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The John A. Blume Earthquake Engineering Center

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WELCOME TO THE 2001/2002 ACADEMIC YEAR

Welcome to all of our new students and visitors. This year promises to be a very exciting one at the Blume Center. Over the summer we built an Advanced Sensoring Lab in the Center. We also have the priviledge of hosting Professor Luis Esteva as our Shimizu Professor and this quarter we will be presenting the 2nd Annual Blume Distinguished Lecture (to be featured in the Winter Newsletter). These events along with all of the regular Blume Center research and activities will make it a busy and challenging year.

BLUME CENTER NEWS

On June 18-19, **Prof. Anne Kiremidjian** served on the Committee of Visitors for the Civil and Mechanical Systems Division of the National Science Foundation. She also presented a paper on *Assembly Based Vulnerability* co-authored with **Dr. Keith Porter** at the International Conference on Structural Safety and Reliability, Newport Beach, June 19-22.

Prof. Anne Kiremidjian, along with **Dr. Nesrin Basoz** and graduate student, **Ayse Hortacsu**, participated in the ESRI Users Conference in San Diego on July 9-12.

Prof. Helmut Krawinkler present recent research results on seismic demands and their dependence on ground motions at the US-Japan Seminar on Advanced Stability and Seismicity Concepts for Performance-Based Design in Kyoto, Japan, July 23-27.

On Aug. 1, **Prof. Anne Kiremidjian** attended the symposium on Crowding the Rim at Stanford University.

On Aug. 17-18, **Profs. Gregory Deierlein** and **Eduardo Miranda** participated in the Third US-Japan Workshop on Performance-Based Earthquake Engineering Methodology for Reinforced Concrete Building.

Prof. Eduardo Miranda was invited to participate as keynote speaker in the VII International Symposium and First National Conference on Earthquake Engineering in Colombia. The event took place in Bogota, Columbia on Aug. 22-25 and was organized by the University of Los Andes.

Prof. Anne Kiremidjian was invited to give two presentations at the Nanyang Technical University, Singapore, on *Wireless Health Monitoring Systems* and *Stochastic Simulation Model for Risk Assessment of Port Facilities*.

ESTEVA AT STANFORD - 2001/2002 SHIMIZU VISITING PROFESSOR

Prof. Luis Esteva, an internationally renowned earthquake engineering professor from the National University of Mexico and a rare Foreign Member of the U. S. National Academy of Engineering, is spending the academic year in the Blume Center as the Shimizu Visiting Professor. This is a return trip, for he was here just last Spring as the Shah Family Lecturer to speak before a large audience on his special interests in probabilistic approaches to a wide variety of subjects in this field.

This year he will be participating in research with a number of the Stanford faculty and their students. As a first step he has volunteered to conduct a six session set of seminars and joint discussions. The subjects started with estimating the nonlinear dynamic response of buildings in probabilistic terms, a topic of interest to at least five of our faculty and even more of the students, and a fundamental step in the PEER Center's approach to performance-based earthquake engineering. Subsequent sessions specialized this topic to frame and shear wall systems. The subjects continue through health monitoring, strong ground motion simulation, and soft-soil site effects. The unique format of each is a lecture by Prof. Esteva followed first by two shorter presentations by Stanford students working on identical or closely related topics and then by a open discussion on an hour or more. We have already found that the series has promoted fresh discussion among our own faculty and student researchers, as well as point students to Prof. Esteva for advice on their thesis research.

Prof. Esteva has also participated in meetings at both PEER and COSMOS. In the latter case he advised a two-day workshop on how best to deploy some 3000 strong motion instruments that are promised for location in buildings by the national ANSS program over the next decade.

His wife, Gloria, has also made an immediate impact on the campus, teaching English classes at the Bechtel International Center.

RESEARCH SPOTLIGHT

Advanced Wireless Structural Monitoring: Past, Present and Future

By Jerome P. Lynch, Kincho H. Law, Anne S. Kiremidjian, Ed Carryer and Thomas W. Kenny

Introduction

There is a clear need for a rational and economical method of monitoring the performance and safety of civil structures throughout their life spans. To offset the high installation and maintenance costs associated with a permanent monitoring system, only structures that fulfill an essential role in society or those with high everyday demand, are currently instrumented. Owners of ordinary structures are reluctant to pay for monitoring systems especially when they consider them an unnecessary yet expensive amenity.

