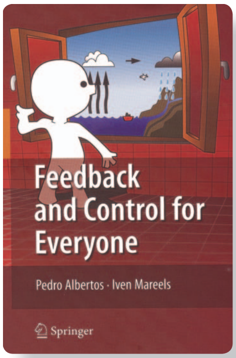
IEEE Control Systems Magazine welcomes suggestions for books to be reviewed in this column. Please contact either Michael Polis or Zongli Lin, associate editors for book reviews.



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Feedback and Control for Everyone

By PEDRO ALBERTOS and IVEN MAREELS

Reviewed by JAN C. WILLEMS

Books of the kind written by Albertos and Mareels are very rare but very needed. The goal of the book is to explain in layperson's terms the essence of feedback and the basic tenets of the field of systems and control. The exposition aims at readers with a modest technical background. The relevant concepts are explained through prose and mathematics, through a wealth of multidisciplinary examples, and through block diagrams, graphs, photographs, and pictures. Each chapter begins with a humorous cartoon and one or two quotations. There are many footnotes, often with anecdotal tidbits about scientists figuring in the text and what these persons are famous for. All this livens up the reading. The book is carefully edited with highlighted text to summarize the key points.

The authors explain their motivation for writing this book in a nicely written preface. I quote from it:

> Colleagues, friends, collaborators often ask natural questions like: So, what do you study in control? […] What are the key results? In reply we can point to a wealth of technical literature, rooted in mathematics. […] Our apologetic replies, complemented with the odd reference to the history of the field or some systems philosophy, invariably raises eyebrows, and evokes surprise, disbelief and disapproval.

The authors then state that they ran out of excuses for deploring the absence of general expositions where these questions are answered and that they took up the challenge to write this book explaining the field of control to *everyone.*

The result, *Feedback and Control for Everyone*, is a heroic effort and a work of love, diligence, and perseverance. As a reviewer I am genuinely impressed by the ambition that transpires from this book, by the range of ideas it enters into, and by the breadth of applications presented.

In my review, I will explain what I consider to be its virtues and its shortcomings. Before coming to that, let me briefly list the contents, chapter-by-chapter.

There are 12 chapters, each 20–30 pages in length. Chapter 1 contains a general introduction to feedback, inputs, outputs, systems, block diagrams, and the basic control loop. In the second chapter the authors consider analogies. Through the use of signals and their properties it is possible to classify phenomena from a wide variety of disciplines using a unified set of features. This is viewed as the essence of the systems perspective. The third chapter focuses on feedback and control through examples from a wide variety of disciplines. The fourth chapter is devoted to signal analysis. Fourier series are treated in detail. Also, Fourier integrals and Laplace transforms are defined. Starting with this chapter, the development becomes more mathematical. Chapter 5, "Systems and Models," deals with interconnection of systems, transfer functions, Bode plots, and state-space models. Chapter 6 treats a wide variety of ideas surrounding stability issues, in particular, Lyapunov theory, tests in terms of the eigenvalues of system matrices and polynomials, and input/output stability. The next chapter discusses feedback and its effect on stability, sensitivity, and disturbance rejection. The cybernetic aspects of control are the topic of Chapter 8 with the tradeoffs between open loop, feedforward, and feedback. Controllers as system components are presented in Chapter 9, with sensors, actuators, computer control, and PID control. The next chapter explains elements of controller design, from logic controllers and PID tuning rules all the way to model predictive control. Chapter 11 considers effects and advantages of control in medicine and in industrial applications. The last chapter takes a look into future application areas of the field, as network control, robotics, artificial intelligence, and systems biology.

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The goal of the book is to explain in layperson's terms the essence of feedback and the basic tenets of the field of systems and control.

