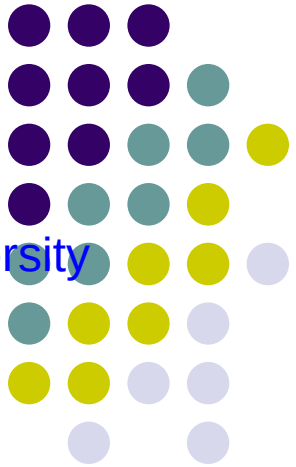
Design of a Low-Power Wireless Structural Monitoring System for Collaborative Computational Algorithms



Yang Wang, Prof. Kincho H. Law

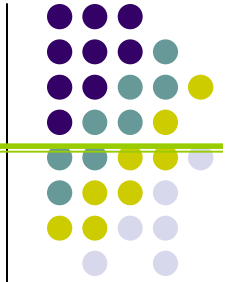
Department of Civil and Environmental Engineering, Stanford University

Prof. Jerome P. Lynch

Department of Civil and Environmental Engineering, University of Michigan

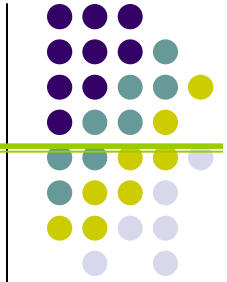
SPIE, San Diego, CA, March 6, 2005

Agenda



- Research background
- Hardware design of the latest wireless sensing unit prototype
- Software design of the latest wireless SHM system
- Large-scale field validation tests
- Future direction

Agenda



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Structural Health Monitoring (SHM)

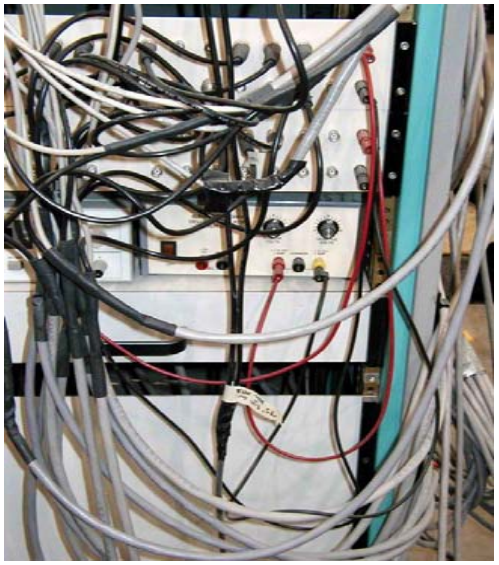
- S. Chase (2001), NBIP Report: Nearly 60,000 bridges in U.S. evaluated as structurally deficient.
- Over 580,000 highway bridges in U.S. mandated for biannual evaluations.

Advanced Sensing Technology for Autonomous SHM:

Rapid, accurate, low-cost

From Wire-based Sensing to Wireless Sensing

Traditional DAQ System: wire-based



Future Wireless DAQ System

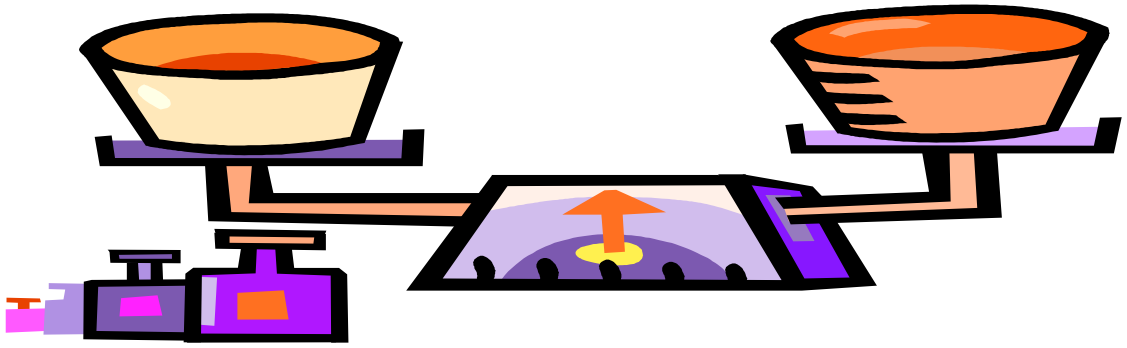
Wireless SHM prototype system Jointly developed by researchers in Stanford University and the University of Michigan

- E. G. Straser, and A. S. Kiremidjian (1998): Installation of wired system can take about 75% of testing time
- M. Celebi (2002): Each sensor channel and data recording system: $2,000; Installation (cabling, labor, etc.) per wired channel: $2,000.

