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# Validation of an Integrated Network System for Real-time Wireless Monitoring of Civil Structures

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IWSHM, Stanford, CA, September 14, 2005

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# Outline

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- Research background
- Hardware and software design of the latest wireless SHM system
- Real-size laboratory structure tests at NCREE, Taiwan
- Large-scale field validation tests at Geumdang Bridge, Korea
- Future research

# From Wire-based Sensing to Wireless Sensing

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## WHY THE CHANGE?

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

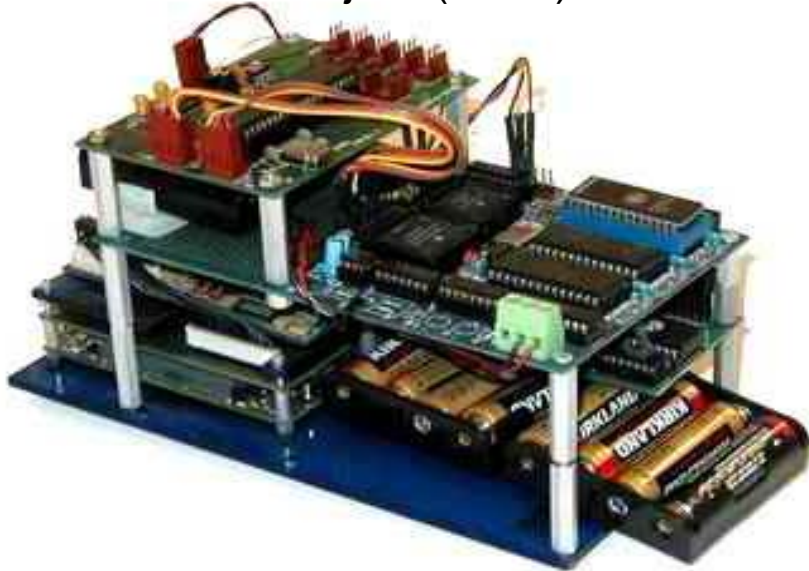
## INDUCED CHALLENGES

- Limited power consumption
- Restricted communication range, bandwidth, and reliability
- Difficulty for data synchronization

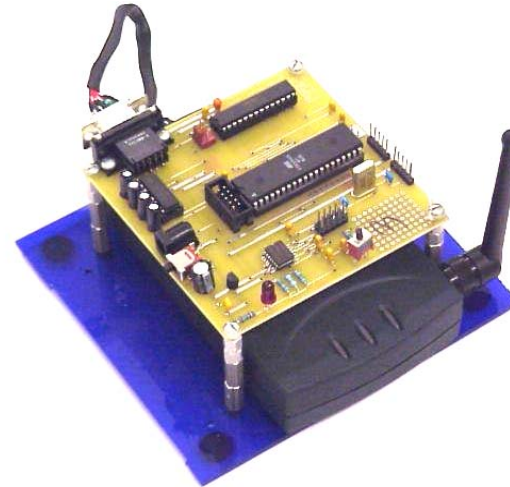
# Wireless SHM Unit Prototypes



Dr. E. G. Straser, Prof.  
A. Kiremidjian (1996)



Dr. J. P. Lynch, Prof. K.  
H. Law *et al.* (2001)

