AC 2009-1203: A NOVEL INTERDISCIPLINARY SENSOR NETWORKS LABORATORY

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A Novel Interdisciplinary Sensor Networks Laboratory

Abstract - *Today, networks of legacy and newer sophisticated sensors and actuators that combine reconfigurable gigascale semiconductor technology with emerging micro-mechanical systems (MEMS) and nanotechnology subsystems (i.e. bio-systems/chemical/fluidics/photonics/ etc) are being designed and deployed in almost every area of technology that impacts human endeavor and commerce. These smart sensors/actuators are being networked together through: either standards based or industry specific, proprietary, wired networks or newly emerging wireless networking technologies. Presently, at the two- and four-year college level, technicians and technologists in a wide variety of impacted disciplines are not receiving an adequate education about: fundamental sensor theory, basic sensor operation, sensor system deployment planning, appropriate data-transport and networking connectivity schemes, applications software, and impending system maintenance support needs of these increasingly more sophisticated and complex, smart sensor/actuator based systems.*

This paper will report on the development, organization, and use of a novel interdisciplinary sensor networks laboratory. The heart of the laboratory is a dedicated data-network (SensorNet) that emulates a wide area network or WAN. The SensorNet WAN nodes and other network access points allow for the interconnection of numerous types of industry specific and standard "area networks" typically utilized for the gathering of sensor data and directing other sensor functions, as well as, the associated PC's and servers used to direct the sensor systems and warehouse the gathered data. This laboratory environment lends itself to real world case-study and problem-based type student-centered learning experiences that can be themselves integrated into established fields of technology that do not normally include this type of activity as part of the field's traditional educational experience at the undergraduate level.

I. Overview

Although it is not uncommon for several different technology fields to converge together, it is somewhat unexpected to observe such an amalgamation rapidly triggering other technologic innovations that have widespread potential to change our relationship with the environment and our daily endeavors. However, this is just what is happening today. Only a short time ago, the Internet, the result of a convergence of several technologies, spawned the development of what is commonly known as the "Information Economy." Today another innovative and important convergence of technologies has recently gained critical mass and recognition by business and industry, government, academia, and professional societies. It is the deployment of intricate systems involving complex sensors with embedded (ambient) intelligence and advanced actuators coupled with modern data-transport and networking technologies and application-enabling software with data fusion capabilities. This rapidly evolving convergence of technologies, which allows us to implement sensor systems that gather *in situ* (remote), real-time, statistically relevant information and interpret it in new and novel ways, has already started to transform automation and process control systems. The technology of networked sensor systems has the very genuine potential to significantly impact almost every aspect of human endeavor by increasing system efficiency, reducing energy consumption, permitting the real-time monitoring of the "health" of the nation's infrastructure and environment, and improving public health and safety. Applications are limitless!

On a global level, the NSF has been calling this "grand convergence," ***cyberinfrastructure.*** One may find many references to this concept, forecasts of potential future applications, reports on in-progress test projects such as HPWREN, NIMS, and ROADnet, and potential research funding opportunities on the NSF's Web site[1] . However, most of this current, enthusiastic attention and promotion of cyberinfrastructure by the NSF is aimed at senior, graduate-level research institutions. Not surprisingly, most of the NSF's recent Requests for Proposals (RFPs) in this area have been targeted at basic research about wireless sensor networks and systems and applications of these systems to infrastructure and environmental monitoring and other technology areas. While many applications of networked sensor systems are yet to be even thought of, the reality is that they are being deployed today and will continue to proliferate for many years to come until they eventually become as commonplace as a typical public utility like electricity.

This paper describes aspects of an NSF funded CCLI project (DUE 0736888), titled, "The Sensor Networks Education Project" (SNEP) that seeks to develop materials and a model teaching laboratory that will be useful for other faculty and organizations at the two- and even the four-year college level to emulate. This project looks at this evolving convergence on a more practical level and speaks to the lack of engineering technology faculty expertise and teaching materials needed to infuse the newly recognized, exponentially growing knowledge base of networked sensor technology into the curricula and hence into the skill-sets of today's two- and four-year technical college graduates – the technicians and technologists of tomorrow. This is the community of workers that will most likely deal with the design, deployment, updating, and maintenance of these systems.