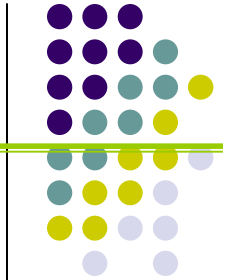
Challenges in Wireless Structural Sensing (1)

- Requirements for long-distance high-speed wireless data acquisition, and extensive local data processing

HIGHER PERFORMANCE **LOWER POWER**



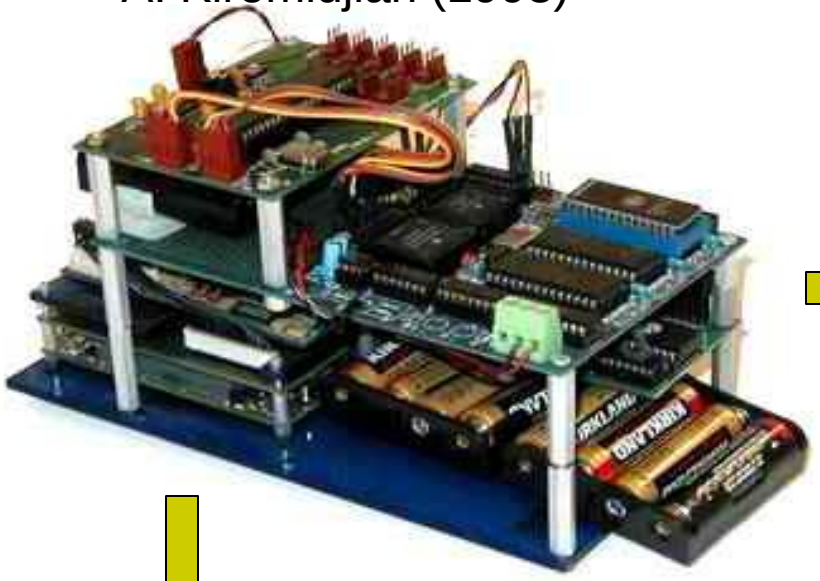
Challenges in Wireless Structural Sensing (2)



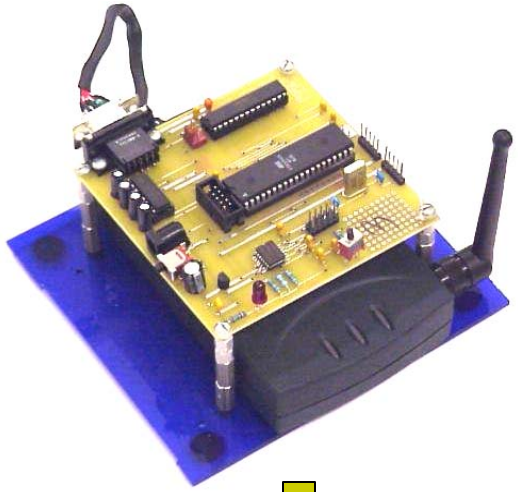
- **Hardware**
  - Restricted communication range
  - Limited bandwidth
  - Unreliable wireless transmission
- **Software**
  - Difficulty for data synchronization
  - Difficulty for robust communication design

Wireless SHM Unit Prototypes from Stanford and UMich

Dr. E. G. Straser, Prof. A. Kiremidjian (1998)



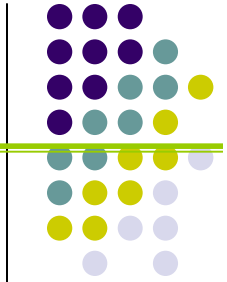
Dr. J. P. Lynch, Prof. K. H. Law *et al*. (2002)