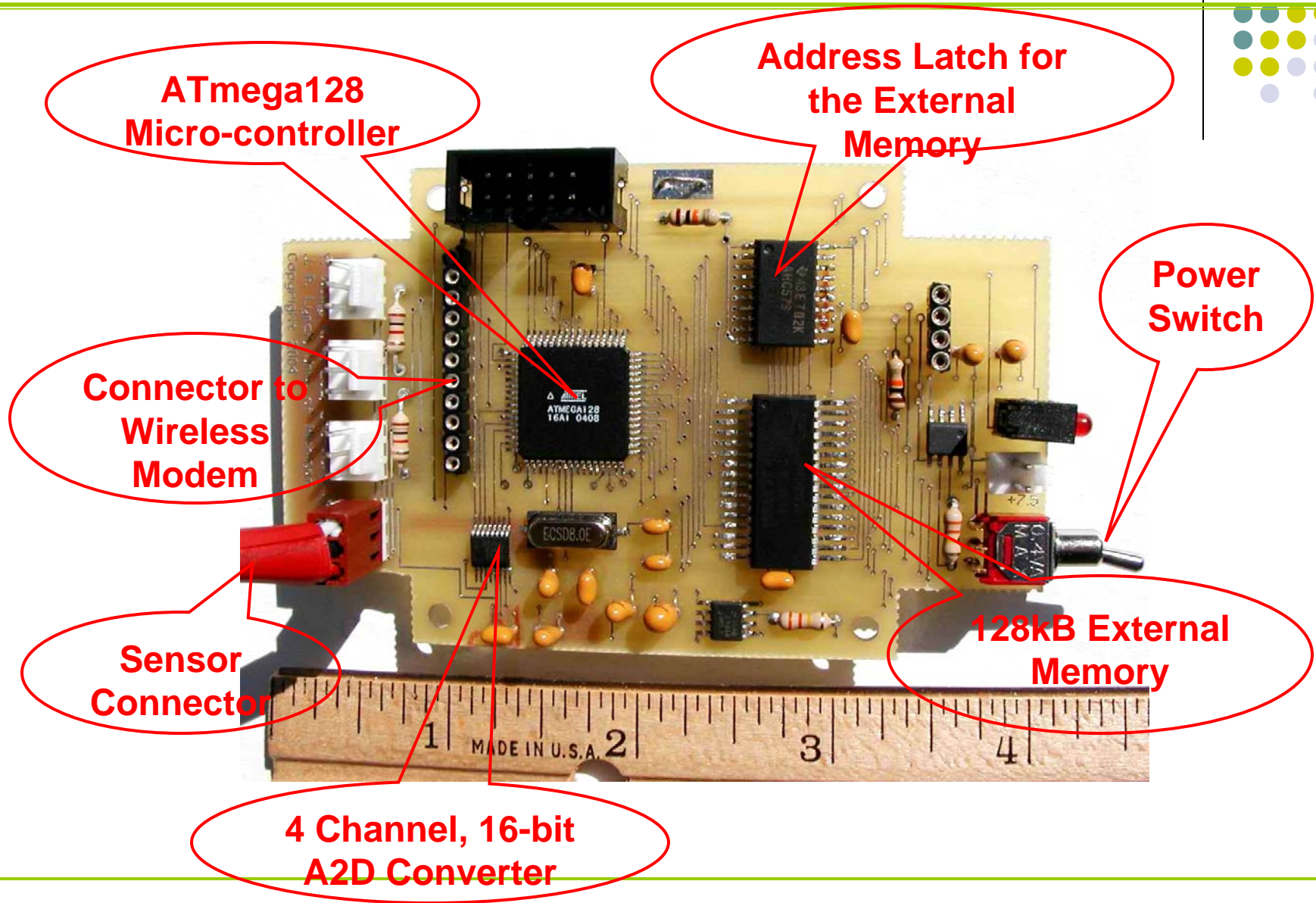


L. Mastroleon, Prof. A.  
Kiremidjian *et al* (2003)



Y. Wang, Prof. J. P. Lynch,  
Prof. K. H. Law (2004)

# Double-layer Circuitry Prototype Board



## Final Package of the Latest Prototype Unit

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Antenna Length:  
5.79" (14.7cm)

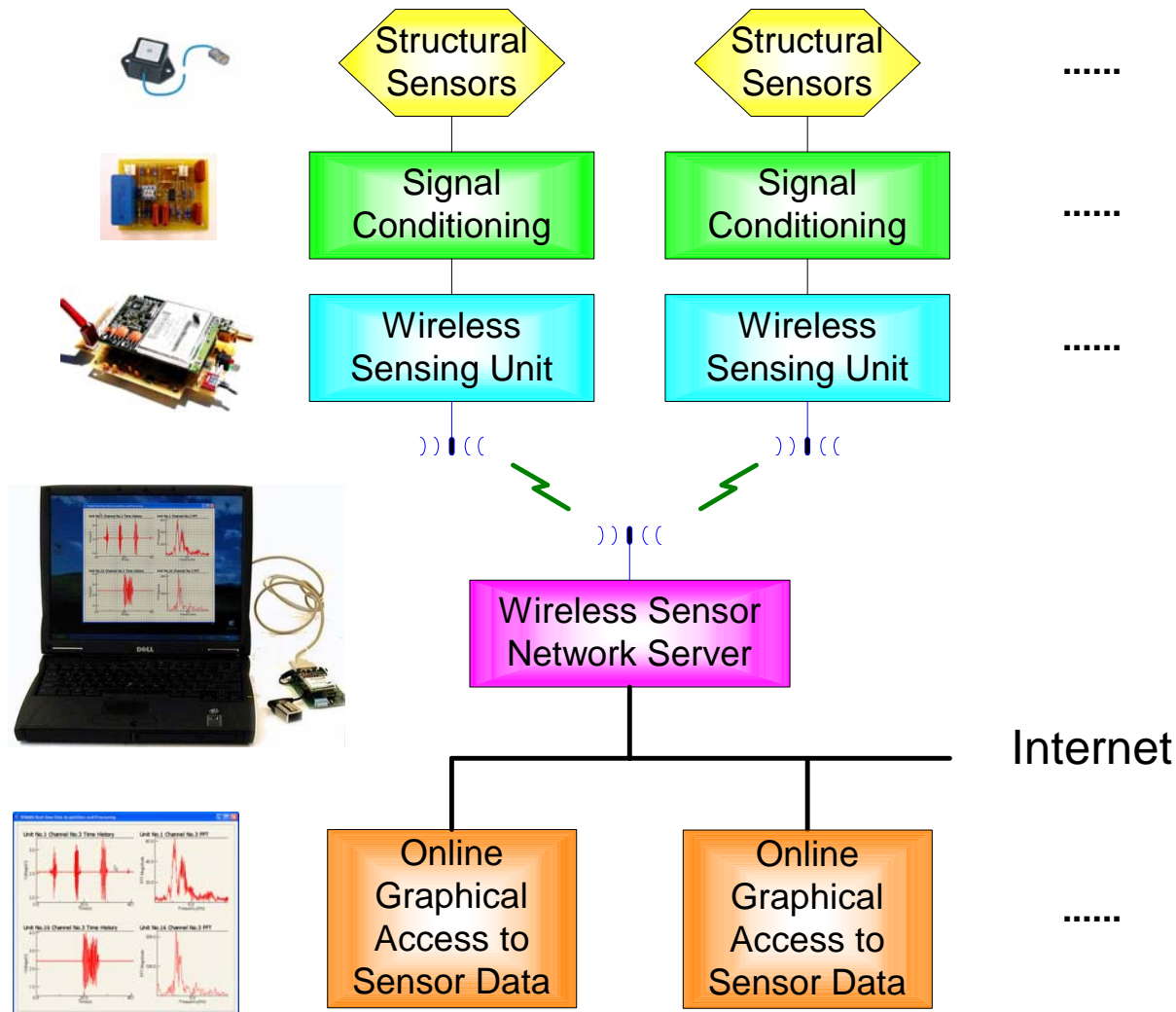


Container Dimension  
4.02" x 2.56" x 1.57"  
(10.2cm x 6.5cm x 4.0cm)

- **Total power consumption at 5V power supply**
  - 75 – 80mA when active; 0.1mA standby
- **Wireless communication with MaxStream 9XCite modem**
  - Communication range: 90m indoor, 300m outdoor
  - Wireless data rate: 40kbps
- **Total unit cost using off-the-shelf components**
  - \$130 for small quantity assembly



# Latest Wireless SHM Prototype System



# Wireless Sensing Network

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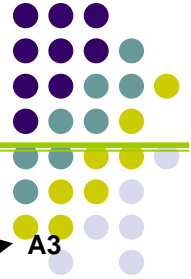
Server-side  
computer software