Today, networks of legacy and newer sophisticated sensors that combine reconfigurable gigascale semiconductor technology with emerging micro-electromechanical systems (MEMS) and nanotechnology subsystems[2] (i.e. bio-systems/chemical/molecular/photonic) are being designed and deployed in almost every area of technology that impacts human endeavor and commerce (i.e. Aerospace, Agriculture, Automotive, Biomedical, Building Automation, Energy Exploration and Production, Environmental Monitoring, Healthcare, Homeland Security, Industrial Automation, Infrastructure Monitoring, Information Technology, Manufacturing, Military, Pharmaceutical, Telecomm, Transportation, Weather Forecasting, etc). These sensors are being networked together through: either standards based or industry proprietary wired networks or emerging wireless networking technologies. Presently, at the two- and four-year college level, technologists and technicians in a wide variety of impacted disciplines are not receiving an adequate education about: fundamental sensor theory, basic sensor operation, sensor system deployment planning, appropriate data-transport and networking connectivity schemes, applications software, and impending system maintenance support needs of these increasingly more sophisticated sensor based systems.

Recently, there has been a great deal of public dialogue about the out-sourcing of American manufacturing jobs and the effect of this reality on the nation's future. Dealing with an ever increasing base of physical sensor networks in all areas of endeavor will not be something that can be done through a call to a help desk located in a foreign country. The apparent curriculum shortcoming regarding these topics within today's associate and bachelors degree technology oriented programs is primarily due to the extremely rapid evolution and convergence of several key areas of electronics, computer, and MEMS technology (i.e. embedded processing, smart sensors/actuators, wired and wireless networking, etc), the lack of appropriate up-to-date educational materials, and a lack of appropriate faculty expertise in this rapidly expanding and remarkably cross-disciplinary field.

II. Project Overview

Over its two-year life-span, this CCLI Phase I project has as its primary goals the creation and testing of interdisciplinary student-centered learning materials primarily designed for a "field laboratory" type environment, the dissemination of these materials, and the development of faculty expertise in the multi-disciplinary field of networked sensors and modern active-learner teaching techniques. To accomplish these goals the project will: (**1**) develop and deploy a model, innovative, replicate-able, multi-interdisciplinary, case-study and problem-based oriented, networked, distributed sensor laboratory, (**2**) develop basic and advanced instructional materials and standard and "hybrid" laboratory activities related to the sensor laboratory that can be utilized for introductory courses in sensor technology or more advanced courses in networked sensor systems for use by both two- and four-year technology programs, (**3**) develop several prototype multifaceted educational modules that integrate traditional science and math based theory, practical real-world laboratory exercises, and science based, high-resolution, interactive simulation software, applicable to several of the major technology areas employing networked sensor technology (i.e. building automation and infrastructure monitoring and industrial automation), and (**4**) provide on-going local, regional, and national dissemination of these developed materials and laboratory experiences through hands-on faculty workshops and web-based distribution technologies including the National Science Digital Library (NSDL).

In addition, for the duration of the project, continuous on-going professional development in the principles and applications of student-centered and active learner techniques will be provided to the recruited college faculty that will take part in the project. Research has shown that long term professional development programs are more effective than short-term workshops. For this project to be successful, the participating faculty must learn how to effectively integrate content and pedagogy in a way that actively engages students in individual and collaborative problem solving, analysis, synthesis, critical thinking, reasoning, and skillfully applying knowledge in real-world situations. It is crucial to the success of the project, that the participating faculty are exposed to the pedagogical underpinnings of these active-learner techniques so that their way of thinking about teaching and learning and hence their practice in the classroom may be enlightened and hopefully moved away from a teacher-centered methodology.

In summary, the primary project objective is to create learner-centered, educational laboratory materials that will empower technology faculty to be able to begin introducing networked sensor systems into their technology programs via real-world based applications and simulations. An additional, and almost as important, project objective is to create materials that can also be used to help bridge the technology gap experienced by non-electronics based technology disciplines when introducing these complex electronics based systems into their curricula.

