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Automatic Control with Experiments

Springer

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To Judith, my parents, and my brothers.
To the memory of my grand-parents.

Victor.

To my wonderful children – Ale, Rhomy,
Robert, and Rhena – and to my mother.

Ramón.

Foreword

Control systems are described by differential equations; hence, mathematics is an important tool for the analysis and design of control systems. This is the reason why most books on control systems traditionally have a strong mathematics content. However, control systems are also part of engineering and it is practical engineering problems that have motivated the development of control systems as a science. As the influence of advanced mathematics on the subject has grown over time, the modern control design techniques become less comprehensible each time to practitioners. Moreover, this problem is so important that it is also present on basic control courses, i.e., courses on classical control. Because of this situation, several control system scientists have pointed out the necessity of reducing the gap between theory and practice.

Automatic control with experiments is a book intended to reduce the gap between theory and practice in control systems education. The book focuses on classical control techniques and modern linear control techniques. The first chapters of the book are devoted to theoretical aspects of these control techniques, whereas the last chapters are devoted to practical applications of this theory. Moreover, several theoretical examples in the first chapters of the book are intended to be employed in the experiments reported in the latter chapters of the book.

Practical applications presented in the book include feedback electronic circuits (amplifiers with dead-zone, sinusoidal oscillators, and regenerative radio-frequency receivers), brushed DC motors, a magnetic levitation system, the ball and beam system, a mechanism including flexibility, and some systems including pendulums. All theoretical and practical aspects that are necessary to design and to experimentally test the complete control system are described for each prototype: modeling, plant construction and instrumentation, experimental identification, controller design, practical controller implementation, and experimental tests of the complete control system.

Another important feature of the book is that the reader is instructed how to build her/his own experimental prototypes using cheap components. The main objective of this is that the reader has his or her own experimental platforms. In this respect it is the authors' experience that the use of scholars' facilities is restricted in both time and space. Thus, this proposal of the book is attractive.

The electronic components employed are basic and the authors know that today's technology offers more powerful alternatives. However, the subject of the book is automatic control, not electronics or programming languages. Hence, it is the intention of the authors not to divert the reader's attention from automatic control to electronics or computer programming. Thus, the electronics and programming are kept as simple as possible. It is the authors' belief that once the reader understands automatic control she/he will be capable of translating the simple designs in the book to sophisticated platforms based on modern advanced electronics and programming technologies.

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Preface

Automatic control is one of the disciplines that support the technologically advanced lifestyle that we know today. Its applications are present in almost all the activities performed by humans in the twenty-first century. From the Hubble spatial telescope and spacecrafts, to the fridge at home used for food preservation. From residential water tanks to large industries producing all the products demanded by people: automobiles, aircrafts, food, drinks, and medicines, to name but some.

Although it is known that applications of automatic control have existed for more than 2000 years, the Industrial Revolution motivated its development as scientific and technological knowledge oriented toward the solution of technological problems. Since then, automatic control has been instrumental in rendering human activities more efficient, increasing the quality and repeatability of products.

It is for this reason that courses on automatic control have become common in academic programs on electrical engineering, electronics, mechanics, chemistry and, more recently, mechatronics and robotics. However, the fact that conventional automatic control techniques are based on mathematics has traditionally posed difficulties for education in this subject: to learn to design automatic control systems the student is required to understand how to solve ordinary, linear, differential equations with constant coefficients using Laplace transforms. This is an important obstacle because this subject is commonly difficult for most undergraduate students. The problem becomes worse because in automatic control the most important part of solving a differential equation is the physical interpretation of a solution, which is difficult for undergraduate students because most do not even understand how to find the solution.

Another difficulty in automatic control education is how to teach students to relate abstract mathematical results to the practical issues in a control system. How do they implement a controller given in terms of the Laplace transform, i.e., as a transfer function in practice? How do they implement a controller using digital or analog electronics? How do they take into account sensors and power amplifier gains? How do they determine the gain of a pulse width modulation-based power amplifier? What are the effects of these gains in a control system?

The problems related to the practice described in the previous paragraph have been traditionally solved using commercial teaching prototypes. However, this has two drawbacks: (1) this equipment is excessively expensive and (2) many practical issues in control systems remain “invisible” for students. This is because this equipment is designed under the premise that it is not necessary for an automatic control student to know how to solve practical issues related to electronics and programming, for instance, that are present in several components of a control system. This is a case of how do we build a power amplifier? How do we design and implement a controller using operational amplifiers or a microcontroller? How do we build our own sensors?

