Do You Have a Control Tool or a Control Toolbox?

In most universities, control engineering is not its own department but is usually a small component of a much larger department in a traditional engineering discipline, such as electrical, aerospace, mechanical, or chemical engineering. As such, most engineers graduate with very little to no knowledge of control, despite the fact that nearly all modern products are efficiently manufactured to specifications only through the implementation of feedback control systems and that many modern products, from airplanes to robots to automobiles, would not function without feedback control systems.

This situation means that control faculty need to think carefully about which content should be contained in the limited number of control courses that will be taken. One approach taken in many engineering programs is to have a single undergraduate course focusing on single-loop, single-output transfer function methods, preferably in conjunction with laboratory experiments, and to have introductory state-space methods be the focus of the one graduate control course that serves as the prerequisite to later graduate control courses. The focus of later graduate control courses at many universities is in the research area of the control faculty teaching the course(s), which is understandable as researchers consider their research area to be very important and the most fun topic to teach. Some graduate programs in control engineering strive to provide a balanced suite of control engineering tools upon graduation, but the scope of content is limited by the small number of courses in most programs and by the expertise and interests of the control faculty.

Control engineering graduates from our programs should be trained to be "toolbox people" rather than "tool people."

Based on my experience in interacting with control engineers graduating from a wide variety of engineering departments worldwide, most recent graduates are comfortable with applying only one control *design* tool. Most graduating control engineers understand some basic stability analysis tools—such as Nyquist plots, the poles of a transfer function, or the eigenvalues of the A matrix—but their ability to actually *design* practical control systems is more limited. Most graduating control engineers have a basic knowledge of linear quadratic control theory, perhaps learned from the introductory state-space control course, but are not comfortable with designing such a feedback controller for a real application. A typical Ph.D. graduate in the control field has a strong background, familiarity, and comfort level only with the control design tool that was the focus of the Ph.D. thesis.

Most Ph.D. control engineers are not able to design an effective control strategy for a real application with multiple inputs and multiple outputs and do not know how to practically deal with nonlinearities, spatially distributed states, and model uncertainties. Many Ph.D. graduates in control theory do not know how to deal with actuator or state constraints, which are ubiquitous in real applications. The number of graduates with some expertise in constraints has increased in recent years due to the popularity of model predictive control research among many control faculty, with the downside being that fewer Ph.D. graduates in the control field are effective in designing a high-performance feedback control system for a system with a fast sampling rate.

The production of control engineering graduates with a limited control toolbox is partly a result of control engineering not being a "traditional" engineering discipline. There is an expectation that the graduate of traditional engineering disciplines has taken certain specific courses with an understanding of how to apply the tools learned in those courses. For example, an electrical engineer is expected to have taken courses in circuit analysis, digital electronics, and signal processing, and a mechanical engineer is expected to have taken courses in statics, dynamics, and strength of materials. This expectation is reinforced by exams that need to be passed before an engineer can be a "professional engineer" and by organizations that accredit engineering programs

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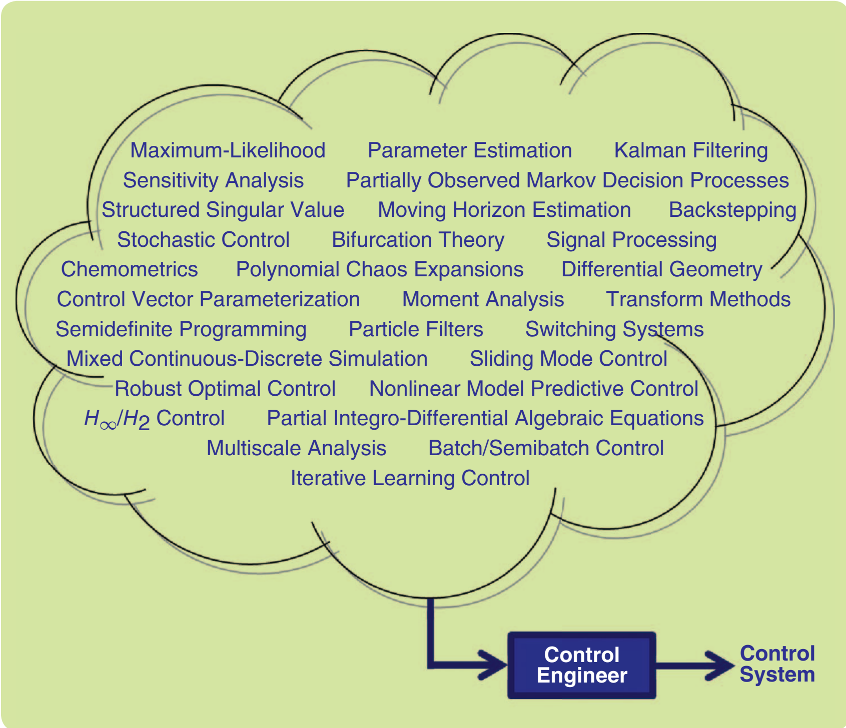

FIGURE 1 The choice of the most effective control tool strongly depends on the needs of the particular application (adapted from [2]).

such as the Accreditation Board for Engineering and Technology (ABET) in the United States [1]. This lack of professional standing and accreditation for control engineering in most countries is partly the reason that most curricula are not optimized to produce the most effective control engineers, that is, control engineers who can draw from a broad set of control tools to produce the most effective solution for a particular control application.

A control theorist must be deep in at least one specialized topic to successfully push control theory forward, and control theorists should not throw away their deep specialization to have only shallow knowledge in many areas of control theory. On the other hand, many engineering departments have multiple control faculty, and it is reasonable that, collectively, faculty could design and teach a curriculum with the objective of producing graduates who have a wide set of practically useful control tools in their toolboxes. A control engineer who is an expert in only a single control tool can be less useful than a carpenter who only knows how to use a hammer (see Figure 1).

In other words, control engineering graduates from our programs should be trained to be "toolbox people," people who have a rich toolbox of systems and control techniques, rather than "tool people," people who know how to use only a single tool.

REFERENCES

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Richard D. Braatz

An Emerging Period of Control

Three characteristic periods can be distinguished in the development of the theory of automatic control. For convenience, they are briefly called the periods of determinism, stochasticism, and adaptivity. … At the present "long-suffering" time (from the standpoint of automatic control theory), we become more convinced each day that in the modern complex automatic systems which operate in the most diverse conditions, the equations of the controlled plants and the external actions (or their statistical characteristics) are not only unknown, but that for certain reasons, we do not even have the possibility of determining them experimentally in advance. … Although all this makes the control of such plants more difficult, it still does not make this control impossible in principle. This is evidenced by the emergence of a new, third period in the theory of control—the period of adaptivity.

—Ya. Z. Tsypkin (translated by Z. J. Mikolic),
Adaptation and Learning in Automatic Systems, Academic Press, New York, 1971, p. 1,
(First published as *Adaptatsia i obuchenie v automaticheskikh sistemakh*, Nauka, Moscow, 1968)