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Jump Linear Systems in Automatic Control*

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THE TOPIC OF THIS book is control of uncertain systems. The model is rather specific, it consists of a deterministic or stochastic control system of which the parameters vary over a finite set according to a finite-state Markov process. The book contributes to systems and control, in particular to the research areas of system identification, adaptive filtering, and adaptive control. The character of the book is that of a research monograph. It does not contain exercises.

The audience for whom the book is intended consists of control engineers, and researchers in systems and control. The background required for a study of the book includes control of linear systems, identification, stochastic control of Gaussian systems, and elementary probability and stochastic processes. The level at which these topics should be known is last year undergraduate or first year graduate. The book is quite suitable for self study.

Before presenting a summary of the book's content, it seems appropriate to introduce the model and to motivate its use for control. Consider a control process and a mathematical model of it in the form of a deterministic or stochastic control system. Such a model is in general only an approximation of the control process. Moreover, the dynamics of the control process may change in time. The main control objectives usually are that the controlled system is stable, has satisfactorily transient response, and does not use too much input energy. The control problem is to synthesize a control law that meets these control objectives while keeping account of the uncertainty about the model. Two synthesis procedures are generally considered for this problem, robust control and adaptive control. This book is devoted to the second approach. In adaptive control one assumes that the control system is uncertain and that the character of the control process may change in time.

The book restricts attention to a specific model. The parameters of the control system are assumed to vary over a finite set according to a finite-state Markov process. This process is called the *regime*. The model is realistic only if the time constants of the Markov chain are an order of magnitude larger than those of the control system. The combination of the control system and the finite-state Markov process is called the *hybrid system*. The state of this system consists of the state of the control system and that of the Markov chain.

The finiteness of the parameter values is a reasonable modelling assumption. It supposes that changes in the parameters occur as jumps with long intervals without changes; it excludes slow and gradual movements of the parameters. For adaptive control the hybrid system is an elementary model for which one may expect to derive structural properties of control laws. The author credits Krasovskii, Lidskii, and Florentin with proposing this model around 1961. The author has been inspired by the publications of Sworder on the subject.

A description of the book's content by chapter follows. In Chapter 1 the model for control under uncertainty is introduced and motivated. Examples of control processes with changing dynamics are: a manufacturing process in which machines may be in one of several operating states; a solar thermal receiver in which the controller must adapt to the rapidly changing radiation intensities; control systems that must satisfy high-fault-tolerance specifications as in spacecraft. Chapter 2 presents concepts of controllability, stability, and stabilizability for the class of hybrid systems with linear control systems. Examples are presented that show the interaction of the continuous and discrete parts of the hybrid system.

Control synthesis starts in Chapter 3. Attention is restricted to a deterministic time-invariant finite-dimensional linear system of which the parameters are modelled by a finite-state Markov process. In the complete observations case both the state of the control system and the regime are observed. The set of admissible control laws includes only functions of past states and the past of the regime. The cost function is the expected value of an integral of a quadratic form in the state and the input process. The optimal control law is linear in the state while the parameters of the control law depend on the regime. For each regime there is a set of coupled Riccati equations, coupled to those of other regimes. The methods to derive the control law are dynamic programming and use of a maximum principle. Optimal control with partial observations and synthesis of suboptimal control laws are also covered. Computation of the control law requires solution of the coupled set of Riccati equations. For this a successive approximation algorithm and a homotopy algorithm are described and illustrated with examples.

Chapter 4, titled "Robustness", actually concentrates attention on the sensitivity of performance measures for changes in the model and in the control law. The cost criterion used in the preceding chapter is the expected value of an integral of a quadratic form in the state and input process. In this chapter the distribution of the integral is considered. In statistical decision theory it is common practice to use nonlinear utility functions that will bring out the risk-sensitivity of a statistical decision problem. In stochastic control the emphasis on minimum variance control and on the Linear Quadratic Gaussian (LQG) problem has long obscured the risk-aspect of control of stochastic systems. Only the recent interest in the exponential cost criteria has rekindled interest in the risk-sensitivity of stochastic control problems. In this chapter attention is focused on the variance of the integral cost, on the probability that the integral cost exceeds a specified bound, and in a special case on the distribution of the cost. The effect of different feedback laws on these performance measures is evaluated. Next a minimax solution is derived in which the upperbound on the support of the integral is minimized. Another viewpoint is that in which the regime process is chosen by nature. The optimum is obtained for a constant regime, hence the optimal control problem reduces to a deterministic control problem. This result is called an *equalizing solution*.

In Chapter 5 the jump linear quadratic Gaussian regular problem is considered. The continuous-time stochastic control system is described by a stochastic differential

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IEEE Transactions on automatic control, vol. 45, no. 5, may 2000. Output Feedback Control of Markov Jump Linear Systems in Continuous-Time D. P. de Farias, J. C. Geromel, J. B. R. do Val, and O. L. V. Costa. Abstractâ€”This paper addresses the dynamic output feedback control problem of continuous-time Markovian jump linear systems. The fundamental point in the analysis is an LMI characterization, comprising all dynamical compensators that stabilize the closed-loop system in the mean and -norm control problems are studied, and square sense. The the and filtering problems are solved as a by produc