It is easy to expound the many benefits associated with monitoring the performance of structures. For example, recordings of structures during ambient vibrations and seismic disturbances are essential in determining the demand placed upon structures. Knowledge of real structural demands could have far reaching applications that include assisting researchers working on maturing the area of performance-based design. In the case of structures in high seismic areas, information provided by monitoring structural responses will inevitably lead to better scientific understanding of how structures behave in the nonlinear realm. Within the structural health monitoring research community, a significant amount of research is focused upon developing ways of detecting damage in structures [1]. Damage detection strategies that can hypothesize locations of damage will need dense arrays of sensors located throughout a structure. Many notable cases can be cited that prove the value associated with monitoring key structures. For instance, measurements taken of the County Services building during the 1979 Imperial Valley earthquake revealed striking discontinuities of the building's time history response indicating sudden changes in structural integrity during the disturbance [2].

Commercial structural monitoring systems can find their origins in data acquisition systems used regularly in the laboratory. Systems of this type are optimized in their design to be well suited for small structures tested in the laboratory. Unfortunately, they do not scale well when used for large-scale system implementation such as in bridges and buildings. As a result, installation time and costs can be very high. For example, installation time of a moderate size monitoring system can consume over 75% of the total system testing time with installation costs approaching over 25% of the total system cost. In the state of California, 61 of the state's 22,000 bridges have been instrumented with costs reported to be well over $300,000 per toll bridge for a 60-channel system [3].

Proposed Wireless Sensing System

A low cost alternative to the widely used traditional wire-based monitoring system is proposed for application in civil structures, as shown in Figure 1. The realization of such a low cost monitoring system is now possible due to the reducing price and rapid advancement of key technologies such as sensors, microprocessors, wireless networks and integrated circuits. The single most important innovation of the proposed system is the inclusion of wireless communication into the sensing units. Wireless communication eradicates the need for wires and therefore represents a significant cost reduction over a wire-based counterpart. The flexibility of the wireless communication network of system sensors allows for system modularity as well as reduced dependence upon a centralized data acquisition unit for coordination of system activities. The new wireless systems are termed Wireless Modular Monitoring Systems, or rather, WiMMS. Another significant innovation of the system is the migration of computational power from the centralized data acquisition system to the sensor units. The distributed on-board computational power of the system can potentially facilitate parallel data processing that will partially render applications like damage detection procedures feasible in real time.

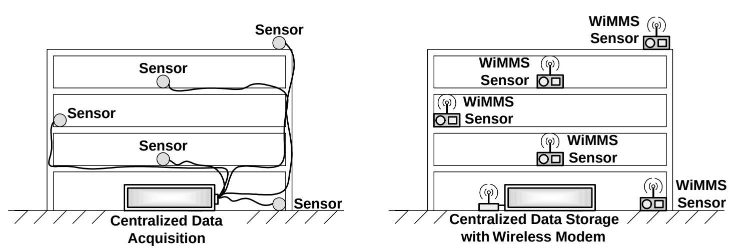

Figure 1 – Evolution from a Cable-Based to a Wireless Monitoring System

Current Prototype Design

A fully functional proof-of-concept sensing unit to be used in the proposed WiMMS system has been proposed and designed from commercially available components. An overview diagram of the sensing unit is shown in Figure 2.

Perhaps among the most important choices in the development of the wireless sensing unit is the hardware chosen to act as the unit's computational core. This core will be responsible not only for aggregation of sensing data from on-board sensing transducers (i.e. accelerometers), but they will also take part in the task of cleansing and processing the data. Various suitable alternatives are available ranging from field programmable gate arrays (FPGA) to digital signal processing (DSP) chips. The final selection was based upon the criteria of efficient power consumption characteristics of the core. Presently, an 8-bit microcontroller core architecture was chosen because of their low power and high performance specifications. In particular, an enhanced Atmel RISC (Reduced Instruction Set Computer) microcontroller was selected from microcontrollers currently available on the market.

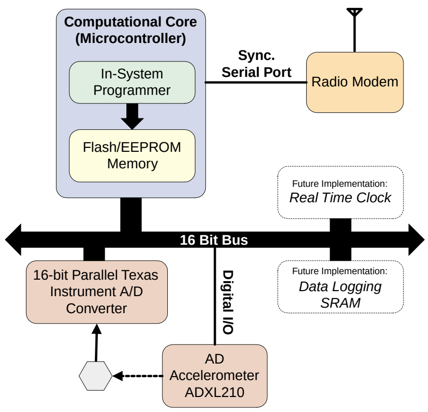

Figure 2 – Functional Layout of the Proposed Wireless Sensing Unit

Resonating with the demands of the current monitoring system end users, a low cost but highly reliable wireless solution is sought. This task can be accomplished using wireless modem technology. The Proxim ProxLink MSU2 wireless modem was selected for inclusion with the proposed wireless sensing unit. Operating in the unlicensed 902-928 MHz Industrial, Scientific, Medical (ISM) radio band, the radio modem employs direct sequence spread spectrum communication techniques to ensure a secure digital communication link between modems. The range of the ProxLink modems in open space is as far as 1000 feet. The communication range of the ProxLink modems inside buildings has been shown to be as far as 100 feet [4]. Within buildings, the shielding behavior of common structural materials such as steel and concrete cause a reduction of power of the radio frequencies.