Central to this project's first year will be the implementation and deployment of a teaching and learning data-network that will be used for the life of the project. What will be special and innovative about this data-network is that it will be separate from the College's academic data-network and additionally it will utilize numerous different network transport media and transport technologies. Since it is distinct from the College's internal IT network, it will be possible to perform maintenance functions, reconfigure the network, and interconnect various sensor area networks to it, within the context of the project, without the fear of causing harm or down-time to the College's sensitive and secure academic/administrative IT network. Since the network will also be accessible from the Internet, it will be possible for project participants to access the connected sensor networks from anywhere. This fact will allow the network to be expanded at other locations and therefore potentially develop into a regional networked sensor laboratory. It is expected that the network will be continually up-graded and expanded over the life of the project. Using this approach to the creation of the central sensor network, it is possible that "one-of-a-kind" sensor systems can be attached to the network for others to share from a distance. It is not out of the realm of possibility that in the future, a fiber-optic cable sensor used to measure stress in a bridge or highway in New Mexico or a moisture sensor in a field in Iowa could be connected to this network for educational purposes.

III. SensorNet

The actual physical data-network (industry standard Cisco integrated services routers and various interface modules) that support the project's diverse, distributed sensor systems will be located primarily on the sixth floor of Putnam Hall (a major academic building on the Springfield Technical Community College (STCC) campus consisting of classrooms, laboratories, lecture halls, and home to the School of Engineering Technologies' Electronics Group). To make the teaching network reflect real world conditions it will be set up to emulate a wide area network (WAN) with the capacity to provide connectivity to many other types of "area networks" and hence facilitate the operations necessary to perform the functions involved with distributed sensor systems (see Figures #1).

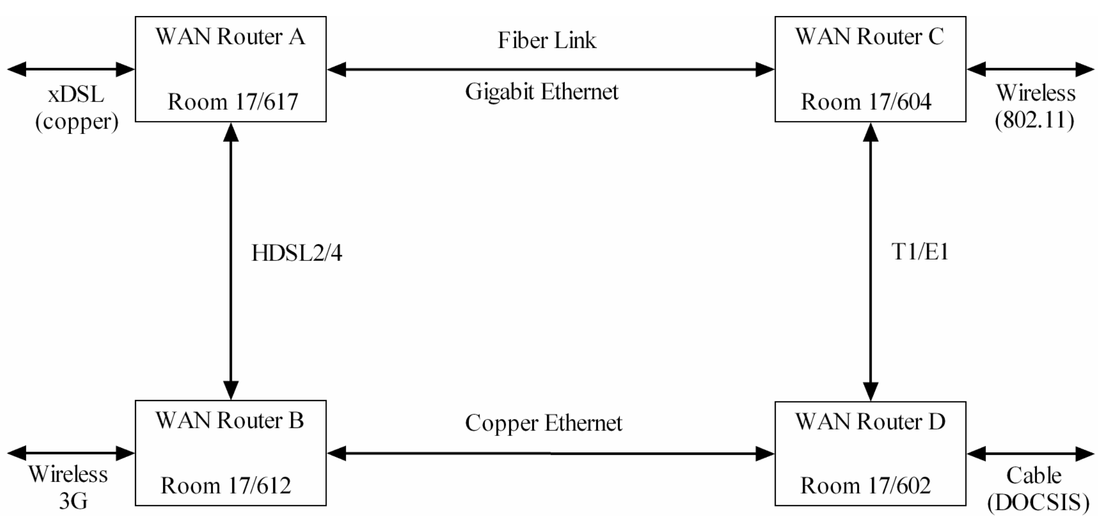

Figure #1 – SensorNet WAN Layout – Sixth Floor of Building 17

It will also be attached via a gateway to provide remote access to and from it over the core IP network (i.e. the Internet). This dedicated sensor network (**SensorNet**) will consist of four or more WAN nodes that will make use of various different transport technologies (i.e. ATM, Fast

Ethernet, Gigabit Ethernet, HDSL2/4, xDSL, 3G, 802.11/ OC-3, T/E-carrier, etc) and a variety of media types (i.e. wireline, fiber, wireless, etc) to further reflect real world networks. From its central location, SensorNet will eventually be extended to several other secondary campus locations (other buildings) using various forms of wireless bridge technologies. This will allow for several other technology programs (i.e. Energy Systems, Civil, and Electrical/Robotics, etc) not located in Putnam Hall to also be connected to the SensorNet system. The SensorNet WAN nodes and other network access points (see Figure #2) will allow for the interconnection of numerous types of "area" networks typically utilized for the gathering of sensor data and directing other sensor functions, as well as, the associated PCs and servers used to direct the sensor systems and warehouse the gathered data.