Firmware for  
wireless sensing  
units

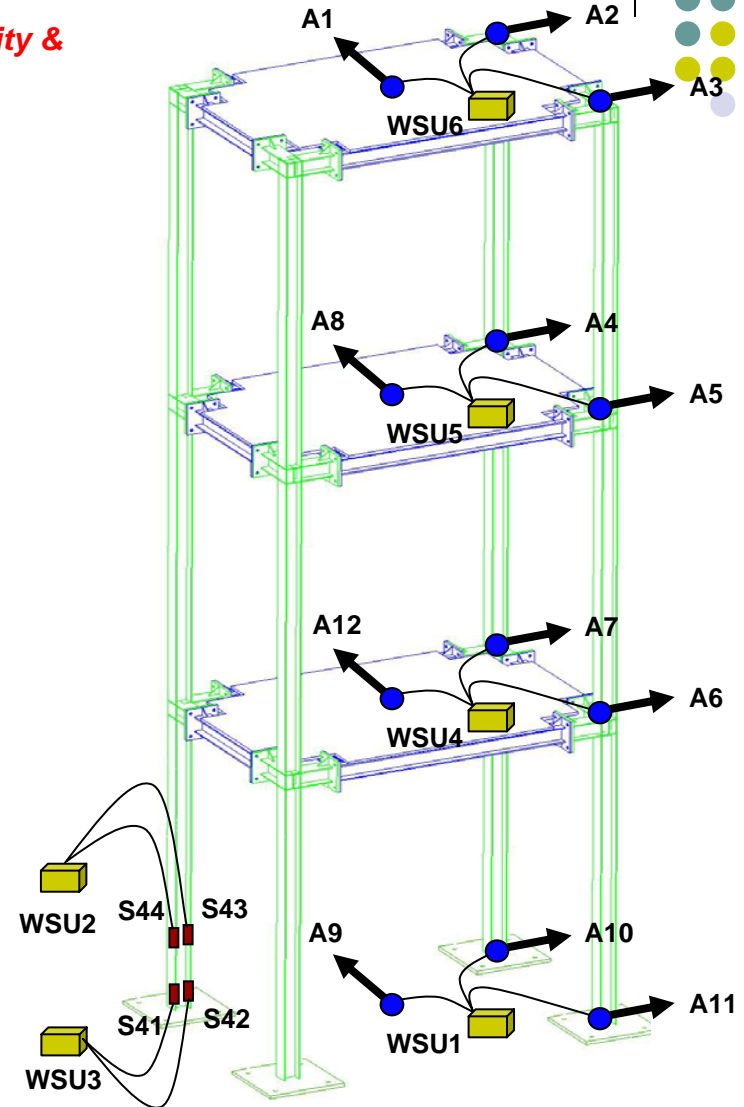
- Simple star topology network
- Near-synchronized and reliable data collection from all wireless sensing units



# Laboratory 3-Story Structure on a 6-DOF Shaking Table

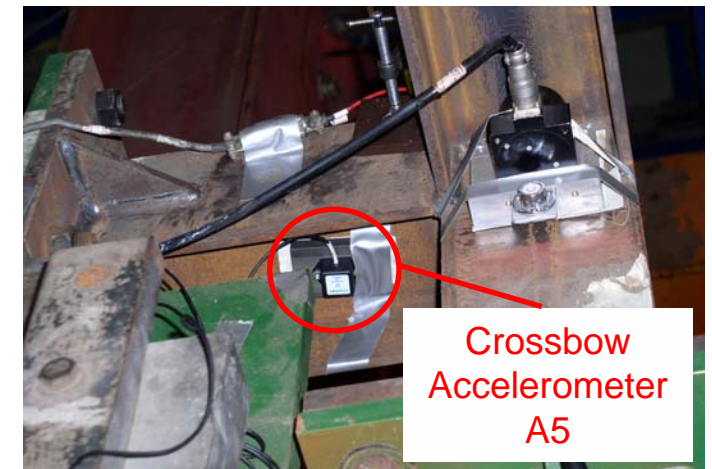
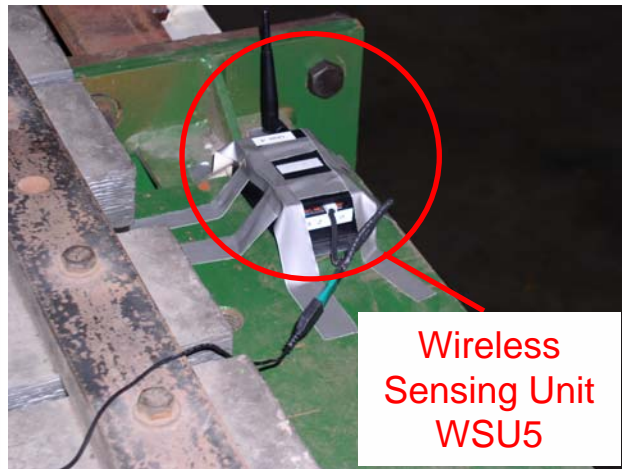
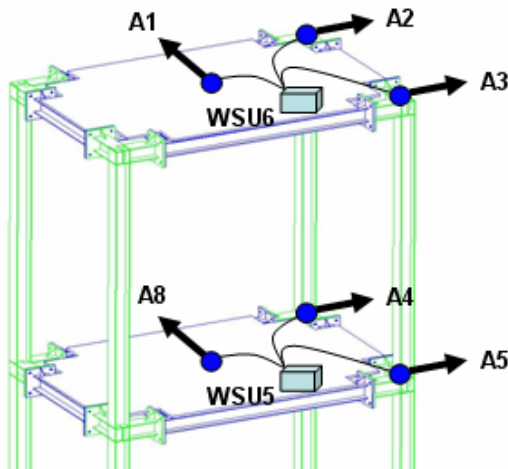
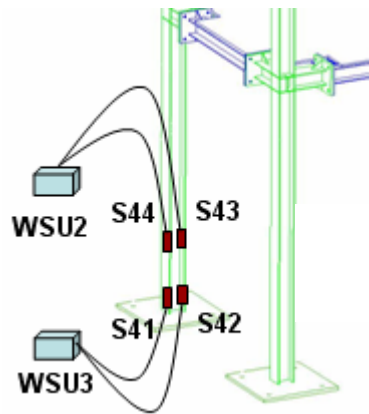


*Collaboration with Prof. C. H. Loh, National Taiwan University &  
National Center for Research on Earthquake Engineering*

