovery (LTR), historically, has its origins in the age of linear quadratic control, where it was at a certain point discovered that controllers based on measurement feedback did not at all, in general, possess the appealing properties known from the state feedback cases such as guaranteed gain and phase margins. When this observation (which was also the origin of robust control theory) became accepted, there was a significant research effort to describe synthesis procedures which allowed state feedback properties to be *recovered* by measurement feedback controllers. This line of research became established as LTR. Later on, the original problem got other tractable solutions, but LTR persisted since it had meanwhile proven useful in a wide variety of control design problems.

In contemporary control technology, LTR methods are motivated especially by virtue of the possibility of complete decoupling in the design process between the design of desirable loop shapes from arbitrary criteria and the design of an implementable dynamical controller with specified performance and robustness properties in different frequency regions. This allows for combinations of design criteria that cannot be handled by other strategies. Moreover, LTR is relevant by virtue of the capability of designating specific observer and/or controller structures, such as low order ones, to the resulting closed-loop system. This is in contrast to most other optimization-based methods where specific structures cannot be assigned or can be designed only through very tedious procedures.

Usually, the origin of LTR is credited to Kwakernaak [4]. It was explicitly formulated in a couple of papers by Doyle and Stein [2], [3]. A general formulation addressing nonminimum phase systems, which later became the crucial interest of research, was presented in [1], followed by the more detailed paper [5]. Since then quite a number of papers in this area appeared, and LTR is by now a quite well-established field of research which has grown to a high level of maturity. Therefore, already for some time a monography in the area has been justified and motivated.

II. The Book

Loop Transfer Recovery: Analysis and Design by Saberi, Chen, and Sannuti is the first comprehensive collection of results on LTR and constitutes a very thorough treatment of the subject.

First of all, credits should be given to this book for its deep insight in linear systems theory. LTR has a widespread perception as a typical "engineering" subject. Hence, in judging from titles this book might not be the first that comes to mind when planning a control curriculum, e.g., for mathematics students. However, it should be emphasized that the approach taken in the book is based on a very solid and systematic understanding of linear systems which makes it instrumental for two dual pedagogical objectives: to teach control engineering to mathematics students and to provide a sound mathematical line of thought for engineering students.

The reviewer is with the Department of Mathematics, Technical University of Denmark, DK-2800 Lyngby, Denmark (e-mail: jakob@mat.dtu.dk).
Publisher Item Identifier S 0018-9286(96)08255-4.

The preface mentions as an appropriate background for reading the book a first graduate course in linear systems along with an elementary knowledge of linear quadratic control. These preliminaries must be considered an absolute minimum. Whereas the book is quite self-contained, the scope is rather ambitious, and probably for a vast majority of students with these minimal preliminaries, it will turn out quite demanding to acquire the material in its entirety.

Less experienced students will encounter a threshold for understanding within the introductory part of the book. Here, the main instrument in the book, the so-called *special coordinate basis* is introduced. The construction of this concept comprises most properties known about linear systems, and it is quite a mouthful to swallow. However, having deeply understood this part, the main line of the book is quite easily followed, as all results are subsequently based upon the special coordinate basis and large amounts of elementary matrix algebra.

For the readability it is of immeasurable value that a huge amount of examples have been included. Basically, any concept has been illustrated by means of worked examples. There are, though, no exercises, which leaves some work to do if the book is to be employed as the main body in a graduate course. On the other hand, the organizer of such a course can utilize the optionality in the book to turn the course in a more applied or in a more mathematical direction by constructing exercises in accordance with the objective.

For the university scientist or the professional engineer, the book serves excellently as a source of knowledge in the area, since care has been taken to make it rather complete, even considering the vast number of papers in the field of LTR. Of course, a specific approach has been taken, and the book does not offer any usefulness until that line of approach has been understood, meaning especially the special coordinate basis. But once this effort has been done, the book will constitute a valuable source of inspiration and as a reference tool.

