P.J. Antsaklis, "Educational Challenges and Opportunities in Intelligent Control Systems," P roc o f I ntern. Symposium o n I ssues a nd C hallenges o f M anufacturing a nd C ontrol E ducation f or t he 2 1st C entur y , pp. 31-34, University of Patras, Rion, Greece, June 26-28, 1997.

EDUCATIONAL CHALLENGES AND OPPORTUNITIES IN INTELLIGENT CONTROL SYSTEMS

by

Panos J. Antsaklis
Department of Electrical Engineering
University of Notre Dame
Notre Dame , IN 46556
antsaklis.1@nd.edu

Summary

There are challenging control needs in manufacturing and process industries, in communications, in air-traffic control, in space, air, land and underwater vehicles, to mention but a few. The all too familiar automobile is changing drastically under the hood with the addition of sophisticated controls to satisfy safety, handling, comfort and environmental needs. Advanced sensors, actuators, computers, communication networks, offer unprecedented opportunities to implement highly ambitious control and decision strategies. There are many interesting control problems out there which desperately need good solutions. If we look closely at some of these problems, we will realize that in order to solve them, we will perhaps need to expand our horizons and our way of thinking and add new mathematical concepts and methodologies in our arsenal.

Intelligent Control

Highly demanding control requirements in industrial processes coupled with the complexity and uncertainty of the models require the use of sophisticated control methods. To meet highly demanding control specifications in complex systems a number of methods have been developed that are collectively known as *intelligent control methodologies*. They enhance and extend traditional control methods. An alternative term used is *intelligent autonomous control*. It emphasizes the fact that an intelligent controller typically aims to attain higher degrees of autonomy in accomplishing and even setting control goals, rather than stressing the (intelligent) methodology that achieves those goals. Intelligent controllers are envisioned emulating human mental faculties such as adaptation and learning, planning under large uncertainty, coping with large amounts of data etc. in order to effectively control complex processes; and this is the justification for the use of the term intelligent, since these mental faculties are considered to be important attributes of human intelligence.

Hybrid Systems

The needs for efficient intelligent methodologies in control and automation demand that significant progress in the area of hybrid systems be made. Hybrid systems arise from the interaction of discrete planning algorithms and continuous processes, and as such, they provide the basic framework and methodology for the analysis and synthesis of autonomous and intelligent systems. Hybrid systems contain two distinct types of components, subsystems with continuous dynamics and subsystems with discrete event dynamics, that interact with each other. Such systems are important in a variety of contexts: Hybrid systems frequently arise from computer aided control of continuous processes in manufacturing, communication networks, autopilot design, computer synchronization, traffic control, and industrial process control, for example. Another important way in which hybrid systems arise is from the hierarchical organization of complex control systems. In these systems, a hierarchical organization helps manage complexity and higher levels in the hierarchy require less detailed models (discrete abstractions) of the functioning of the lower levels, necessitating the interaction of discrete and continuous components. Examples of such systems include flexible manufacturing and chemical process control systems, interconnected

P.J. Antsaklis, "Educational Challenges and Opportunities in Intelligent Control Systems," P roc o f I ntern. Symposium o n I ssues a nd C hallenges o f M anufacturing a nd C ontrol E ducation f or t he 2 1st C entur y , pp. 31-34, University of Patras, Rion, Greece, June 26-28, 1997.

power systems, intelligent vehicle highway systems, air traffic management systems, computer communication networks. The study of hybrid control systems is essential in designing sequential supervisory controllers for continuous systems, and it is central in designing intelligent control systems with a high degree of autonomy. The investigation of hybrid systems is creating a new and fascinating discipline bridging control engineering, mathematics and computer science.

Challenges And Opportunities

To address the new problems, we need to enhance our traditional control methods, we need new ideas, new concepts, new methodologies and new results. To control a system means to affect its behavior in a desirable way. The challenge is that the system may not necessarily be linear, or time-invariant or it may not be described by differential equations at all. The question is then how do we control such systems. Can we set up meaningful and rigorous descriptions for their behavior, the specifications, and the desired performance? Can we then develop theories which will help us design good controllers for such systems? Can we take in our designs full advantage of existing technologies? This is the challenge and the opportunity.

