

INCREASING NEED FOR ADVANCED CYBER-PHYSICAL SYSTEMS



ELECTRICAL ENGINEERING PROFILE

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No longer the stuff of science fiction, cyber-physical systems (biological, physical or engineered systems that depend upon and are controlled by computational and communications components) surround us and we increasingly rely upon them. Cars that have features like adaptive cruise control, buildings that are designed to be “smart,” medical devices such as insulin pumps or cochlear implants, auto pilot systems in aircraft, systems to control prosthetics, and a power grid that reliably delivers electricity are examples of the multitude of cyber-physical systems that affect daily life. The theoretical aspects that make possible the trustworthy operation of these systems are the focus of ND researchers, whose work directly or indirectly impacts our lives.

Because of the successful use of cyber-physical systems in so many sectors, the demand for more such systems is increasing. Not only are more systems desired, but more advanced systems are needed to support the enhanced capabilities demanded in applications such as manufacturing, transportation, power delivery, biomedical needs and energy management. As the systems become more complex and more autonomous, and the sheer number of systems increases, unintended interactions among systems becomes of greater concern.

For example, consider that a modern automobile contains hundreds of processors and millions of lines of code that control systems such as engine performance, pollution emissions, and safety features such as lane keeping and adaptive cruise control. If each system is designed and produced separately, without an integrated system of design, control modules for different functions could interact unintentionally, endangering drivers. Without an integrated system of design, as the number and complexity of component systems increases, the likelihood of unintended interaction increases. A similar problem affecting the power grid could have far-reaching consequences.

These systems must be reliable, resilient under stress, dependable, scalable, and robust; consequently there is an urgent need to design the systems in a way that anticipates potential interactions among all the constituent component systems. The President's Council of Advisors on Science and Technology has identified CPS as a top priority for federal research and development funding. The critical need for efficient, systematic design of cyber-physical systems is clear, and requires

intense focus on the theories needed for producing tightly integrated systems and simultaneous design methods. This mathematically challenging, multidisciplinary approach to theoretical design is the hallmark of ND researchers working on CPS projects. The efforts of Systems and Control faculty at Notre Dame have made the University a leader in CPS from the start, particularly in the theoretical aspects.

A multi-university project funded by the National Science Foundation focuses on the development of theories, mathematical models, and simultaneous design methods necessary to produce tightly integrated systems that combine computational, communications, and physical components. Notre Dame, Vanderbilt University, the University of Maryland, and General Motors Research and Development are involved jointly; Vanderbilt leads the project. Notre Dame leads the theoretical research under the guidance of Panos Antsaklis, H. Clifford and Evelyn A. Brosey Professor of Electrical Engineering and his colleagues, Vijay Gupta, associate professor of electrical engineering, and J. William Goodwine, associate professor of aerospace and mechanical engineering. The specific design situation of the project involves automotive applications like adaptive cruise control. Designing the system and the controls together cuts across disciplines and uses energy-like concepts to model behaviors.

Some CPS applications make life more convenient, others improve safety on the highway or make possible the use of robots in conditions that would be life-threatening to humans; still others offer the possibility of restored function through the operation of artificial limbs. Every area of modern life, from mundane household applications to concerns of national security or issues of human health, is affected by cyber-physical systems.