

# Boston University College of Engineering

## NEWSLETTER

*"For every one piece of information I give the students, I think I should know ten times more."*

Anuradha Annaswamy



### Keeping a Variable Very Precise— Between Limits

Balance a broom upright in the palm of your hand. The pole sways, your hand dips to save it, the broom stays on end—if you're good.

This careful juggle is, in a sense, what's studied by Anuradha Annaswamy, assistant professor of aerospace and mechanical engineering: the process, theory, and application of controlling unstable systems.

"Even as the robot is moving, as the jet turbines are turning," says Annaswamy, her research seeks to identify and measure a critical variable and use that information to increase efficiency

"Everything stems from the point of view of performance. You want to push that performance just a little bit more. For example, in product purity, you want to make [a product] efficient and, at the same time, cost effective; [or in] a big building, you try to control the temperature or humidity, and those variables change with time as people come in and out of the building, and vary the thermostat setting. It's [with] questions like these, where you want to keep a variable very precise, in between the two limits, or you want to maintain it optimally, that the whole issue of control comes about. And when the issue of control comes about, there's a need for theory and that's what my research is about." To do this work, Annaswamy continues, "you study the dynamics of the problem, using the physics that tells you how [the given system] behaves. That gives you a predictive edge, and you use that information to actively control the inputs to the system."

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Which brings us back to the broom. "What do human beings do to balance this pole? We keep watching how it moves away from the vertical, and how fast it moves. Essentially we measure the angular position, the angular velocity and we use that information to decide, okay, this is by how much I'm going to move my hand.

"Adaptive control says: 'If systems characteristics are going to change, how are you going to build controllers that will control them in a satisfactory manner, and at the same time give stable performance?' You try to collect as much information about the system as possible, and you adjust your controllers very carefully.

"The control theory we came up with," says Annaswamy of her work with Professor Kumpati Narendra of Yale University

"provides the principles under which you can adjust these controllers." Narendra and Annaswamy wrote *Stable Adaptive Systems* (Prentice Hall: 1989) and the winner of the George Axelby Outstanding Paper Award for 1986-88 from the journal *IEEE Transactions on Automatic Control*.

Annaswamy's approach includes "qualitative theory of differential equations, stability theory, analytical and algebraic methods. That," she says, "is the map. There are lots of techniques for analyzing differential equations in clever ways, and that's the theory I start with.

"The next step is to simulate [the systems], using computers. The simulations give me a little more insight into not just that the broom goes forward, but how much time it takes to fall down—more qualitative information as to how it behaves. More details regarding the dynamics. [Next] would be to verify experimentally—build in the laboratory a scale model of the dynamic system that I'm trying to [control], a model that actually turns and evolves with time and performs in some way."

Annaswamy has taught at the College since September 1988. "I always think of research and education as going hand in hand," she says. "Students—especially undergraduates—should be taught by people who are at the forefront of research so they don't just get whatever is relevant for the course, whatever's relevant for the grade.

"For every one piece of information I give the students," she continues, "I think I should know ten times more—just so I provide them with that depth. Not so much that I should be able to teach them everything, but I should be able to give them an indication of what a field is all about, and that what we are touching is just the tip of the iceberg, that there's so much more to know—if they want to know."

Her ideas about teaching go even further. "My vision," she says, "is to build a center for studying adaptive control—a control laboratory—in the College of Engineering." And, in collaboration with Professors Baillieul and Gevelber, she has written a proposal to the National Science Foundation to do just that.

"Right now everything is in the form of classroom

instruction. The students listen to the lectures, and they listen to lots of examples, but they're essentially limited to theory. When I say [something's] going to oscillate and then it's going to die down, sure, they can see it's a  $\sin t$  function, and mathematically they know that such a function does this. But it's a whole different ball game for them actually to see the motor sort of vibrate before it comes to a steady state.

"What I'd like to provide with a laboratory," Annaswamy explains, "is a place where undergraduate and graduate students can see the empirical dimensions of control theory; a place to study the principles of dynamical systems, to see exactly what uncertainty is present in [a system], how to go about trying to understand it and cope with it. So, for example, we say loosely that we want to make the performance of some thing just a little bit better, what exactly do we mean by that? Even if we are able to find a good performance measure, what do we have under our control that we can twiddle to squeeze out that extra bit of performance? And how exactly do we twiddle it, and how often?"

While such laboratories are not unheard-of in aerospace and mechanical engineering departments, says Annaswamy, they are more common in electrical engineering department because of the historical evolution of control theory.

In electrical engineering, she explains, "the big impetus for the whole field of control came from World War II, when they had to make military systems behave very precisely. There was a need to understand how to build these things, and a need to understand the theory behind these control systems." The use of active control in the context of aerospace and mechanics engineering is more recent. Now, however, "researchers and engineers have realized it's a concept that can be used to make our machines and vehicles and gadgets work better."

At the core of the field, however, is a concept that's hardly new. "The whole idea of measuring a variable, massaging the information somehow, and putting it back had been here since before Christ," says Annaswamy. "By 300 B.C., the Chinese and the Greeks had come up with water clocks that told time in a very precise manner. Using the principles of feedback, they controlled the flow of water that trickled into a tank. If it was too much, they sensed it and used that information to correct, to regulate the flow of water. So the principle has been there since way back when." KA