The Role of Technology

What makes control different today from the way it was, say twenty or thirty years ago is primarily technology. Sensors, actuators, digital computers are all better, faster, cheaper while providing many more capabilities than we ever dreamed or asked for. Communication technology has also opened the channels, so to speak, to fast reliable data communication among distributed controllers making it easier than ever to implement large numbers of such controllers. All indications are that this trend will continue and the technology will keep improving along these and other fronts opening new exciting horizons for control. The new technology offers tremendous opportunities for design and implementation of new generation of control systems, systems we have not seen or did not think would be possible to implement before. How can we take advantage of these exciting and unique opportunities? This is I think the main issue that needs to be addressed . The question is what can we do today to take advantage of existing and future technologies that are and will be used to implement advanced control systems.

The Implementation Issue

First, our research or at least part of it should be influenced by technological advances. When we design controllers, the (digital) implementation issue should be an integral part of the design-here I am perhaps influenced by my personal research interests in hybrid systems. It seems that many of our control methodologies have their origins and are influenced by basic building blocks of control mechanisms that are closer to RLC circuits than the sophisticated CPUs of today. If we pay closer attention to the control implementation issue, answers or partial answers are bound to emerge. I firmly believe also that such approach will lead to fundamental and challenging theoretical questions which will require solutions.

Partnerships With Industry

But, to learn about these wonderful advances in control technology we have to learn first about the new challenging applications of control. Such knowledge can only come with the help of control engineers who work with such applications. There is a great role industry can play here which can take many forms. Models and problem descriptions may be provided along with descriptions of available or desirable sensors and actuators, workshops on particular classes of control problems can be organized with the help of industry to bring together interested practitioners and researchers, research money could be provided to support specific projects, exchanges and partnerships between industries and universities could be encouraged. I think that industry should be and will be playing a new expanded role in the future, in view of the industrial control challenges and the

P.J. Antsaklis, "Educational Challenges and Opportunities in Intelligent Control Systems," P roc o f I ntern. Symposium o n I ssues a nd C hallenges o f M anufacturing a nd C ontrol E ducation f or t he 2 1st C entur y , pp. 31-34, University of Patras, Rion, Greece, June 26-28, 1997.

government funding realities. I think such partnerships between industry and universities are better developed in other countries than in the US, particularly in Europe and Japan.

Closer relations between industry and universities will also make it easier for the research to be applications driven. This is I think very desirable as it will not only help solve important problems, but it will also help identify significant new directions in control theory and create perhaps new control subdisciplines. Recall that the greatest mathematicians over the centuries were quite familiar with the important practical problems of their day!

Innovations In The Curriculum

To make all this possible, we will need to implement innovations in the university curriculum. If we are to build the control systems of tomorrow, we need to enhance and improve the way we have been teaching control systems. We will need to also talk about control implementation and the technology that exists, and to introduce material that makes it possible to use that technology in an integrated way. Our students are typically able to handle continuous-time systems and discrete-time systems in the time and transform domains. They will also need to learn some logic, automata theory, Petri nets etc. so they may be able to handle event driven systems as well; computer engineering courses on discrete-mathematics may be appropriate. Other material of course may be incorporated; for example, biological systems may suggest architectures for novel control and decision making approaches.

Electronic Dissemination Of Information And Electronic Publishing

We should also be taking advantage of available information technologies for the dissemination of information. Courses and experiments on the Web have already started and I expect many more innovative uses to emerge in the near future. Exchange of information via the Internet is of course a very rapidly evolving area and we certainly should keep a close watch on the developments there.

What Can Be Done?

We could organize workshops to map new research directions and develop educational programs-model courses, short courses, extension courses. We could also establish a task force on control education to identify the new tools and ideas and suggest ways to implement them; we could for example start by recommending initially a Master's control program that incorporates the elements we discussed-maybe some universities have such program already in place.

Conclusion

All indications are that control systems with high degrees of autonomy will be playing an increasingly important role in the technological systems of tomorrow. We are at a turning point in control, reminiscent of the 1960's but more exciting in my opinion. Rapid advances in related technologies are changing the control landscape. Computers are getting smarter by quantum leaps and bounds. It is up to us to find ways to use their enhanced capabilities to design and build highly autonomous control systems so "to go where no man has gone before." These are golden opportunities and we should take advantage of them. Rethinking control education is one of the most important steps we can take. It is our future after all. Of course it is up to us to rise to the challenge.