L. Mastroleon, Prof. A. Kiremidjian *et al* (2004)

Y. Wang, Prof. J. P. Lynch, Prof. K. H. Law (2005)

Agenda



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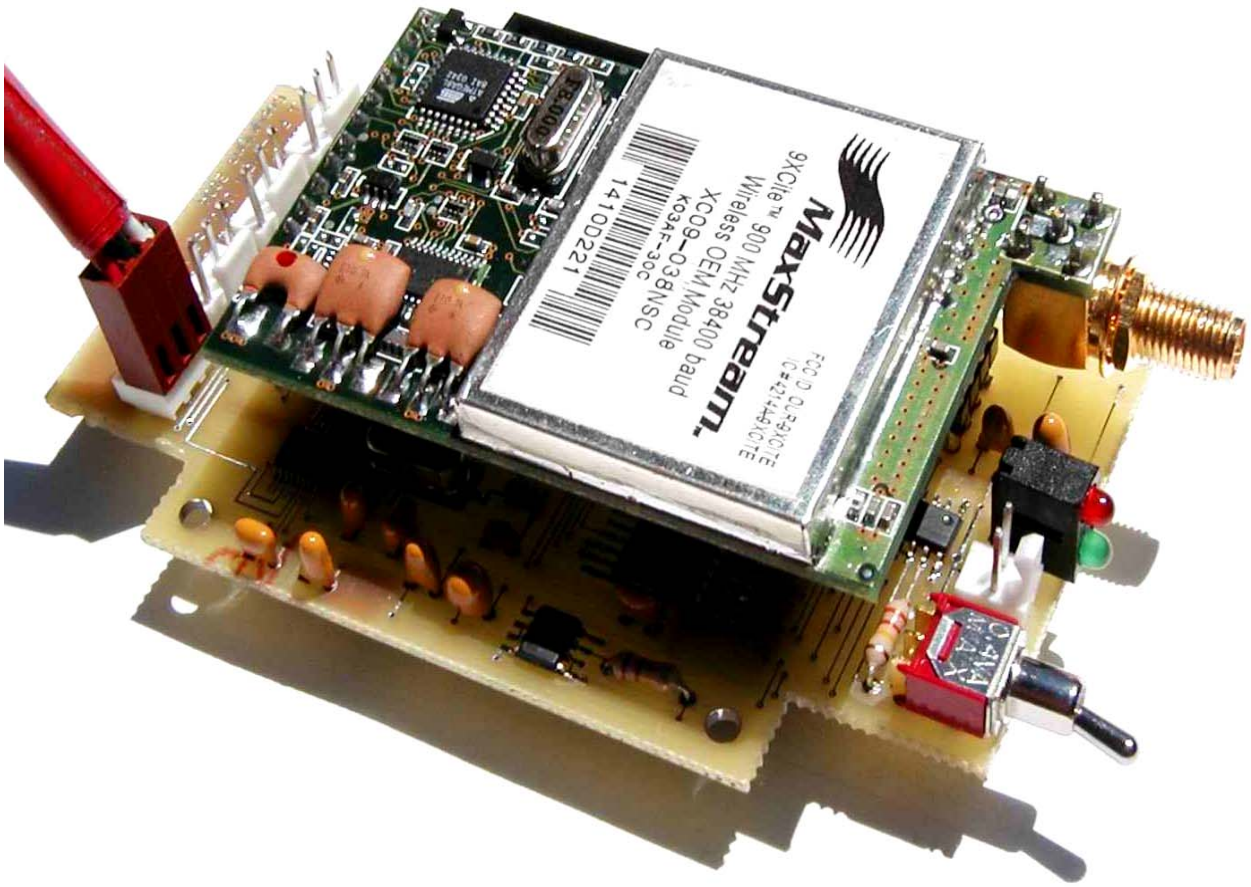
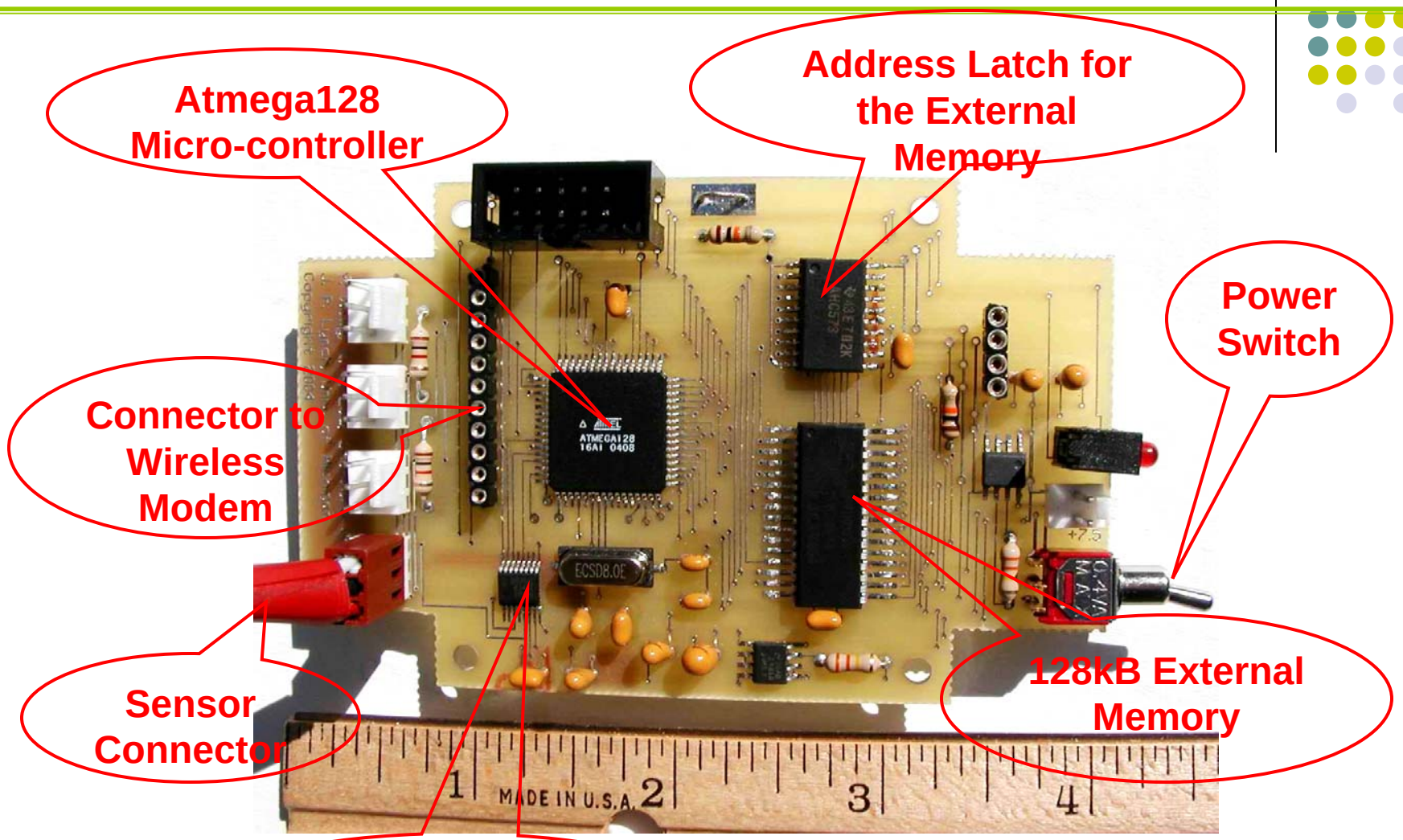
Picture of the Prototype with Wireless Modem