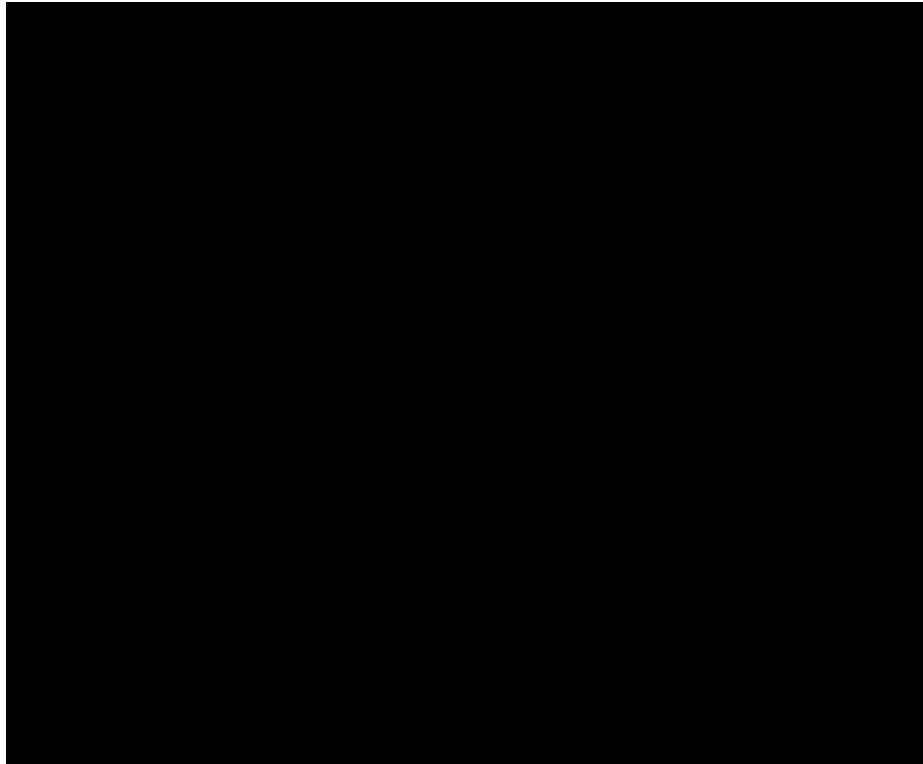
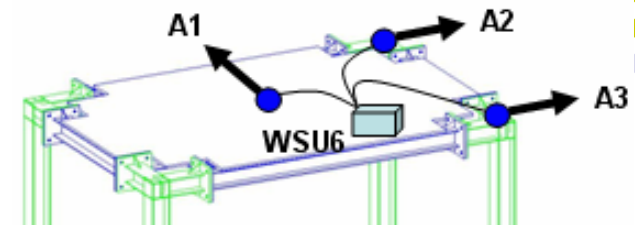




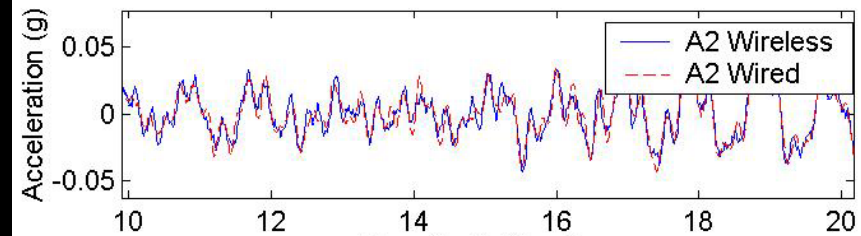
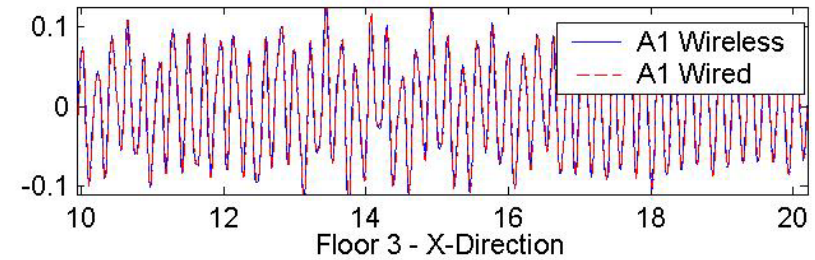
# Wireless Sensor Installation Details



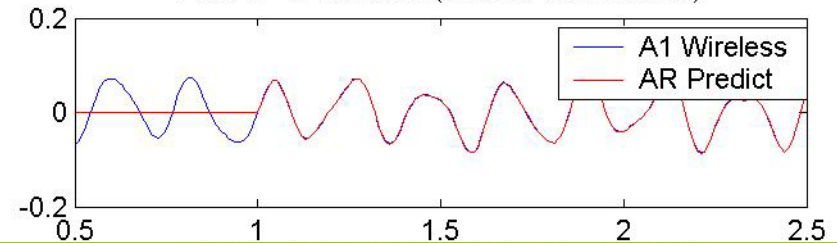
# Structural Response Data



Floor 3 - Y-Direction



Floor 3 - Y-Direction (100 AR Coefficients)

