Computer-Aided Design of Feedback Control Systems for Time Response

Clarence J Maday

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Preface

The material in this "how-to" book builds upon a first course in classical control. Appropriate concepts from modern control are used. Explanations are based upon the author's insight and intuition gained through his experience with dynamical systems. In particular, the author tries to show how error compensation networks are developed. In most classical control courses, this topic is usually scheduled near the end, which often means it is not covered. This problem is addressed directly here because the subject of error compensation unifies the presentations in the book.

Frequency domain analysis herein is limited to pole assignment. Time domain analysis through numerical simulation dominates the presentation. In linear systems, the solution to the eigenvalue problem gives only a glimpse of the system response. In large systems, we can determine stability and a bit about oscillatory behavior. The usual worth of a picture — 1000 words — certainly holds true here. In nonlinear systems, numerical simulation may be the only available tool. The first system in Chapter 3 is nonlinear and emphasizes this. This is also true for linear digital systems where the sampling frequency is only two to five times greater than the highest system frequency. Such cases are described in Chapter 5. Frequency domain analysis for digital systems generally provides only little insight into the transient behavior of the system. The situation becomes virtually intractable when one tries this approach to evaluate the robustness of the system.

The material in Chapter 6 on the error observer has not been published or described before. Beyond its novelty, the error observer establishes a neat connection between classical control and modern control.

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Clarence J. Maday
Raleigh, NC

CHAPTER 1

Introduction

Historical accounts trace the use of self-regulating or feedback control systems at least as early as the third century B.C. Given the ingenuity of man, we can conjecture that earlier uses may have gone unnoticed because the inventor neglected to document such efforts. The recorded history of automatic control, however, is fascinating, and the interested reader can refer to one of the available monographs for a detailed account. We note only that today we tend to think primarily in terms of classical control and modern control. The topic usually called classical control was developed in a period that extended from the late 1930's to the early 1950's. Pontryagin's *Maximum Principle* renewed interest in state-space methods, and the general availability of high speed digital computers contributed to the development of what is called modern control theory. It has been noted in the literature that the term *modern* may be somewhat inappropriate because state-space or state variable techniques date back to the work of Poincare, Gibbs and Lyapunov around the beginning of this century. Nonetheless, the application of these methods to the analysis of control systems has proven to be valuable, and there is every indication that new developments will continue. It is generally agreed that *modern control* includes the state variable methods just indicated, as well as optimal control and digital control.

Optimal control has given us the linear quadratric regulator (LQR), and its counterpart, the linear quadratic servomechanism, both of which use complete state feedback. Difficulties are encountered when one or more of the states are inaccessible, i.e., they cannot be measured in the physical setting. The concept of the observer, which synthesized the missing states, was put forward to overcome this problem.

Digital control or sampled-data systems experienced a surge of interest during the 1950's when much of the theory was developed. Interest in these systems is renewed at the time of this writing because of the availability of very high speed microprocessors. Moreover, digital systems offer the potential of handling numbers with precision and with accuracy.

The need for feedback in electromechanical systems, chemical process control, aerospace guidance systems, internal combustion engines, and precision machining is accepted today. Feedback control systems are widely used and may be taken for granted. In view of this, it seems appropriate to reexamine the purpose of a feedback controller and to question our expectations of such a system. In short, what do we expect of an automatic feedback control system? For single-input, single-output (SISO) systems we expect the feedback system to be better than the sum of its constituent components. That is, the closed-loop performance of a controller should be superior to its open-loop performance. We expect also that the system will track faithfully any reasonable input command. Moreover, it should continue to perform well with approximate models of physical systems, and it should be insensitive to external disturbances; that is, it should be robust.

Let us consider a seemingly simple example that highlights these requirements and also serves to introduce more sophisticated concepts. The temperature control of a house is the example. The control element is an on-off heating/cooling device controlled by a thermostat, which is also an on-off device, often with a thermal anticipatory provision. The model of the house is generally taken to be a first-order one whose elements are known only approximately. Outdoor temperature variations and opened doors and windows are external and usually unpredictable disturbances. Yet the system works well even if it does not lend itself to linear analysis. We keep in mind the on-off character of the controller as a desirable feature for a controller because this