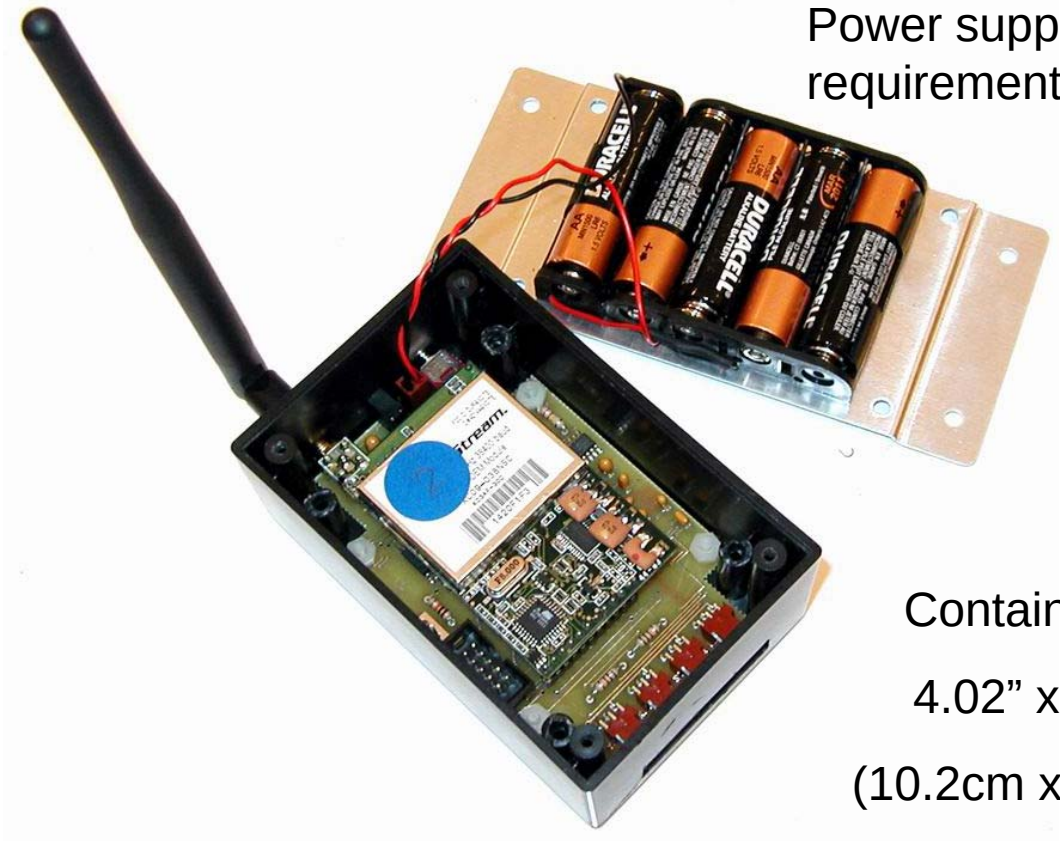


Prototype Double-layer Circuitry Board



Wireless Sensing Unit Prototype Package

Antenna Length:
5.79” (14.7cm)



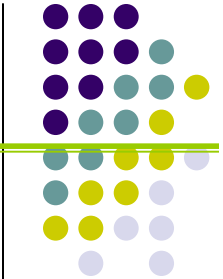
Power supply requirement: 5.2V

Container Dimension

4.02” x 2.56” x 1.57”

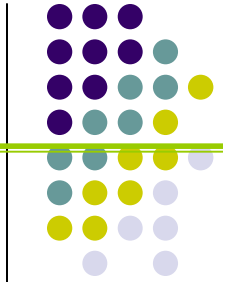
(10.2cm x 6.5cm x 4.0cm)

Hardware Performance Summary



- Power consumption: 75 – 80mA when active; 0.1mA standby
- Communication range: 90m indoor, 300m outdoor
- 16bit Analog-To-Digital conversion, 4 A2D channels
- Local data processing
- Point-to-multipoint, and peer-to-peer communication
- Low hardware cost

