Control in an Information Rich World

Report of the Panel on Future Directions in
Control, Dynamics, and Systems

30 June 2002

Abstract

The field of *control* provides the principles and methods used to design engineering systems that maintain desirable performance by automatically adapting to changes in the environment. Over the last forty years the field has seen huge advances, leveraging technology improvements in sensing and computation with breakthroughs in the underlying principles and mathematics. Control systems now play critical roles in many fields, including manufacturing, electronics, communications, transportation, computers and networks, and many military systems.

As we begin the 21st Century, the opportunities to apply control principles and methods are exploding. Computation, communication and sensing are becoming increasingly inexpensive and ubiquitous, with more and more devices including embedded processors, sensors, and networking hardware. This will make possible the development of machines with a degree of intelligence and reactivity that will influence nearly every aspect of life on this planet, including not just the products available, but the very environment in which we live.

New developments in this increasingly information rich world will require a significant expansion of the basic tool sets of control. The complexity of the control ideas involved in the operation of the Internet, semi-autonomous command and control systems, and enterprise-wide supply chain management, for example, are on the boundary of what can be done with available methods. Future applications in aerospace and transportation, information and networks, robotics and intelligent machines, biology and medicine, and materials and processing will create systems that are well beyond our current levels of complexity, and new research is required to enable such developments.

The purpose of this report is to spell out some of the prospects for control in the current and future technological environment, to describe the role the field will play in military, commercial, and scientific applications over the next decade, and to recommend actions required to enable new breakthroughs in engineering and technology through application of control research.

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Preface

This report documents the findings and recommendations of the Panel on Future Directions in Control, Dynamics, and Systems. This committee was formed in April 2000 under initial sponsorship of the Air Force Office of Scientific Research (AFOSR) to provide a renewed vision of future challenges and opportunities in the field, along with recommendations to government agencies, universities, and research organizations to ensure continued progress in areas of importance to the industrial and defense base. The intent of this report is to raise the overall visibility of research in control, highlight its importance in applications of national interest, and indicate some of the key trends that are important for continued vitality of the field.

The Panel was chaired by Professor Richard Murray (Caltech) and was formed with the help of an organizing committee consisting of Professor Roger Brockett (Harvard), Professor John Burns (VPI), Professor John Doyle (Caltech) and Dr. Gunter Stein (Honeywell). The remaining Panel members are Karl Åström (Lund Institute of Technology), Siva Banda (Air Force Research Lab), Stephen Boyd (Stanford), Munzer Dahleh (MIT), John Guckenheimer (Cornell), Charles Holland (DDR&E), Pramod Khargonekar (University of Florida), P. R. Kumar (University of Illinois), P. S. Krishnaprasad (University of Maryland), Greg McRae (MIT), Jerrold Marsden (Caltech), George Meyer (NASA), William Powers (Ford), and Pravin Varaiya (UC Berkeley). A writing subcommittee consisting of Karl Åström, Stephen Boyd, Roger Brockett, John Doyle, Richard Murray and Gunter Stein helped coordinate the generation of the report.

The Panel held a meeting on 16-17 July 2000 at the University of Maryland, College Park to discuss the state of the field and its future opportunities. The meeting was attended by members of the Panel and invited participants from the academia, industry, and government. Additional meetings and discussions were held over the next 15 months, including presentations at DARPA and AFOSR sponsored workshops, meetings with government program managers, and writing committee meetings. The results of these meetings, combined with discussions among Panel members and within the community at workshops and conferences, form the main basis for the findings and recommendations of this Panel.

A web site has been established to provide a central repository for materials generated by the Panel:

`http://www.cds.caltech.edu/~murray/cdspanel/`

Copies of this report, links to other sources of information, and presentation materials from the Panel workshop and other meetings can be found there.

Several similar reports and papers highlighting future directions in control came to the Panel's attention during the development of this report. Many members of the Panel and participants in the June 2000 workshop were involved in the generation of the 1988 Fleming report [15] and a 1987 *IEEE Transactions on Automatic Control* article [25], both of which provided a roadmap for many of the activities of the last decade and continue to be relevant. More recently, the European Commission sponsored a workshop on future control systems [14] and several other more focused workshops have been held over the last several years [1, 2, 33, 34]. Several recent papers and reports highlighted successes of control [35] and new vistas in control [11, 23]. The Panel also made extensive use of a recent NSF/CSS report on future directions in control engineering education [1], which provided a partial basis for Chapter 4 of the present report.

The bulk of this report was written before the tragic events of September 11, 2001, but control will clearly play a major role in the world's effort to combat terrorism. From new methods for command and control of unmanned vehicles, to robust networks linking businesses, transportation systems, and energy infrastructure, to improved techniques for sensing and detection of biological and chemical agents, the techniques and insights from control will enable new methods for protecting human life and safeguarding our society.

The Panel would like to thank the control community for its support of this report and the many contributions, comments, and discussions that help form the context and content for the report. We are particularly indebted to Dr. Marc Q. Jacobs for his initiative in the formation of the Panel and for his support of the project through AFOSR.

Richard M. Murray Pasadena, June 2002