As an overall structure, the book consists of two parts: one dealing with LTR for continuous time systems and one dealing with LTR for discrete-time systems. These two parts can be read in parallel, since the treatments are very alike in the two parts, or independently if the reader has preferences in terms of time domains.

In each time domain, LTR is described in three chapters, organized as: preliminary analysis, detailed analysis, and design.

The two chapters on preliminary analysis deal mainly with controller structures, i.e., especially with observer architectures. It is demonstrated how different observer architectures have different advantages and drawbacks. It turns out that the recovery properties of the various controller types all can be characterized in terms of a certain matrix valued function, *the recovery matrix*. Different variations of the recovery problem are then restated in terms of the recovery matrix.

In the two chapters containing a detailed analysis, LTR is investigated by means of the special coordinate basis. The analysis is quite insightful and sheds light on a variety of related problems also. In this context the authors introduce a new concept, *recovery in subspaces*, where the idea basically is to extract for a given system the properties that actually can be recovered and then concentrate upon these.

The chapters dealing with synthesis characterize the degrees of freedom involved with recovery design. Explicit design methods include: eigenstructure assignment, $\mathcal{H}_2$ and $\mathcal{H}_\infty$ optimization, and subspace recovery design.

Also, both for the continuous and for the discrete-time case, closed-loop recovery is discussed. Historically, LTR was formulated as open-loop problems, but obviously, if the design objective is a concrete, closed-loop property, it is more natural to pose the whole problem in a closed-loop formulation. The treatment and the applied methods are in form and spirit similar to the open-loop results.

The final chapter of the book discusses controller architecture in the light of the design problems that have been given treatment in the preceding chapters. As a main point here is the introduction of the so-called CSS architecture (the acronym is formed by the initials of the authors). It is demonstrated that in most cases this controller architecture does significantly better than the classical architectures. One problem, though, is that a CSS controller by construction is internally stable. Since there exist a class of unstable systems that can be stabilized only by unstable controllers, the CSS controllers do not apply always. The CSS architecture is formulated both in terms of full-order and reduced-order controllers.

Since *Loop Transfer Recovery: Analysis and Design* is the first book dedicated to this subject, it is not directly comparable with other monographs. It does, however, in an elegant way combine the tradition from classical monographs on observer theory (like [6]), on loopshaping (like [7]), and on geometric methods (like [8]). In comparison to these references *Loop Transfer Recovery: Analysis and Design* offers a broader and more unified approach to multivariable control synthesis.

III. Conclusions

In short, *Loop Transfer Recovery: Analysis and Design* is a highly recommendable book to everybody who is working professionally with control synthesis, especially on loop shaping and related problems. It is relevant for graduate students in control at a certain level, for university researchers working with state-space and/or observer-based methods, and for practitioners in industry who can benefit from the associated MATLAB$^{\mathrm{TM}}$ toolbox.

To understand the book in detail takes some effort for nonexperts, but the outcome makes it all worthwhile.

References

[1] M. Athans, "A tutorial on the LQG/LTR method," in *Proc. Amer. Contr. Conf.,* Seattle, WA, 1986, pp. 1289–1296.
[2] J. Doyle and G. Stein, "Robustness with observers," *IEEE Trans. Automat. Contr.,* vol. AC-24, pp. 607–611, 1979.
[3] ——, "Multivariable feedback design: Concepts for a classical/modern synthesis," *IEEE Trans. Automat. Contr.,* vol. AC-26, pp. 4–16, 1981.
[4] H. Kwakernaak, "Optimal low-sensitivity linear feedback systems," *Automatica,* vol. 5, pp. 279–285, 1969.
[5] G. Stein and M. Athans, "The LQG/LTR procedure for multivariable feedback control design," *IEEE Trans. Automat. Contr.,* vol. AC–32, pp. 105–114, 1987.
[6] J. O'Reilly, *Observers for Linear Systems.* London: Academic, 1987.
[7] J. M. Maciejowski, *Multivariable Feedback Design.* Workingham, England: Addison-Wesley, 1989.
[8] W. M. Wonham, *Linear Multivariable Control: A Geometric Approach.* New York: Springer-Verlag, 1979.