Agenda



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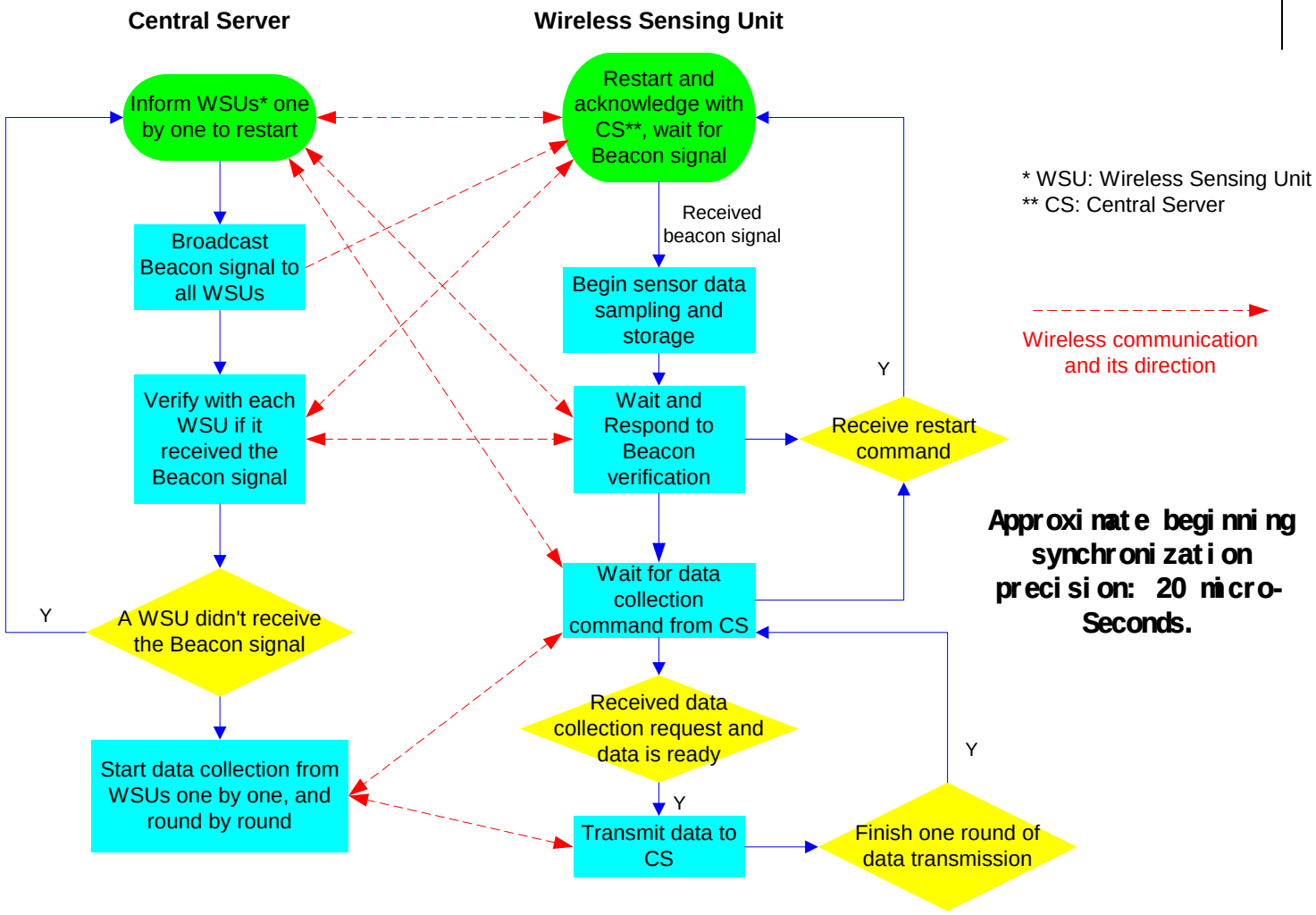
Wireless Sensing Network