The book is quite dense with information. Almost all areas of the field are to some extent discussed. The book goes rather deeply into signal analysis, sensors, and networks. We meet periodic signals, stochastic signals, even chaos (on more than one occasion). Simple PID feedback, logic control, as well as decoupling, robustness, adaptive control, and model predictive control are all discussed. The book contains a very wide range of examples, illustrated by block diagrams, color figures, pictures, and photographs. The technological examples range from hydraulic systems to distillation columns and kilns, from disk drives to motors and electronic audio systems, from flocking to cars and transportation systems, and so forth. There are many biological and physiological examples. In addition there are also examples drawn from our immediate environment where feedback is perceived to be active, such as teacher/student interaction, temperature control in a shower, and our body's temperature regulation system. The rich range of examples is quite demanding. It requires the reader to concentrate. The exposition shies away from overly abstract and vague explanations that are all too often characteristic of areas that emphasize systems thinking as, for example, general system theory.

The sheer breadth of topics presented is impressive. But the book also suffers from some shortcomings. I will now discuss two of them in some detail. The first shortcoming is the mathematics. The second is the use of input/output thinking.

The authors have made a laudable effort to make the book accessible and self-contained as far as the mathematics is concerned. However, I feel that they have not been particularly successful in this effort. By trying to avoid complicated statements, the exposition frequently become confusing. Permit me to give a few instances of such slips.

- In Section 4.2.2 it is explained that "almost all" periodic signals can be represented as a sum of sinusoidal signals. Here, the "almost all" is certainly acceptable for signals defined on a finite time interval. But the statement in Section 4.3 that "almost any" signal can be expressed as a Fourier integral carries, in my opinion, the "almost any" beyond its permissible limit. "Almost no" would in a sense have been more accurate. To state that almost every function belongs to $\mathscr{L}_2([0,T])$ is acceptable, but to state that almost every function belongs to $\mathscr{L}_2((-\infty, +\infty))$ is confusing. In any case, the convergence of Fourier series and integrals is easily explained in an informal and yet reasonably precise way.
- The explanation of Fourier and Laplace transforms and their inversion in Section 4.3 through cold formulas with integrals without limits is confusing even for the initiated and incomprehensible for the uninitiated. In fact, throughout the book there is a liberal use of integrals without limits, which are strange mathematical expressions.
- On page 188 it is stated that input-to-state stability requires that the loop gain be less than one. I fail to understand why input-to-state stability is preferred above input-to-output stability here and elsewhere in the book, as well as in many other places in the literature. More seriously, however, is the complaint that the loop gain being less than one is not a *requirement* for stability, but simply a conservative sufficient condition.
- In Section 6.4.1 the difference equation $y(k+n) + \alpha_{1y}(K+n-1) + \cdots + \alpha_n y(k) = 0$ is studied. It is stated that using $\mathscr{Z}$-transform this equation leads to $(z^n + \alpha_1 z^{n-1} + \cdots + \alpha_n)y(z) = 0$. I will not quibble with the use of the same symbol for a function and its $\mathscr{Z}$-transform. But I am not sure what this last equation is supposed to imply; it seems to say that $y(z) = 0$ but that cannot be the aim. It is confusing to mix up the shift (an operator) with the $\mathscr{Z}$-transform variable (a complex number).
- On page 177 it is stated as a highlight that "A system is stable if its behavior (which includes all initial conditions) has the property that for all bounded inputs, all conceivable signals are bounded." The "all conceivable" part of this statement is meaningless at best and wrong at worst.

My second point of criticism has a more personal flavor. My gripe aims more at the field as a whole, but the present book gives me the opportunity to enter into the issue of the perceived universality of input/output thinking.

Is the universal picture of a system as a black box driven on one side by inputs and producing outputs on the other side useful and universal? The input/output partition is surely very effective pedagogically as an "intuition module" by allowing us to visualize what influences what. It is also convenient mathematically for viewing a system as a map acting on inputs in the domain of the map and producing outputs in the codomain of the map. But do physical systems act as input/output devices? Yes, they sometimes definitely do. But not always. As a general picture the input/output black box is misleading. Typically, physical systems interact with their environment through terminals, and there is usually more than one variable associated with each individual terminal: a current and a voltage for an electrical wire, a force and a position for a mechanical pin, a heat flow and a temperature for a thermal duct. In many situations it is indeed possible to partition these variables into inputs and outputs. Nevertheless, the classical picture of a system with an input on one side and an output on the other side is unfortunate and misleading pedagogically. It shows two variables on two distinct terminals, whereas in reality they live on one and the same terminal. The picture suggests that the input and output variables act at different points, whereas in reality they act at one and the same point. A physical system is not a signal processor.