The present textbook offers undergraduate students and professors teaching material that is intended to solve some of the above-mentioned difficulties. To render the learning of theoretical aspects easier, a chapter devoted to solving ordinary, linear, with differential equations with constant coefficients using Laplace transforms is included. Although this chapter may be seen as a course on differential equations, the main difference with respect to a mathematics course is that our book is intended to help students to interpret the solution of differential equations. Furthermore, effects that the differential equation parameters have on the solution waveform are highlighted. According to the experience of the authors, automatic control textbooks in the literature merely present a compendium of solutions of differential equation and they do not succeed in making students reason what they are doing. To overcome this problem, in the present textbook, we resort to explaining differential equations through examples that every undergraduate student has observed in real life, i.e., we resort to students’ everyday experience to understand the meaning of mathematical results.

Difficulties related to practical aspects in control systems are overcome through applications in several experimental control systems. Each one of these examples is studied using the same procedure. First, tasks performed using the control systems under study is described. Then, a complete explanation is given to the reader on how to build each one of components of that control system. After that, it is shown how to obtain the corresponding mathematical model and it is explained how to experimentally estimate the numerical values of the system mathematical model parameters. Automatic control techniques studied in the first chapters of the book are then used to mathematically design the corresponding controller. It is also explained in detail how to practically implement the designed controller using either digital or analog electronics, and, finally, results obtained when testing the designed control system experimentally are presented.

The present textbook is organized as follows. Chapter 1 presents a general view of automatic control systems. The aim is to explain to the reader the main ideas behind designing automatic control systems. This is achieved using several practical examples whose main tasks are well understood by most people: a position control system, a steering control system, a video camera recording control system, etc. A brief history of automatic control is also presented and related to the content of this book. The idea is to render the reader capable of identifying reasons why each automatic control tool and concept has been developed. Chapter 2 is devoted to physical system modeling. This chapter is oriented toward physical systems that are common in electrical, electronics, mechanics, and mechatronics engineering. One important reason for including this subject is that the reader realizes that control systems are described by ordinary, linear, differential equations with constant coefficients. This motivates the solution of differential equations in Chap. 3, as this is instrumental to understanding how a control system responds and what the designer has to modify in a control system to achieve the desired response.

Mathematical tools employed to design classical and modern control systems are presented in Chaps. 4 to 7: stability criteria and the steady-state error (Chap. 4), the root locus method (Chap. 5), the frequency response approach (Chap. 6), and the state variables approach (Chap. 7). Exposition of these subjects is oriented toward their application to practical examples presented in subsequent chapters of the book. Hence, several examples in the first chapters of the book deal with the design of controllers that are practically implemented and experimentally tested in the later chapters.

Chapter 8 is included to study the theory required to understand some interesting phenomena appearing during experiments when controlling some of the mechanisms in the last chapters of the book. This is the case of: (a) large overshoots observed even when all closed-loop poles are real, and (b) limit cycles in the Furuta pendulum. Furthermore, a methodology useful for selecting controller gains such that limit cycles are avoided is proposed using ideas in this chapter.

The structure of Chaps. 9 to 16 is the same, as they have the same objective: the application of control techniques in Chaps. 4 to 8 to analyze and design practical control systems. The designed controllers and the complete control systems are practically built, employing low-cost components. Finally, experimental results obtained when testing the complete control systems are presented.

In Chap. 9, several feedback electronic circuits are studied and designed. Among them are some sine-wave oscillator circuits based on operational amplifiers (audio-frequency) and bipolar transistors (radio-frequency), in addition to some power amplifiers and a regenerative radio-frequency receiver. In Chaps. 10 and 11 velocity and position are controlled respectively in a permanent magnet brushed DC motor. Position of a mechanical system with flexibility is controlled in Chap. 12. A magnetic levitation system is controlled in Chap. 13 whereas a ball and beam system, a well-known mechanical system in the automatic control literature, is controlled in Chap. 14. Finally, in Chaps. 15 and 16, two mechanisms including a pendulum are controlled: the Furuta pendulum and the inertia wheel pendulum.

The authors hope the readers this material find useful.

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