Prototype system: simple star topology network

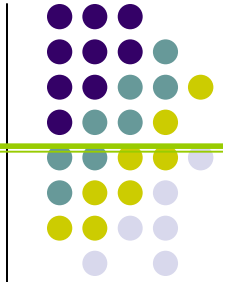
Server-side computer software

Firmware for wireless sensing units

Reliable Beacon Signal Synchronization Protocol



Agenda



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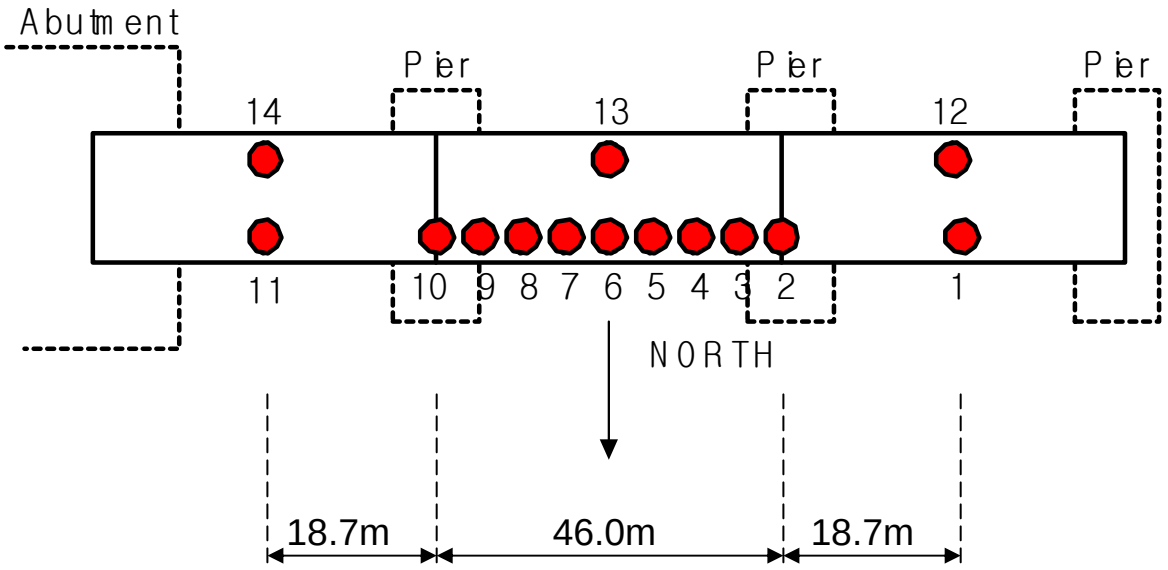
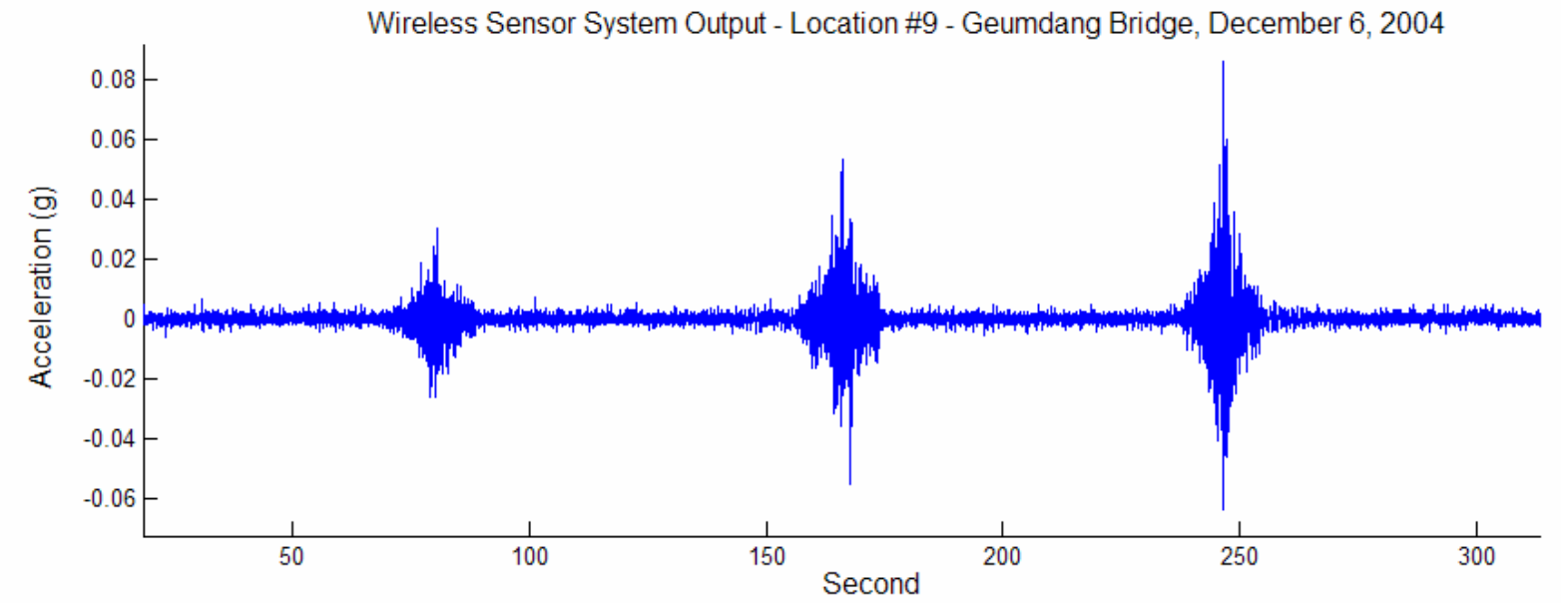
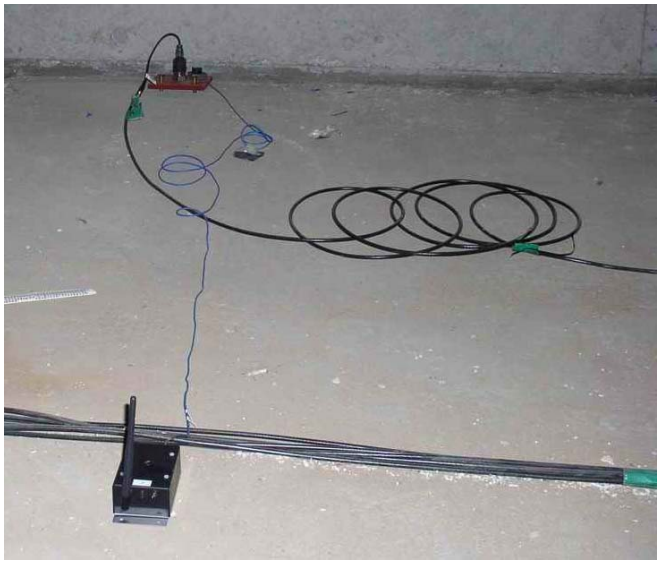
Geumdang Bridge Test, Korea