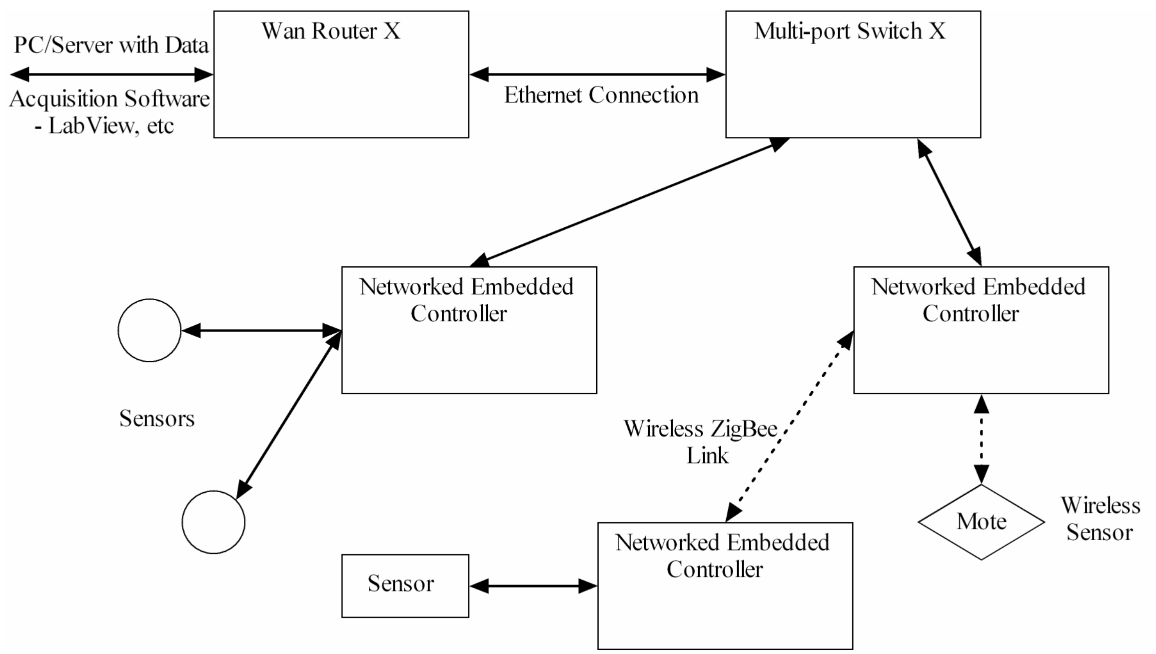

Figure #2 – Multi-port Ethernet Switches connected to or integrated within the WAN node will facilitate the connection of various sensors to the system

Today, most will recognize the popular network acronyms of LAN, MAN, PAN, WAN, and WLAN (i.e. local, metropolitan, personal, wide, and wireless local area network, respectively). However, many other types of not as well known "area networks" exist to support specific sensor/system functions in a multitude of diverse environments and application areas (e.g. controller area network [CAN] for automotive and control applications and Fieldbus [or the generic, field-area networks] for industrial and process automation and LonWorks and BACnet for building automation, but to name a few). Additionally, emerging, unlicensed, wireless networking technology (like IEEE 802.15.4) utilizing mesh and multiple hop interconnections between wireless nodes threatens to further revolutionize the rapidly growing field of sensor technology. An on-going objective of this project will be to set up and integrated these sensor system support networks into the teaching network (SensorNet) thus providing an environment that lends itself to real world case-study and problem-based type learning experiences that can be themselves integrated into established fields of engineering technology study and serve as models for others to duplicate or adapt to their own needs.