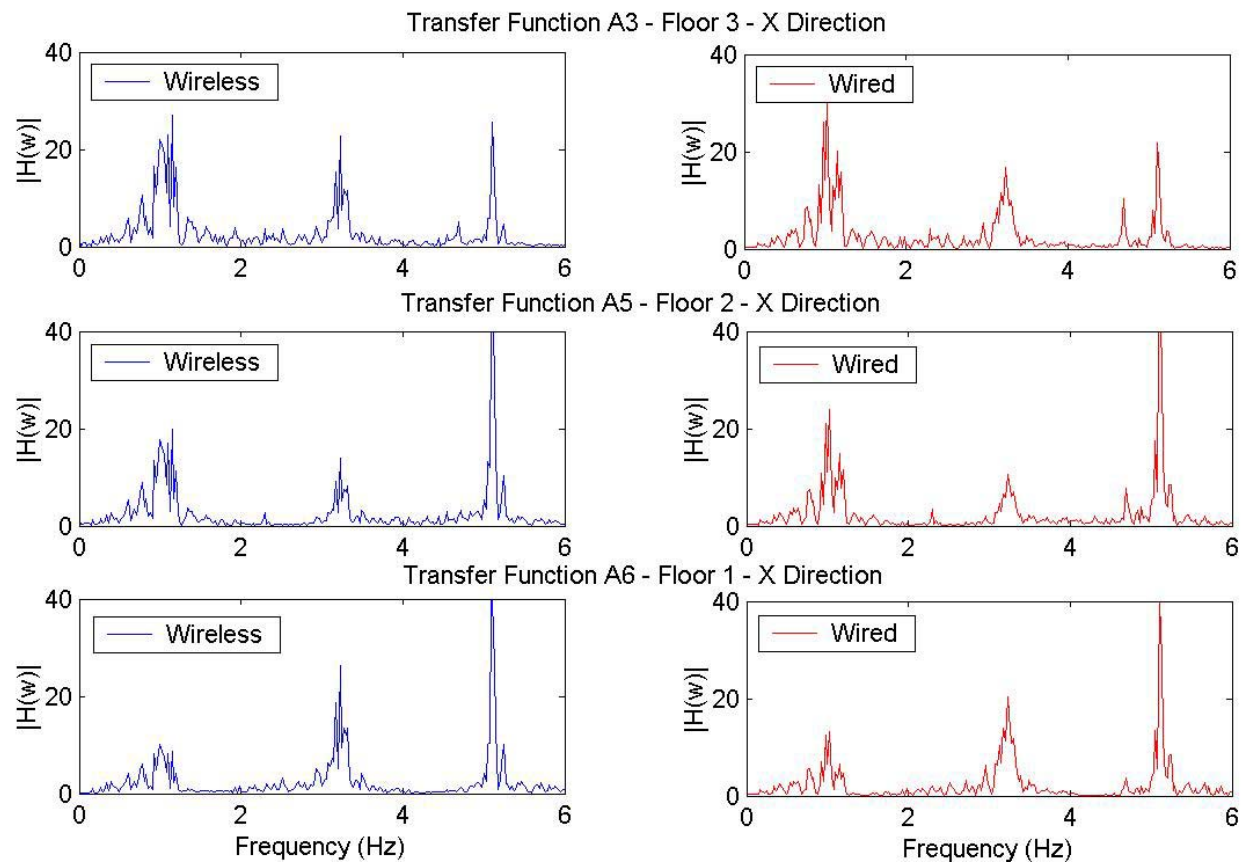






# On-board FFT Analysis

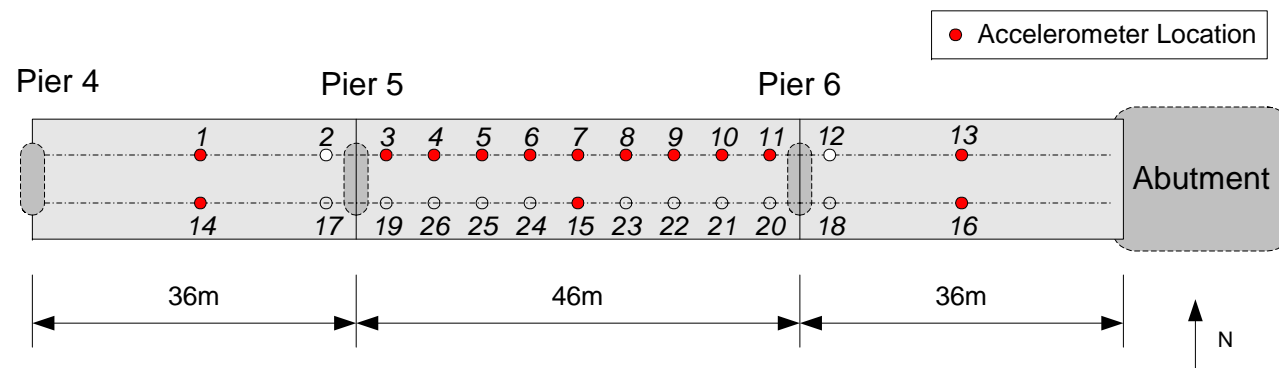
- 4096-point complex valued FFT computation
- Results for interested frequency spectrum wirelessly transmitted



# Geumdang Bridge Test, Korea

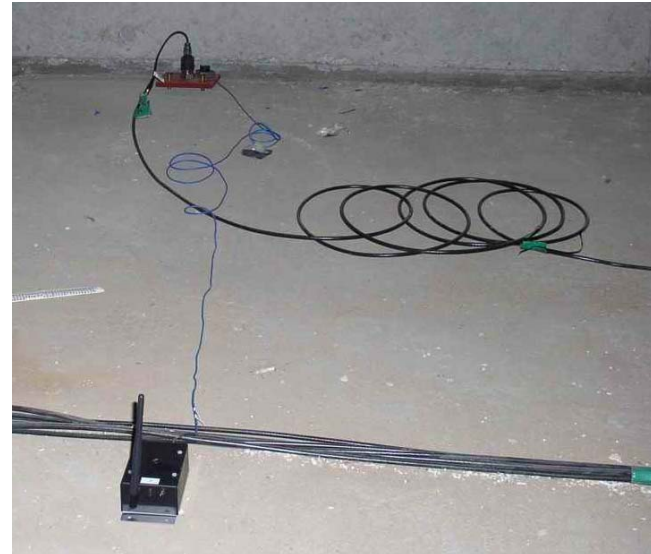


*Collaboration with Prof. Chung Bang Yun, Prof. Jin Hak Yi, and Mr. Chang Geun Lee, Korea Advanced Institute of Science and Technology (KAIST)*