Bridge Traffic Excitation

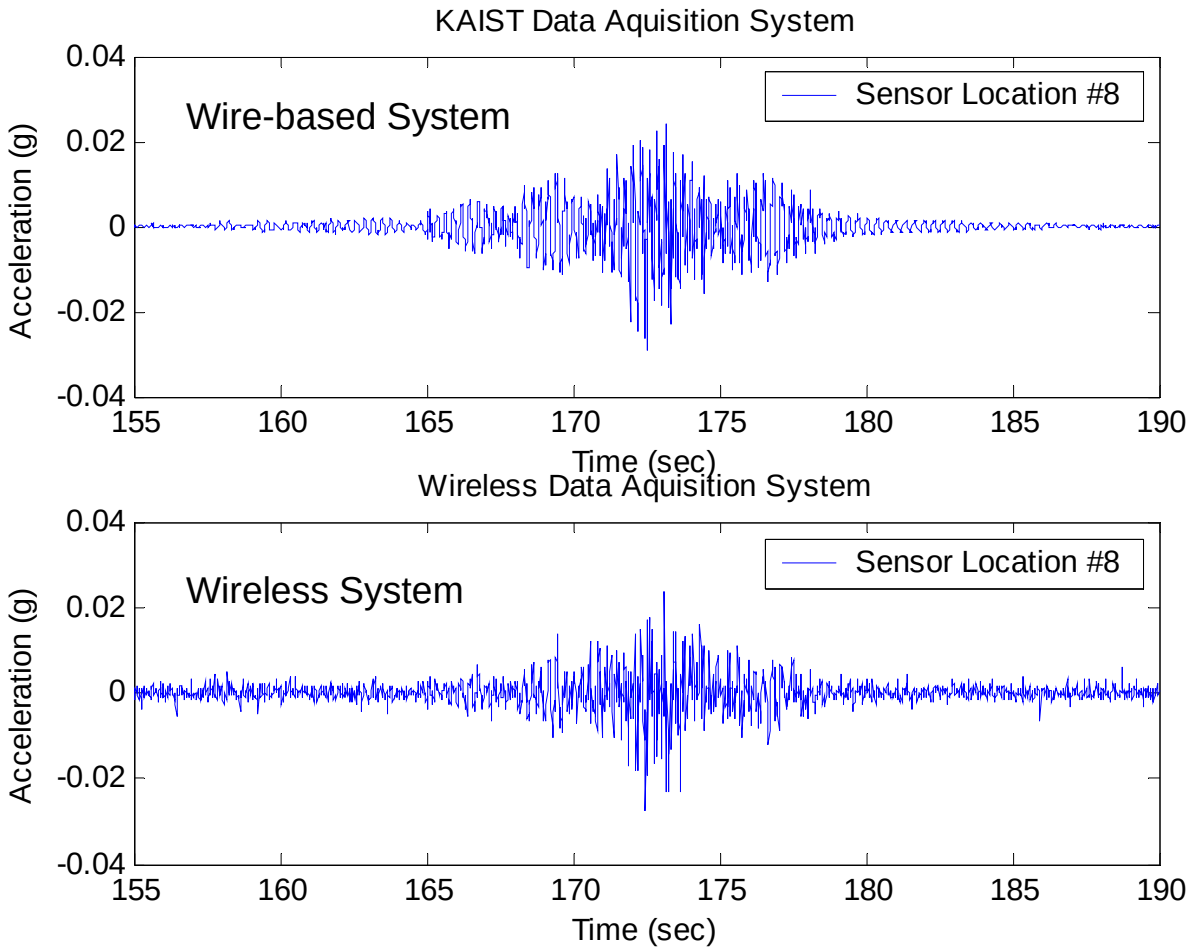


Wire-based System versus Wireless System



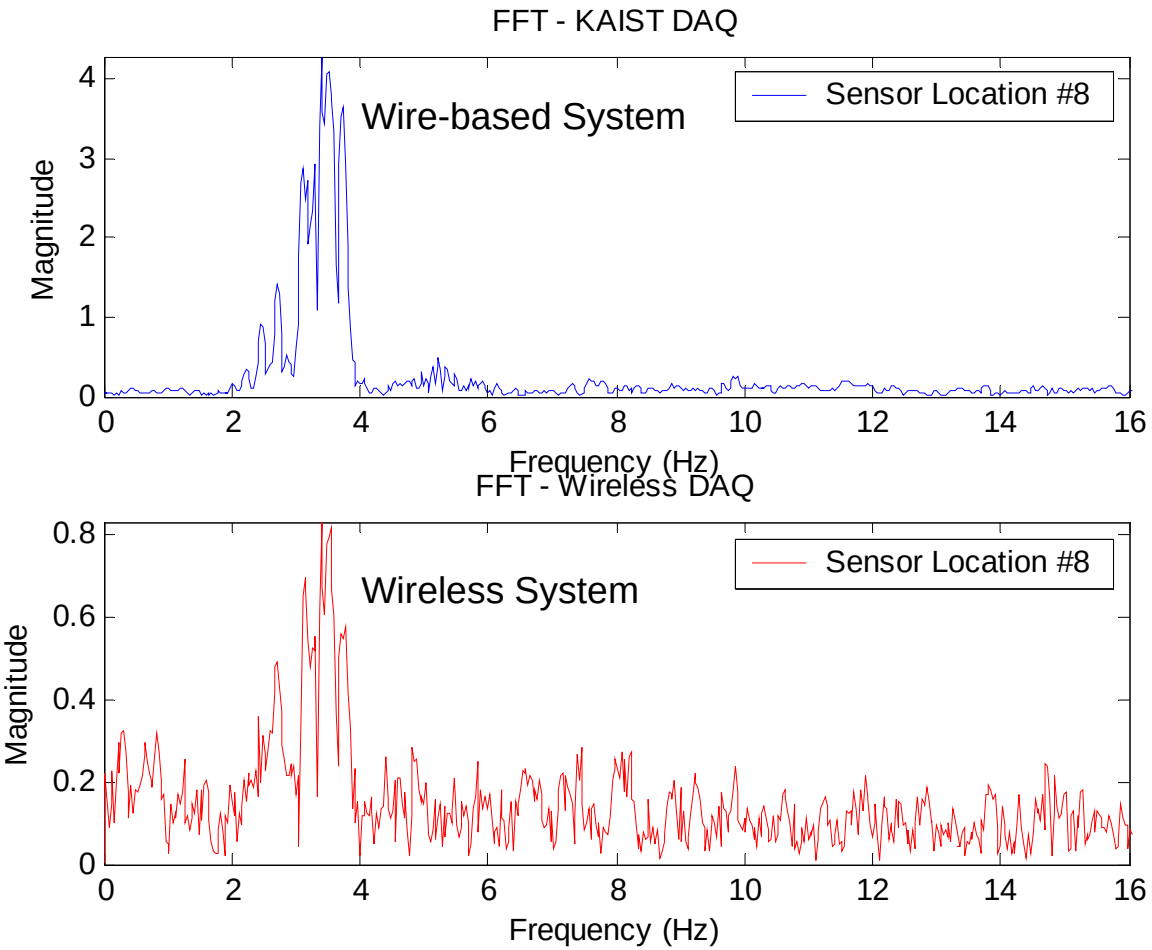
Sensor Property	PCB Piezoelectric (Cable System)	PCB MEMS Capacitive (Wireless System)
Maximum Range	1 g	3 g
Sensitivity	10 V/g	0.7 V/g
Bandwidth	2000 Hz	80 Hz
RMS Resolution (Noise Floor)	50 μg	0.5 mg
Sampling Frequency	200Hz	70Hz

Time History Comparison Between Two Systems

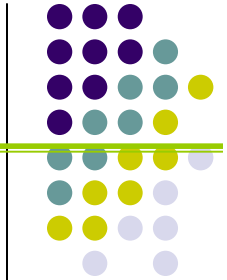


- Difference in sensors and signal conditioning

Comparison of FFT Results

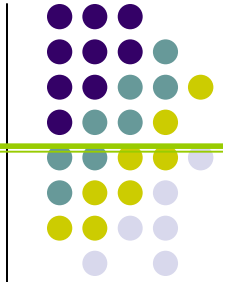


Validation Results Summary



- Rapid installation, and low cost
- Communication range: 50 – 60m in box girder
- Networked real-time and non-stopping data collection: up to 24 wireless sensors at 50Hz sampling frequency
- Data is near-synchronized: modal analysis
- Local data processing capability: 4096-pt FFT by wireless sensing unit

Agenda



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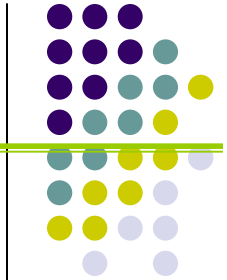
Future Direction



To be improved for current prototype system:

- Sensor signal conditioning
- Greater wireless communication range, higher data rate
- Large-scale data collection from densely allocated sensors
- Local data analysis and damage identification algorithm

Acknowledgement

- National Science Foundation CMS-9988909 and CMS-0421180
- The Office of Technology Licensing Stanford Graduate Fellowship
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- Prof. Law, Prof. Kiremidjian and Prof. Miranda

The End