Is it really true that systems interact by letting the output of one system become the input to another system, as stated on page 121 of the book? I have discussed this question in detail in an article in the December 2007 issue of *IEEE Control Systems Magazine*. Figure 6 of that article explains my disagreement with the output-to-input assignment view of interconnection. Interconnected systems interact by variable sharing. When we solder two electrical wires together, we identify two currents and two voltages. When we screw two mechanical pins together, we identify two forces and two positions. When we weld two thermal ducts together, we identify two temperatures and two heat flows. It is seldom useful to view this interconnection as *two* output-to-input assignments [see Figure 6(c) of the article mentioned above]. What is imposed physically is variable sharing. There are no arrows on the interconnecting terminals. Signal flow graphs are not an appropriate way of representing the interaction between physical subsystems. An interconnected physical system is not an interconnection of signal processors.

Is feedback as universal an idea as we are led to believe by this book? Yes and no. Feedback is an excessively important idea in control and decision making. No question about that. The idea to act on the basis of observations is the very basis of rationality. But to view feedback as a universal phenomenon is a bit banal. When we connect two terminals of subsystems we impose variable sharing on the terminal variables. Consequently what happens or will happen in one of the subsystems influences what happens in the other subsystem and vice-versa. Often people suggest that $(d/dt)x_1 = f_1(x_1, x_2)$, $(d/dt)x_2 = f_2(x_1, x_2)$ shows that x_1 influences x_2 and vice-versa. Is it useful to elevate these vice-versas to a demonstration of the universality of feedback? I am skeptical. Principally because it demeans sensor-to-actuator feedback, acting on the basis of observations, to a mere synonym for interaction.

The enthusiasm for feedback as a big idea expressed in this book is contagious and endearing but cannot withstand scrutiny, I am afraid. The very first example given in the book is a thermostat. It is stated that "feedback is at the heart of it." But is it really? I fail to see what a thermostat as a device has to do with feedback. Yes, of course, by using the output of a thermostat to drive a heating system and use the temperature caused by the heating system as the input makes the thermostat part of a feedback loop.

The question emerges whether this book is really for *everyone*. If so, this everyone must not just be anyone but rather someone very special. No one can convince me otherwise. The book is not an easy read for a layperson. It requires interest in a very large range of technological applications and familiarity with mathematics.

A book about systems and control written with the explicit aim to be accessible *for everyone* faces the challenge that not everyone is conversant with mathematical language. To cope with this, the authors make a serious attempt to introduce all the mathematics they need from scratch. There is, for example, a highlighted explanation of complex numbers on page 92 comprising addition and multiplication, and ending up with $e^{j\pi} = -1$, a "rather remarkable property" as the authors call it. I would have taken up the occasion to explain to *everyone* that $e^{j\pi} + 1 = 0$ is so remarkable because it combines in one simple formula $e, \pi, j, 1, 0$, basic constants of physics, geometry, algebra, and arithmetic. Further, is it reasonable to assume that a layperson reading this book needs reminding of what a complex number is, while assuming that e is common knowledge?

Another item that must be quite a stumbling block for the uninitiated is the liberal use of transfer functions in the book. Discussing systems through transfer functions defined by Laplace and $\mathcal{Z}$-transforms and yet hoping to reach a general audience is unrealistic. It simply cannot be done. *Laplace transforms for everyone* is, in my opinion, an oxymoron. By introducing transfer functions through differential equations and exponential responses, one may be able to reach a larger audience. But I am afraid that even this audience would not have included our dear egalitarian friend "everyone."

Feedback and Control for Everyone is not a textbook. It is a worthwhile attempt to outline the main ideas about feedback control to laypersons. It shies away from the precision and rigor of mathematics. But the wealth of physical examples to illustrate the ideas and concepts make it an excellent source for anyone who wants to learn what the subject of feedback control is all about. It can also serve as a useful companion in elementary and intermediate courses on the subject.

REVIEWER INFORMATION

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