STRUCTURAL HEALTH MONITORING FOR CIVIL INFRASTRUCTURE – FROM INSTRUMENTATION TO DECISION SUPPORT

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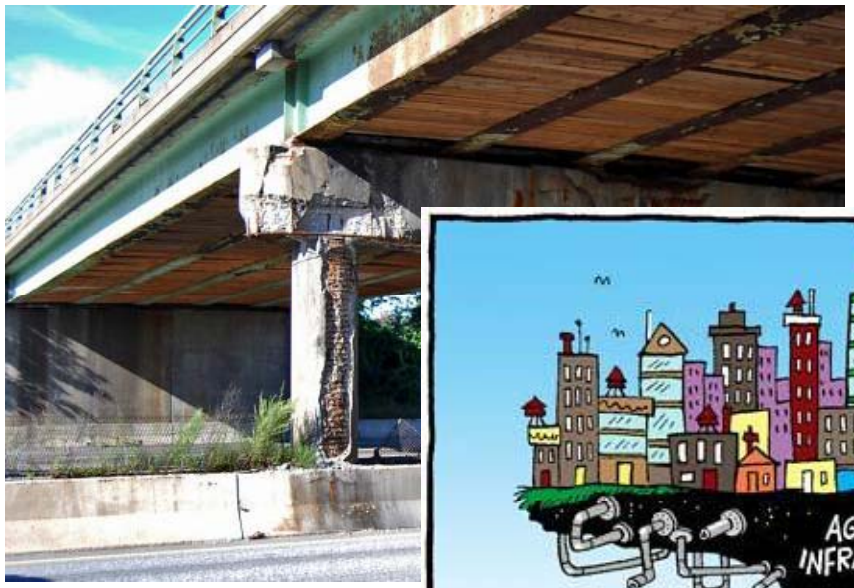
IWSHM 2011
September 13-15, 2011

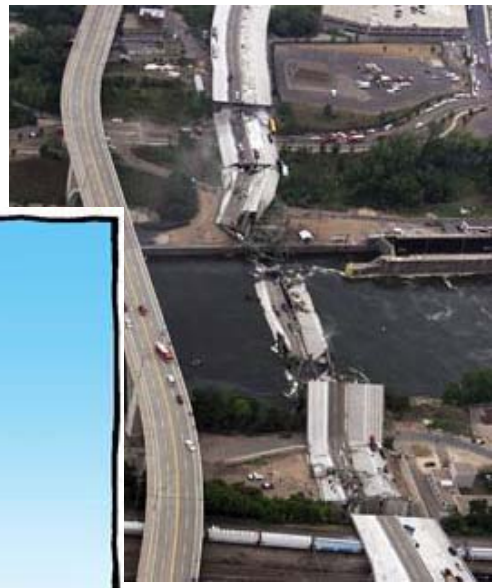
This research is supported by the NSF CMMI Research Grant No. 0800932, the John A. Blume Fellowship, and the Samsung Scholarship.

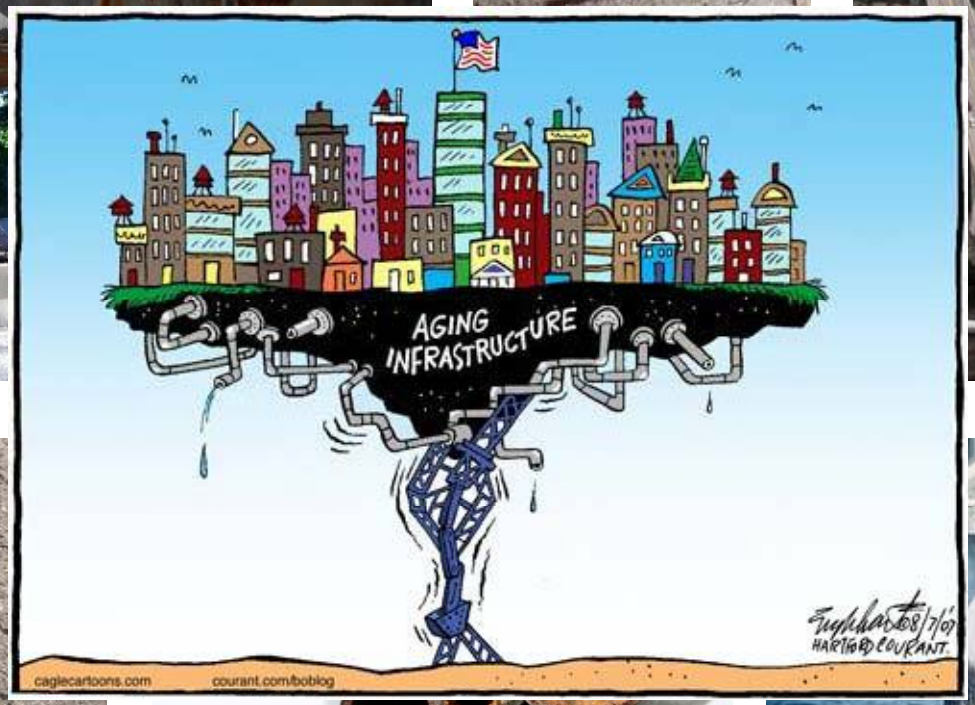
Diversity of Civil Infrastructure

Why Monitor Civil Infrastructure?
Gradual Long-Term Deterioration

(from Dr. Hae Young Noh)



