Theorem and Look-up Table

"Book sales are inversely proportional to the number of equations in the text."
Proverb from the publishing industry.

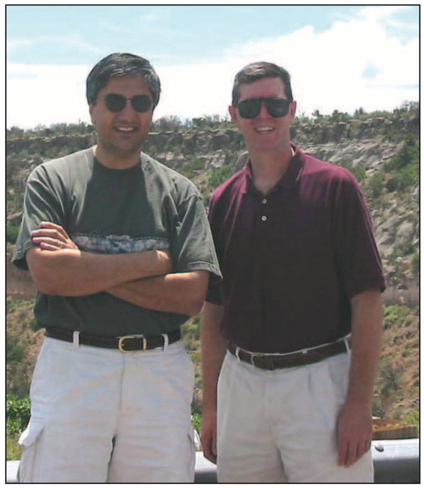
To the nontechnical reader, equations look like a jumble of meaningless symbols. This observation is not confined to the mathematically challenged. If a typical control engineer were to pick up a book on, say, quantum chromodynamics, chances are they would have little idea what most of the equations mean. For someone who doesn't understand a subject, equations can be impenetrable.

Everyone who works in engineering has equations that they know, love, and respect. For example, a control engineer looking at $S = 1/(1 + L)$ can learn a lot about how a feedback system works. This equation is the bedrock from which nuances and variations are investigated ad infinitum.

Sooner or later, however, we have to admit that equations take us only so far. Every equation is wrong to some extent, and has limited usefulness. $F = ma$ is a good starting point, but try connecting a few flexible bodies, spinning the entire assembly, and throw in some damping and thermal effects. Things can get complicated rather quickly, and, when we can barely fit the equations on a page, we get little insight. Even computation becomes difficult.

Sometimes we simply don't have an equation to show us the way. When that happens, engineering becomes empirical. We build a test setup, we take a lot of data, and we fit curves or construct look-up tables. Engineers do this all the time, creating pseudo-equations to make up for a lack of "real" equations or perhaps to replace complicated equations with simpler ones. Our equation culture is often reluctant to acknowledge the need for this real-world approach.

The control community is not unique in its use of equations, but control engineers do have a certain love-hate relationship with mathematical models. Equation-based and empirical models are always approximations, and thus have limited applicability. So control system engineers—like all engineers but more so—know that every model is deficient in some way, and we proclaim it guilty from the start. We know there are always missing effects, and we know that the parameters can never be known perfectly. In fact, even if the parameters are estimated well, we face the possibility that their values might change the next time the system is restarted or the environment changes. As we eke out every drop of performance from a control system, we're increasingly forced to treat models with suspicion. The most trivial unmodeled details, such as a loose nut, can destroy the validity of a model.



Chaouki Abdallah of the University of New Mexico and Dennis Bernstein (right), along the road to Los Alamos in July 2004.

Beyond our distrust of equations and models, control research stands out among most branches of engineering through its mathematical culture. While all branches of engineering use advanced mathematics, control theory is traditionally and routinely written as theorems and proofs. Why do we do this when most other areas of engineering do not? By writing in this formalized style, we discourage outsiders from reading our books and journals, and we contribute to the, sometimes valid, accusation that control theory is "merely" a branch of applied mathematics, hiding meager physical insights behind needless abstraction.

In this 50th anniversary year of the IEEE Control Systems Society, we can be extremely proud of the accomplishments of control systems technology. Control loops led the way (literally, if not figuratively) to the moon and operate unceasingly without fanfare in a vast range of machines and systems. Yet, there is one thing that we can be most proud of. We have worked hard to express our ideas and methods, not just in equations per se, but in careful mathematical terms and arguments. By abstracting the essence of control principles, our techniques are universally applicable, our foundation is solid, and we help bridge the gap between the physical world and the world of idealizations. Our systems discipline and its foundation of rigorous mathematics can be a guiding light to all engineering disciplines, adding clarity, precision, and logic to physical insight. I can think of no greater intellectual contribution of our profession to the engineering community at large for the next half century.

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