The Project's Director and several of the project Senior Personnel (subject matter experts [SMEs]) will have primary responsibility for the basic design and construction of this core sensor network. Presently, the "Electronics Group" is housed on the sixth-floor of the Putnam Building. The Electronics Group consists of Computer Systems Engineering Technology (CSET), Electronics Systems Engineering technology (ESET), Laser Electro-Optics Technology (LEOT), and Telecommunications Technology (TT) (all leading to associates degrees), all of who's students will benefit through interaction with the SensorNet system. On-going network maintenance will be supplied eventually through senior students in the CSET and TT programs as part of their course of study (the network itself can be utilized as a teaching tool by the students in all the Electronics Group disciplines to support laboratory and project activities in many presently required courses (i.e. TCOM-430 LightWave Communications, LEOT-349 Fiber-Optic Communications, ESET-360 Mobile & Wireless Communications, TCOM-415 Advanced Telecommunications Systems, ESET-371 Sensors and Data Acquisition, ESET-471 Sensor Systems, and several other Senior Projects courses). The project's directors and Senior Personnel will have responsibility for the creation of case-study based sensor scenarios that connect to the network and mirror real-world applications and the initial conception of ideas of problem-based scenarios for further development. Furthermore, cross-disciplinary senior projects that address a sensor system/data acquisition problem will be encouraged and documented for possible adaptation or modification in other contexts. The students in the various Electronics Group technologies will serve as "guinea pigs" for the testing of the materials developed in conjunction with the SensorNet system through structured labs and projects and more complex individual and group senior capstone projects. Furthermore, as we gain experience with the network it is expected that students from other technology areas will be given access to the network and be allowed to develop networked sensor applications or other network control scenarios that are relevant to their particular technology. Some of the other application areas that are expected to be explored include: automation and process control (PLCs), infrastructure and environmental monitoring, building automation, etc. It is also expected that various industry standard software packages useful for data acquisition and control (e.g. LabView, Agilent VEE, etc), as well as, other industry specific software (e.g. SCADA, WirelessHART, ISA100, etc) will be implemented in SensorNet activities.

IV. Student Activities

This CCLI project is presently a work in progress and it is this author's intent that at the actual 2009 ASEE Conference and Exposition, this author's presentation will speak at length about examples of various student created and developed SensorNet projects and about the various network architectures employed for the projects. The present senior ESET students in ESET-471 during the Spring 2009 semester will be the first group to utilize the SensorNet system. The goal of the student projects required for this course is to use the network to actually acquire and graph remote sensor data obtained through a remote, embedded controller board interfaced to a simple sensor (i.e. temperature, voltage, pressure, etc). Equipment in the form of Microchip Technology Inc. development boards (both wired and wireless) has been purchased for the projects as have various sensor systems that may be interfaced to the Microchip, network enabled, embedded controller boards[3]. For data acquisition, at this stage of the project, the plan is to utilize several

Agilent Model 34970A Data Acquisition/Switch Units that allow for graphical display of acquired data from a relatively large number of sources through multiplexing and easy to use freely available Agilent BenchLink software. In the future, various data acquisition software packages will be explored and added to the project's available tools. As the project evolves it is envisioned that students in the CSET program will experiment with data fusion software applications and some higher level software applications.

V. Conclusions

The senior students in the ESET program have become extremely enthused over the prospect of utilizing SensorNet for their Senior projects and have commenced the construction/interfacing of the necessary system parts to deploy their projects. This author is also sharing in the student's excitement and looks forward to sharing the results of this potentially multi-disciplinary project with fellow faculty. It is this author's firm conviction that to train our students for what they will encounter in the field, the experience gained by the implementation of a functioning networked sensor system will provide them priceless dividends in the future. Furthermore, several of the Electronics Group's programs have been morphing towards a systems oriented approach to teaching topics in the electronics area. The deployment of SensorNet will allow this process to be accelerated and bring our programs into the next decade.

References:

1. *Reports and Workshops Relating to Cyberinfrastructure and Its Impacts,* available at the following web site: www.nsf.gov/od/oci/reports.jsp

2. *The Emerging World of Networked Wireless Sensors*, by Gary J. Mullett, 2007 SAME-TEC Conference, Dallas, TX, this presentation is available at the following web site: www.same-tec.org

3. Microchip Technology Inc web site: www.microchip.com