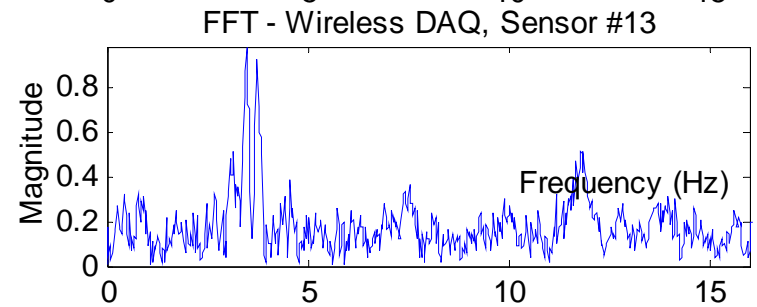
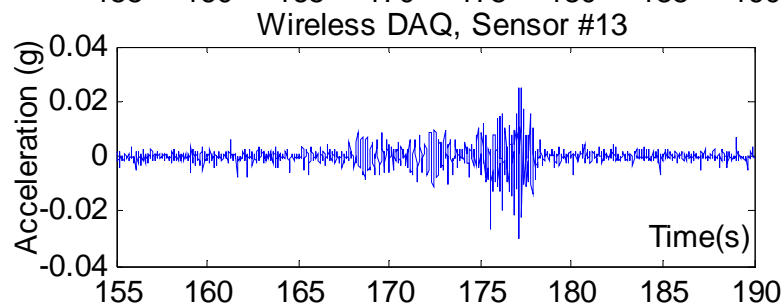
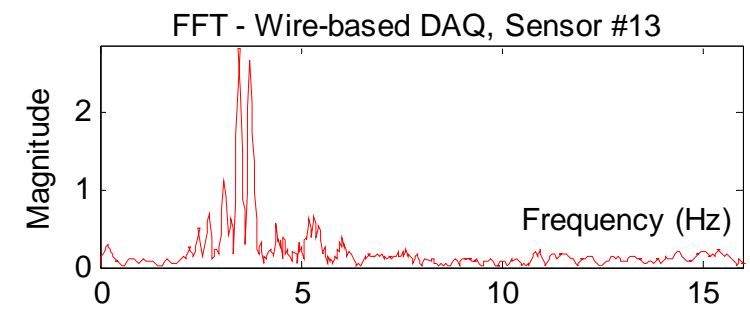
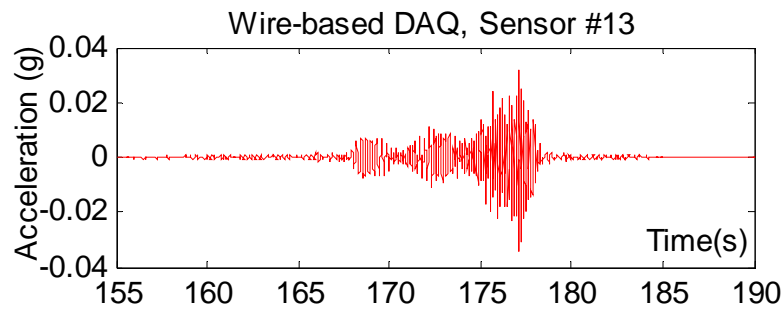
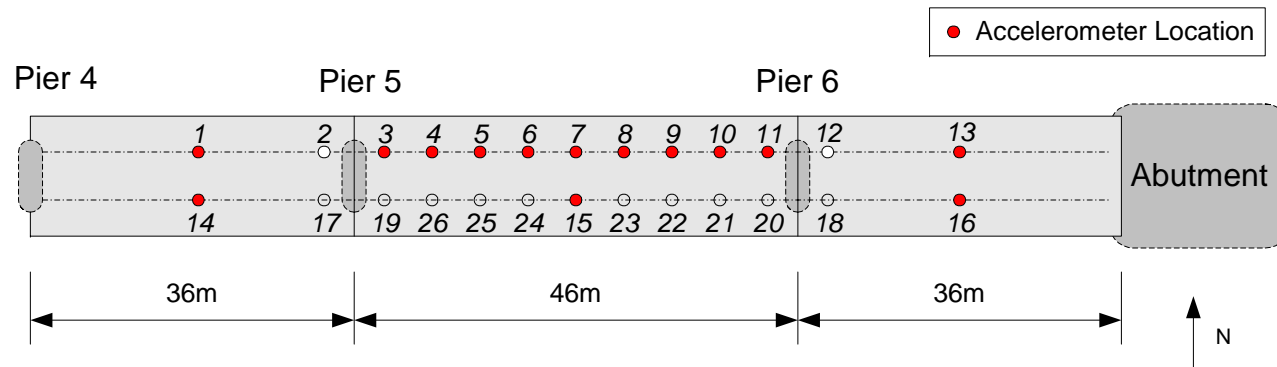
**Sensor Allocation for Tests at Geumdang Bridge, Dec 2004**

# Wire-based System vs. Wireless System



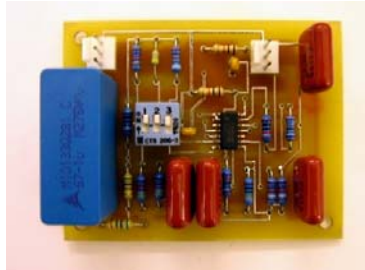
Sensor Property	PCB Piezoelectric (Wire-based System)	PCB MEMS Capacitive (Wireless System)
Maximum Range	1 g	3 g
Sensitivity	10 V/g	0.7 V/g
Bandwidth	2000 Hz	80 Hz
RMS Resolution (Noise Floor)	50 $\mu$ g	500 $\mu$ g
Sampling Frequency	200Hz	70Hz