There exist a large number of sensing transducers that can be used in the monitoring of structures. Some examples include strain gages, accelerometers, velocity meters, and displacement transducers. To ensure flexibility of the sensing unit, the overall design is sensor independent and is compatible with all analog sensors. A low noise, single channel, Texas Instrument 16-bit analog-to-digital (A/D) converter is used to measure the output voltage of the analog sensors and relay these measurements in digital form to the unit's microcontroller.

A prototype wireless monitoring unit has been designed, implemented and validated [5]. To accommodate all of the individual components of the system, a two-layer printed circuit board has been manufactured for the units. With an accompanying 9V alkaline battery power supply, the current demonstration system can be contained within a sealed packaging unit roughly 5" by 4" by 1" in dimension as shown in Figure 3. Numerous validation tests were performed ranging from signal tracking by MEMS (micro-electro mechanical systems) accelerometers to actual instrumentation upon laboratory test structures. For example, Figure 4 shows the time history acceleration response of a two-story test structure instrumented with two wireless sensing units.

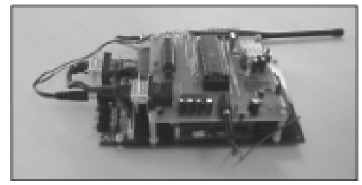

Figure 3 - Proof-of-Concept Wireless Sensing Unit

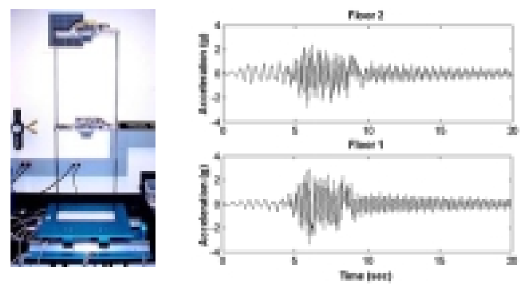

Figure 4 – Time History Response of a Two-Story Test Structure

Conclusion

A wireless sensing unit that fulfills the goal of producing a reliable and low cost monitoring system for civil structures has been designed. As compared to its wired counterparts, the proposed wireless modular monitoring system delivers a compelling cost-benefit advantage as well as the guarantee of a quick yet flexible installation. With computational power included within the wireless units, it can be harnessed to perform computationally intensive procedures in real time. Through wireless collaboration, the units have the potential of solving complex problems characterized by high dimensionality in parallel.

Future generation units will push the technology envelope by incorporating some new technologies just emerging on the marketplace. Efforts are already underway investigating advanced wireless devices that are more power efficient than the current ProxLink wireless modem. A Bluetooth wireless modem, supporting the ad-hoc Bluetooth wireless network protocol, is being considered as an alternative to be incorporated within the sensing unit.

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NEW SENSING LAB COMPLETED

An Advanced Sensing Research Laboratory was recently established at the John A. Blume Earthquake Engineering Center. Research at the new laboratory is focusing on interdisciplinary research and development of sensing devices utilizing wireless and MEMS-based technologies and the application of wireless sensing for damage detection, structural health monitoring and control. Current efforts include the development of Wireless Modular Monitoring Systems (WiMMS) and novel damage detection algorithms that can be embedded in the WiMMS to provide real time information processing for civil structure applications. Current research projects are supported by the National Science Foundation and by the Los Alamos National Laboratory. Collaborators include faculty, researchers and students from Electrical Engineering and Mechanical Engineering, as well as Civil Engineering.

ALUMNI NEWS

Blaise Duvernay (MS '01) and his wife, **Liza,** are pleased to announce the arrival of their first child, **Julien**, who joined their family on September 27.

Eugenio Pellicer (MS '93) successfully defended his doctoral thesis on June 4, 2001 in Valencia, Spain, with Prof. Ronaldo Borja in attendance. The following month, July 14, he married **Victoria Garcia**, in Valencia.

SEG ADMINISTRATIVE ASSOCIATE TO LEAVE STANFORD

Kymberly Herbst, Administrative Associate for the Structural Engineering and Geomechanics program will be moving to Oregon in December with her husband, Joe. Kym has been with the program since October of 1998. She is planning on going back to school to study Childhood Development. We are very sorry to see her go, and wish her the best of luck.

SEG SUMMER GRADUATES

Congratulations to all of the Structural Engineering and Geomechanics Summer 2001 Graduates: **Hesameddin Aslani (MS), Victor Calo (MS), Dejan Krunic (MS), Takekazu Matsukawa (MS),** and **Bert Sweetman (PhD).**

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