A Report on the MTNS'02 Panel on
" Future Directions of Research and Teaching in Mathematical Control and Systems Theory",
University of Notre Dame, August 14, 2002.

PANELISTS :

Panos Antsaklis, University of Note Dame
Vincent Blondel, Belgium
Biswa Datta (Chair), Northern Illinois University
William Helton, University of California, San Diego
Joachim Rosenthal, University of Notre Dame
Hans Schumacher, the Netherlands
Jan H. van Schuppen, the Netherlands
Eduardo Sontag, Rutgers University

Also, Uwe Helmke of Germany and Floyd Hanson of University of Illinois spoke at the panel on invitation by the Chair Biswa Datta.

Belinda King of Virginia Tech, although was not able to attend the panel meeting, made some notable contributions through her communications with the Chair Datta.

Several topics in Control and Systems Theory were identified by panelists for future research and development.

These include: Nonlinear Control, Distributed Parameter Systems, Large-scale and Complex Systems, Hybrid and Embedded Systems, Software Development, Applications areas: Aerospace and Transportation, Biology and Medicine, Robotics and Intelligent Systems Networking, Coding, Cryptography, Control of Traffic, Quantum Engineering, Financial Engineering, Numerical Analysis and Computational Mathematics, etc., Mathematics of Control and Systems Theory, and Control Education.

It is noted that several of the above topics were also identified by previous panels, the latest one of which was the panel on "Future Directions in Control and Dynamics" at University of Maryland, College Park, MD, June 16-17,2002 (Chaired by Richard Murray of California Institute of Technology. Website Address : http://www.cds.caltech.edu/ murray/cdspanel).

Here are some of the specific issues discussed and recommendations made by the panelists on topics of their expertise.

Distributed Parameter Systems: Real life structures such as bridges, highways, buildings, automobiles, airplanes, and others are distributed parameter systems. However, necessitated by practical limitations and computational considerations, the distributed parameter systems are often discretized to matrix second order systems by using techniques of finite elements , control design is carried out and implemented on the discretized models and applied to the real life structures. This approach suffers from discretization errors, control and observation spill-overs and possible instability. Furthermore, techniques for control design directly in discretized matrix second-order systems are not well developed.

Recommendations for Future Research: Control techniques need to be developed so that the design can be carried out on DPS itself using finite dimensional control and computational techniques. If the design has to be discretized model based, then the it should be done in the discretized model itself so that structural properties of FEM can be exploited in computational settings.

Hybrid Systems: In the past decade significant progress has been made in the theory and applications of hybrid systems. Previous theoretical developments have focussed on centralized control action. It is noted, however, there are many open research issues that need to be addressed that are introduced by the distributed nature of the control systems implemented over networks. In addition, of course, there are systems issues in communication networks that should be addressed in a more satisfactory way using hybrid dynamical models.

Applications: Special emphases were placed on applications of control techniques to Biology, Medicine, Coding, Cryptography , Control of Motorway Traffic, and Financial Engineering.

It was mentioned that rigorous research on control applications to biology and medicine should be carried out not only for the sake of advancement of science and engineering, but also on humanitarian grounds. Eduardo Sontag, one of the panelists, will cover some aspects of this in his Bode Lecture at the upcoming IEEE Conference on Decision and Control, Las Vegas, December, 2002.

Financial engineering is a challenging and an emerging area of research for control and systems theorists. Research has so far been mostly close to stochastic control, but, it is noted that robust control techniques could play significant roles here too.

Communications and Network Theory often pose highly complex and interesting control problems. At the MTNS'2002, there were some interesting sessions to discuss these issues and the talks there clearly showed how feedback control can be used to optimize the traffic of packages. Another area is the error control coding that appear in many communication areas. For example, convolutional codes widely used in data transmission simply describe linear systems over a finite field. Finally, in the area of cryptography feedback shift registers are used for various applications and these devices are also well studied in control theory.

Modeling, control synthesis, and control design for highway traffic are basic engineering tasks that require attention of control theorists and engineers, and control researchers. It is expected that in the coming decades much more control measures will be implemented in highway traffic.

Numerical Analysis, Computational Mathematics and Software Development: Sophisticated algorithms are essential for robust control design and implementations. Excellent algorithms are now available for classical state-space based control design. However, algorithms for large-scale computing, especially those arising from discretization of distributed parameter models, powers systems, computer networks and others, are still not well developed. Good algorithms are still lacking for nonlinear, adaptive, and hybrid systems.

Software design and algorithm development go hand in hand. MATLAB and MATLAB-based toolboxes for control systems design and analysis are powerful tools, but mostly restricted to small classes of systems.

What needed are: increased research integrating control, computer science, communications and networking, Reliable, embed, real-time software, and reliable tools for software verifications. To meet these needs, highly interdisciplinary team work blending mathematics, computational mathematics, control and software engineering is essential.

Mathematics in Control and Systems: Mathematics has always played an essential role in the development of control and systems theory and engineering and continues to do so. The examples of how some of the latest developments in control and systems have been influenced by mathematics include the role of semi-definite programming optimizations techniques in Linear Matrix Inequalities (LMI's) and that of operator and interpolation theory in H-infinity control. Here the developments in mathematics led to revolutions in systems and control and accompanied their development. What is next ? While it is hard to predict, there are several areas of operator theory which have their origins in engineering problems and which have developed substantial structure in new directions (including many fundamental new formulas). Examples of such rapidly developing areas are, in types of several complex variables connected with multidimensional systems engineering, some systematizing of the production of LMI's from optimization problems, interpolation, and indefinite inner products. It behooves engineers to be aware of major mathematical developments in areas like these which have the potential for applications.

Control Education: The aspect of Control Education received a wide support both from the panelists and the audience. Although control has impacted a wide variety of applications areas and control techniques are used widely in many daily-life systems, such as power systems, heating and cooling systems, cruise control in automobiles, etc., contribution of control is not widely recognized by many users including scientists and engineers in other fields. Power of control should definitely be made more visible. It is strongly felt that "control" should be made more accessible to scientists and engineers in other disciplines through courses and research partnership.

Some specific recommendations include:

i. The scopes of undergraduate linear algebra and differential courses in mathematics curricula should be broaden by introducing simple control concepts such as controllability, observability, stability and feedback control with motivating examples of use of feedback control in daily- life systems such as power systems, heating and cooling systems and cruise control in automobiles. In similar ways, control can be introduced to the many other disciplines where control has already made substantial impact and continues to do so. These disciplines include physics, chemistry, biology, finances, insurances and economics. It is to be noted in this context that interests in control in these areas are in useful applications and computations of solutions, but not in the pursuit of mathematical rigor for its own sake. Thus, these special-purpose control courses should be taught in a different way than the core control courses and special text books should be developed for such courses. Also, while teaching control and systems courses, some emphasis should be given to the "history" of the subject and fundamental research and teaching in systems and control should be continued.

ii. The current way of teaching control courses in engineering departments should be modified too. New and modern algorithms, both algebraic and computational, and associated software should be included in the existing linear and nonlinear control and systems courses. Finally, it is felt that fundamental research in systems and control theory should be continued

iii. Control should be made more visible in conferences by American Mathematical Society, the Society for Industrial and Applied Mathematics, American Physical and Chemical and Biological Societies and even in conferences of several engineering disciplines such as Vibration and Power Systems engineering where control is still not widely used . Short courses, special sessions and workshops on control and its applications should be organized at such conferences.