# Comparison Between Two Systems

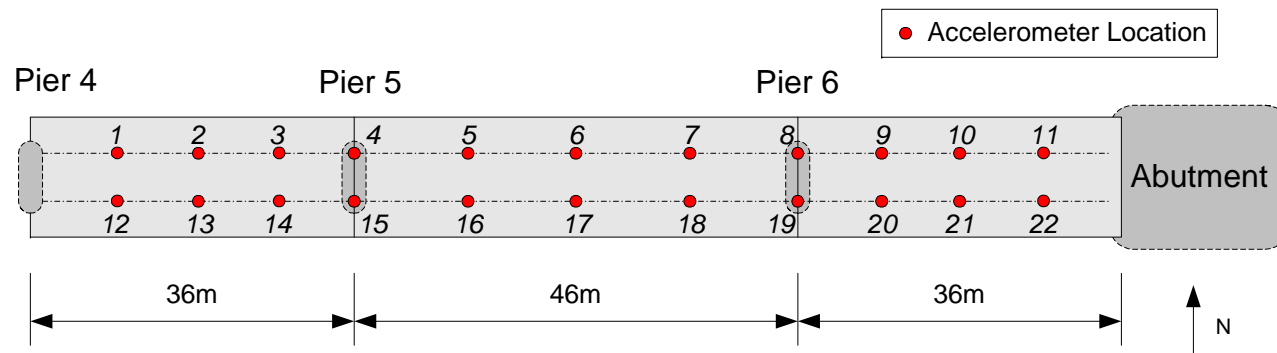




# Latest Bridge Tests with Sensor Signal Conditioning

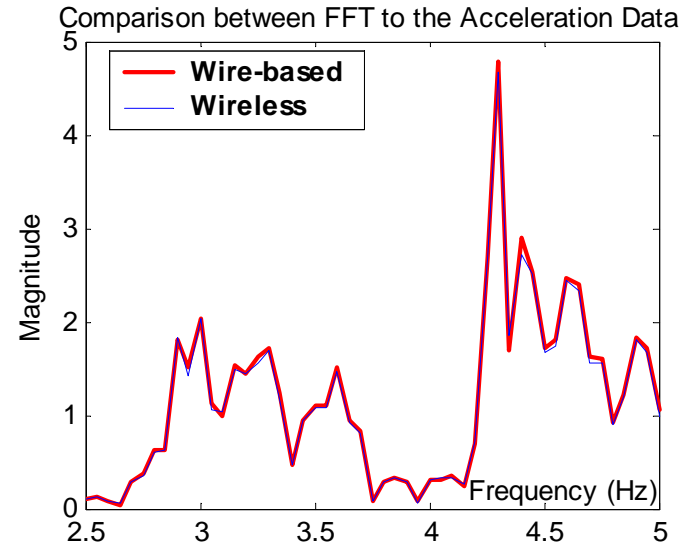
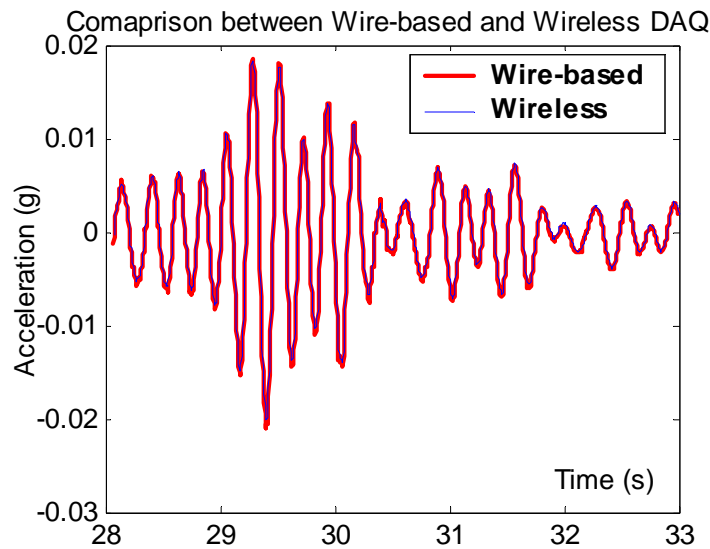
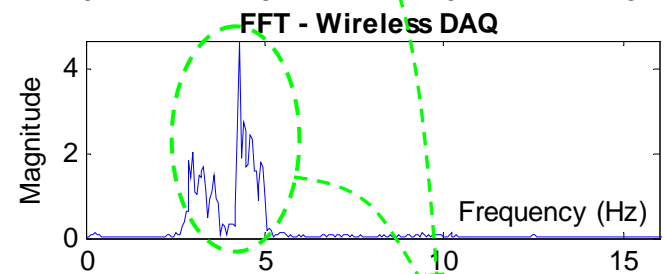
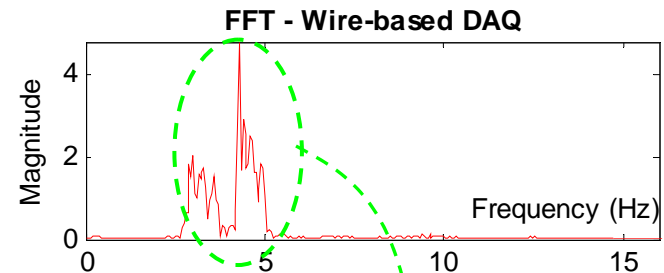
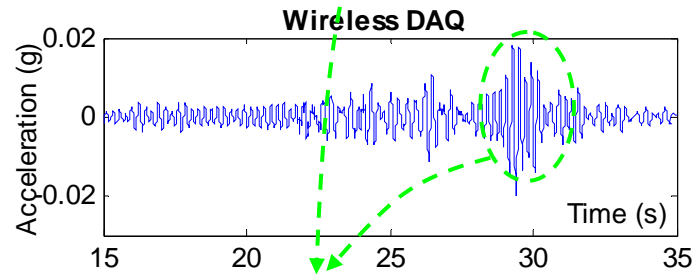
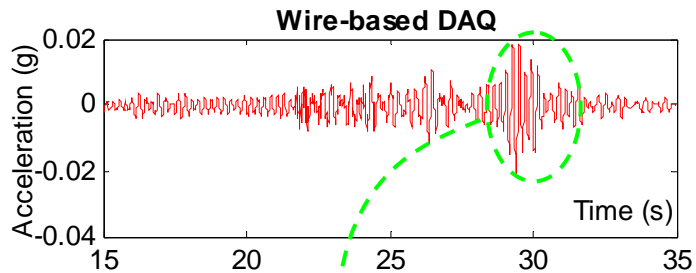


- **Mean shifting:** any analog signal to 2.5V mean
- **Amplification:** 5, 10 or 20
- **Anti-alias filtering:** band pass 0.02Hz – 25Hz



**Sensor Allocation for Tests at Geumdang Bridge, Jul 2005**

# Comparison for Wireless DAQ with Signal Conditioning



# Future Research (1)



*Collaboration with Prof. C. H. Loh, National Taiwan University &  
National Center for Research on Earthquake Engineering*



