Position Paper on Federal R&D Investment in Cyber-Physical Systems

Cyber-physical systems (CPS) consist of the interconnection of numerous physical and computational processes. Numerous examples of CPS may be found throughout the national civil infrastructure. This position paper discusses a recent CPS project called CSOnet that attempts to address national problems concerning wastewater runoff. The objective of this document is to use CSOnet to highlight the broad interdisciplinary nature of CPS, to comment on the importance of encouraging industrial and academic collaborations, and to petition for a greater federal support of such projects.

CSOnet [1] is a sensor-actuator network that is being built in South Bend Indiana to address the problem of combined-sewer-overflow (CSO) events. A combined sewer system combines sanitary and storm water flows into a single system. CSO events occur when storm water flows exceed the capacity of the existing system, thereby causing operators to dump the untreated water directly into a river or stream. As these waters are highly impacted by biological and chemical contaminants, the occurrence of CSO events has a significant negative impact on public health and water quality.

CSO events are a problem of national concern. Combined sewers are found in nearly 800 municipalities, centered primarily in the Midwestern and Northeastern United States. In addition to this, however, is the fact that the US environmental protection agency (EPA) has begun levying fines against local municipalities for each CSO event, as part of the clean water act. These fines are significant and can be construed as an unfunded federal mandate requiring municipalities to reduce their CSO events.

In 2004, under the leadership of the University of Notre Dame, a small group of academic (University of Notre Dame, Purdue University), public sector (city of South Bend, Indiana), and private (EmNET LLC) sector partners began developing the concept of using a sensor-actuator network to control the occurrence of CSO events. At present, the project has deployed a 150+ sensor network in the city of South Bend for monitoring the occurrence of CSO events. The actuation (control) part of the system will control CSO events. This component will be in place by summer 2009. While started at South Bend, the project is starting to expand to other Indiana cities though the small business (EmNET LLC) that was created as part of the original project. CSOnet can therefore be viewed as an example of a successful CPS engineering project.

Sensor-actuator networks such as CSOnet differ greatly from traditional data networks in that the data transmitted across the network is used to control the external environment. Networks having such feedback paths exhibit extremely complex behaviors that can be difficult to predict. Understanding and controlling this complexity requires developers that are comfortable in a wide range of engineering and scientific disciplines. Not only do these developers need to be aware of traditional communication and computer networking practices, they must also be knowledgeable about the physical processes that these networks are being used to control. In the case of CSOnet, we drew on a wide range of engineering expertise that included environmental engineering, fluid dynamics, network middleware, adaptive antenna design, and real-time systems. Identifying a group with such a diverse set of talents and integrating that group into a team was essential for the success of the CSOnet project.

The very breadth of the CSOnet team made it difficult to secure federal funding for such a project. Agencies such as the National Science Foundation (NSF) support fundamental research in very narrow technical disciplines. Technical reviewing panels are often drawn from researchers specializing in one area. It can be difficult for such panels to appreciate the depth of innovation present in projects such as CSOnet because these projects require expertise in such a broad range of specialties. As a result, federal funding for CSOnet has been very limited; $150,000 in the last couple years of the project. This is a small fraction of what was required in the first 3 years of the project. In contrast the related European WIDE project (INFSO-ICT-224168) is being supported (2008-2011) at a level of 2.7 million euros by the European Union. The WIDE project is building a sensor-actuator network similar to CSOnet for the city of Barcelona.

Funding for CSOnet was obtained from state and city governments. The state of Indiana's 21st Century Technology Fund (CTF) supported CSOnet project with a one million dollar grant between 2004-2007. This was used to build a prototype system. An additional one million dollars was obtained from the 21st CTF (2007-2009) to scale up to the entire South Bend metropolitan area. During this period, the City of South Bend contributed over $150,000 in services and funds to the project.

State programs such as the 21st CTF, however, are primarily economic development programs. Their primary interest is in stimulating local businesses in order to grow the state economy. There is little interest in funding the fundamental research required to ensure the success of CSOnet. To ensure adequate freedom for academic partners in this project, we created a small start-up company (EmNET LLC) to serve as a buffer between the actual government stakeholders (City of South Bend) and the academic units (Notre Dame and Purdue). This worked very effectively and it essentially forced the academic units to act as research arms for the local company.

CSOnet is a large-scale CPS system for controlling CSO events; a problem of national importance. The success of the project required assembling a broad team of academics, private, and public sector stakeholders. It required the creation of a small business entity to serve as the technology transfer bridge. It required significant funding (on the level of 2-3 million for 3-5 years) to stimulate interdisciplinary research in a broad range of engineering areas as well as funding for the more mundane job of product development and testing. Increased federal funding that encourages fundamental CPS research while also supporting the participation of small business would be a great help in promoting projects such as CSOnet that have the potential of maintaining and securing our national civil infrastructure.

[1] L. Montestruque and M.D. Lemmon (2008), CSOnet: a metropolitan scale wireless sensor-actuator network, *International Workshop on Mobile Device and Urban Sensing (MODUS)*, 2008