Book Reviews

The following review was selected from those recently published in various IEEE journals, magazines, and newsletters. They are reprinted here to make them conveniently available to the many readers who otherwise might not have access to them. Each review is followed by an identification of its source.

Optimal Sampled-Data Control Systems—T. Chen and B. Francis (London: Springer, 1995). *Reviewed by Tomomichi Hagiwara.*

I. Introduction

During the last few decades, we have developed numerous modern design methodologies for continuous-time control systems, e.g., H_2, H_∞, μ, and so on. They have been implemented using sophisticated software, providing a convenient environment for control system analysis and design. With the aid of such software, modern control theory makes it possible for a modestly skilled engineer to attain a high-performance control system, whereas classical design methods relied totally on the skill of the engineer. We cannot think of control system design without computers any more, and control theory itself is also becoming more intimate with computers.

Computer technology has changed not only the environment of control system design but also the target hardware and the corresponding mathematical models. It is now common to implement the controller digitally. Digital implementation gives rise to the mixture of continuous-time systems/signals and discrete-time systems/signals and hence necessitates the adaptation of our continuous-time control theory to capture this level of complexity.

The new branch of control theory that arose by paying attention to the problems related to the digital implementation of the controller is modern sampled-data control theory. Formerly, the issue of digital implementation was mainly studied in the area of so-called discrete-time control theory, or digital control theory (or what could be called the classical sampled-data control theory). In contrast to the modern sampled-data control theory, however, those former approaches deal with the behavior of the continuous-time signals in the control system only approximately, because, for instance, the behavior of such signals only at the sampling instants can be taken into account. Although there have been many notable exceptions in which the intersample behavior (i.e., the behavior between the sampling instants) of signals is taken into account to obtain a desirable digital controller (e.g., [1] and [2]), it was not until relatively recently that the exact treatment of the intersample behavior in a general setting has received significant attention ([3]–[5]). Clearly, the development of recent computer technology as well as the continuous-time H_2/H_∞ theory has been the driving force. Modern sampled-data control theory provides us with an exact method for the analysis and design of sampled-data control systems with intersample behavior taken into account completely.

II. The Book

This review is concerned with the book *Optimal Sampled-Data Control Systems*, by T. Chen and B. Francis. The authors are among the pioneers who contributed to the development of modern sampled-data control theory. The main contents of the book are mostly based on their research papers published in the last several years, but it is not a mere collection of those papers; while aiming at the state-of-the-art in modern sampled-data control theory, it is intended to be a graduate textbook, rather than a sheer research monograph. To carry out that ambitious plan, the book is divided into two parts.

Part I treats discrete-time control systems with proper attention to practical situations in which a continuous-time plant is controlled by a digital controller. The subjects studied in this part are more or less the same as those treated in such standard titles on digital control, such as [2], [6], and [7]; noteworthy features of the book under review are the careful selection of topics and the collection of good and practical examples. If we view the book as a whole, however, the purpose of Part I is to provide the preliminaries for Part II, where the main topics of the book, i.e., modern sampled-data control theory, are highlighted in considerable depth. The most important feature that distinguishes this book from any other textbooks is the devotion in Part II to the important idea of continuous-time lifting with applications to the sample-data H_2- and H_∞-control problems. Various properties of continuous-time lifting are exploited to show that these sampled-data control problems can be converted into "equivalent discrete-time control problems"; the fundamental results stated in Part I are then used to solve the latter problems.

Looking more closely at the contents of the book, Chapter 1 describes the basic ideas about sampled-data control systems, including notation and approaches to sampled-data controller design (two indirect design methods and a direct design method). The indirect design methods include: 1) designing a discrete-time controller by discretizing the plant first and 2) discretizing the continuous-time controller obtained by applying some continuous-time design method to the continuous-time plant. Part I deals with these *indirect* methods, while Part II deals with the *direct* design method, a method to design a discrete-time controller for a continuous-time plant without any approximation.

Part I consists of Chapters 2–8. Throughout the book, H_2 and H_∞ methodologies are focused on, so Chapter 2 is devoted to the overview of the continuous-time H_2 and H_∞ control; the contents of this chapter are used in the indirect design method of type 2) (and, later, also serve in motivating the necessity of a direct design method). Chapter 3 studies the issue related to the discretization, of both the plant [for the design method of type 1)], and the controller [for the method of type 2)]. Chapter 4 discusses some general techniques for analyzing discrete-time systems, such as model representations and norms.

Chapter 5 describes fundamental design procedures of discrete-time systems, observer-based controllers, the parameterization of all stabilizing controllers, and step tracking. Next, discrete-time H_2 control, including the linear-quadratic regulator problem, is fully addressed in Chapter 6, while discrete-time H_∞ control is explained in Chapter 7 rather briefly (by reducing the problem into a continuous-time one via bilinear transformation). Chapter 8 deals with fast discretization and discrete-time lifting, which to some extent make it possible to take into account the intersample behavior through evaluating the response at several points between the sampling instants.

In order to take account of the intersample behavior completely, Part II (Chapters 9–13) describes the technique and applications of continuous-time lifting, which can be regarded as the limit of fast discretization, where the number of points taken between the sampling instants tends to infinity. Preceded by Chapter 9 describing the fundamental properties of samplers and holds, Chapter 10 introduces the key notion of continuous-time lifting. The most fundamental ideas and techniques underlying modern sampled-data control theory are revealed in this chapter. Then, Chapter 11 studies the stability issue and tracking problem of sampled-data control systems. Chapters 12 and 13, respectively, give the complete solutions to the sampled-data H_2- and H_∞-control problems, which are natural extensions of the continuous-time H_2- and H_∞-control problems to the case where the digital implementation of the controller is the matter of concern.

III. Conclusions

As reviewed above, Part II describes the state-of-the-art in modern sampled-data control theory, which makes the book very attractive and useful especially for researchers and engineers. This is the first book ever published on the modern sampled-data control system design, covering fairly wide (but, of course, not all) areas in considerable depth, and it is written very concisely. Most of the proofs are self-contained.

At the same time, however, it would be fair to say that the book as a whole is hard for naive graduate students; to quote the authors, Part I is aimed at first-year graduate students, while Part II is more advanced. Also, the conciseness of the description, although preferable for researchers, might sometimes be uncomfortable for those students without enough background in control theory in general and/or mathematics. As for the exercises, they are all very good and carefully designed in such a way that solving them helps the reader understand the ideas explained in the text and become confident with the use of the theory. It is unfortunate, however, that no solutions are provided, since some of them are rather hard.

With all these possible difficulties for some students, this excellent book is quite attractive for use as a textbook because the state-of-the-art theory can be taught, including how to use it, through projects with commercially available computer software—the results in this book are stated in such a way that they can be programmed readily in such software (for instructive purposes, and/or in case your site is not eligible to use an existing commercial module [8]). Hence, the book offers you a resource to give an attractive course in modern sampled-data control theory as soon as you decide to prepare for it.

References

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