**Gi-Lu Cable-Stayed Bridge, Chi-chi, Taiwan**  
**Span: 120m (L) + 120m (R)**

# Future Research (2)

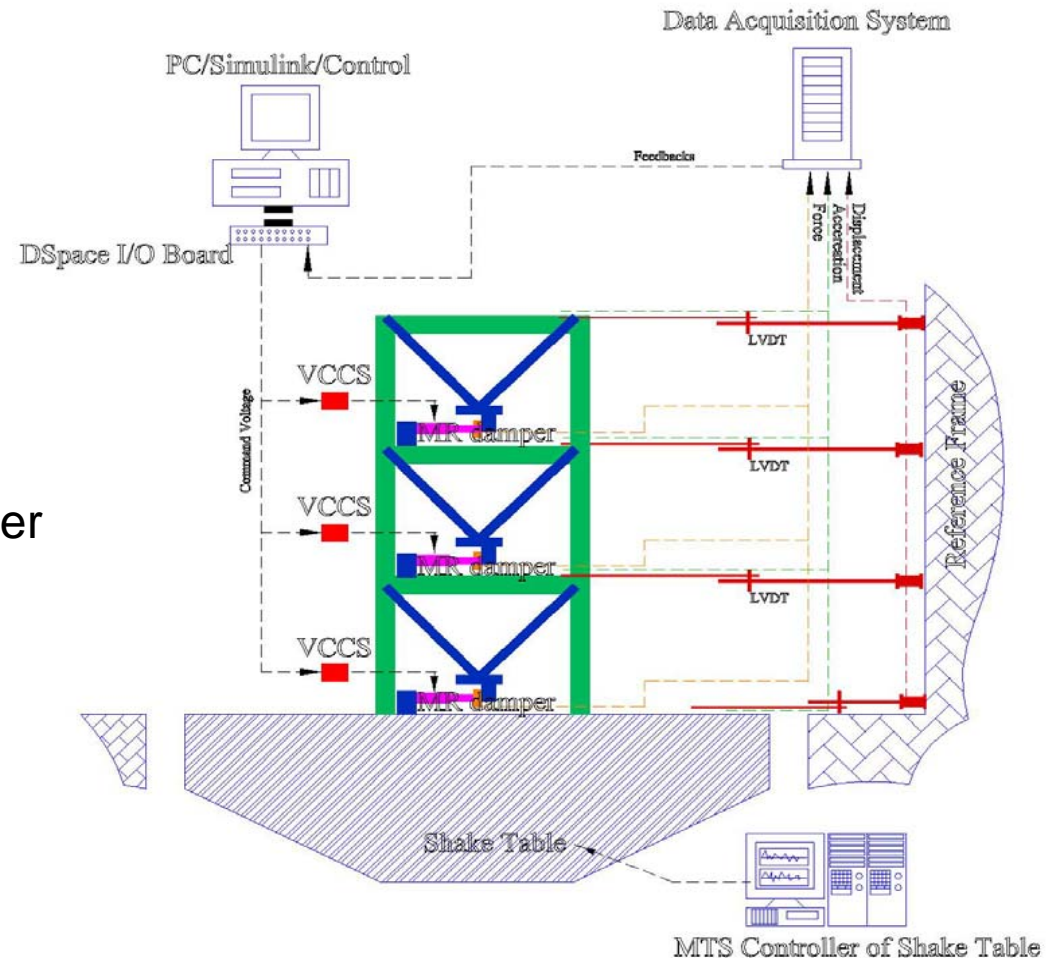


*Collaboration with Prof. C. H. Loh, National Taiwan University & National Center for Research on Earthquake Engineering*



## Magneto-Rheological (MR) Damper

- Stroke : 300mm or +/- 150 mm
- Capacity : 20 kN

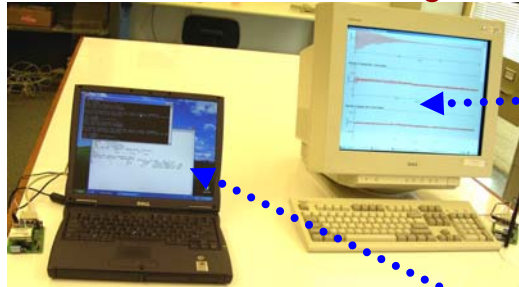




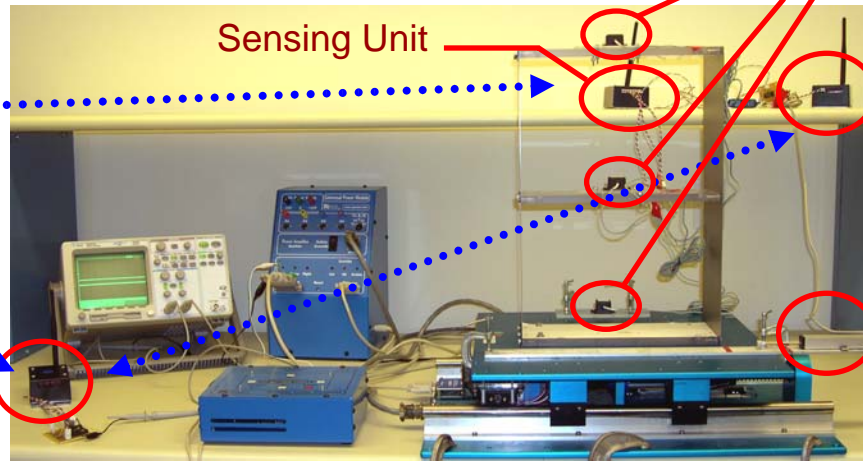
# Invitation to a Live Lab Demo



Actuation Server    Sensing Server



Actuation Unit



Sensing Unit

MEMS Accelerometer

Table Monitoring unit

LVDT

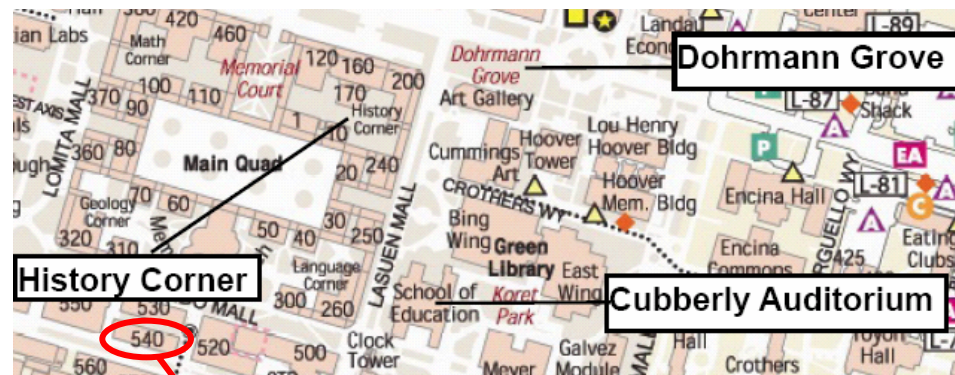
**Presented by:**

Yang Wang, Prof. Kincho H. Law,  
*Stanford University*

Prof. Jerome P. Lynch, *University of Michigan*

**Time:**

4:30pm, Wednesday, Sep 14<sup>th</sup>



★ Rm 106, Bldg. 540, John A. Blume  
Earthquake Engineering Center

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- **Prof. Anne Kiremidjian** from Civil Engineering, and **Prof. Ed Carryer** from Mechanical Engineering at Stanford University
  
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The End

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*Thank You*