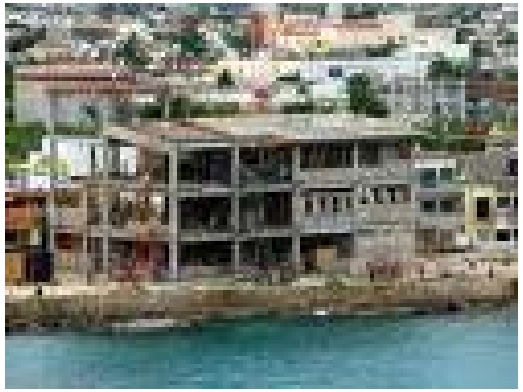




Why Monitor Civil Infrastructure? - Extreme Event Damage





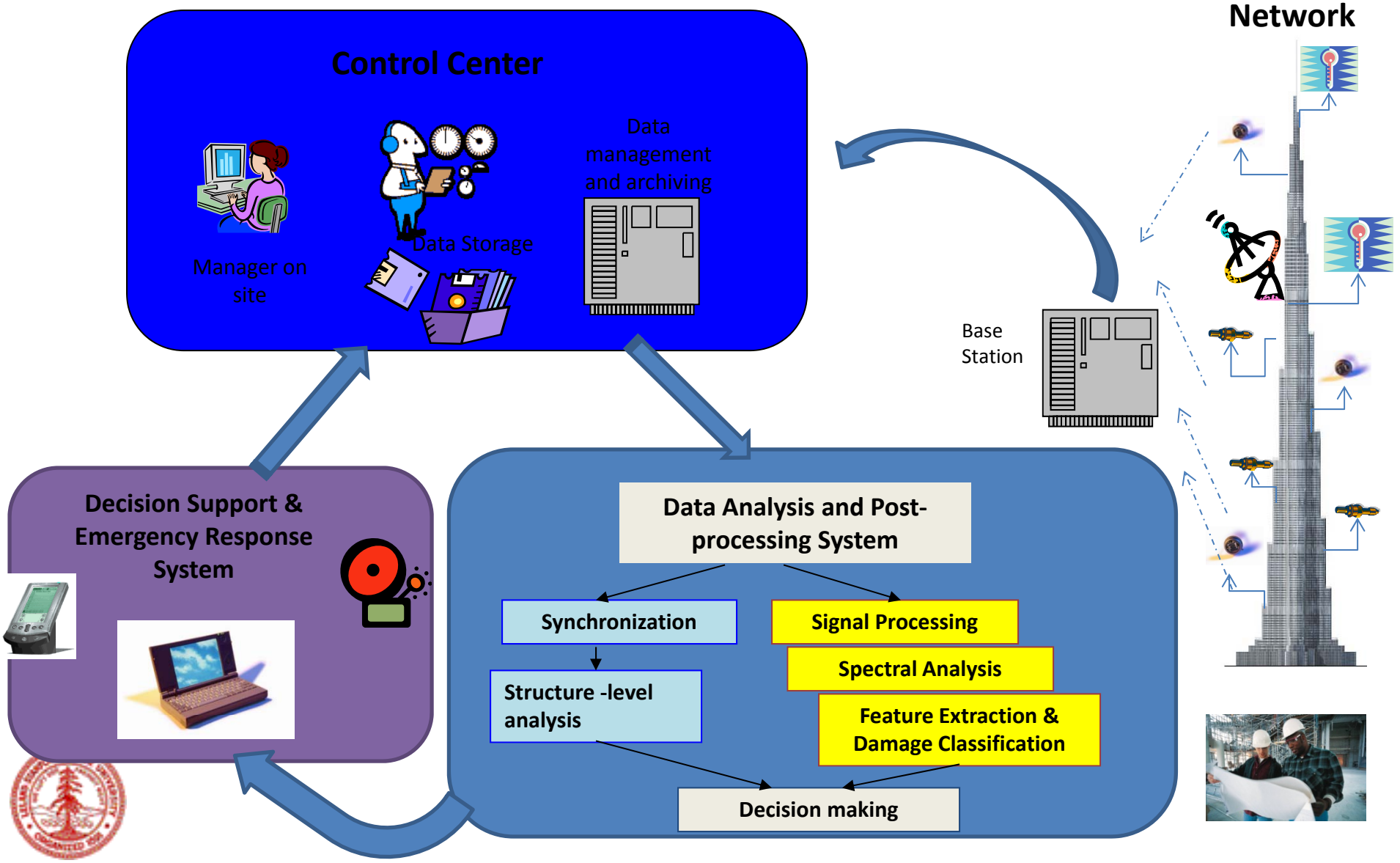




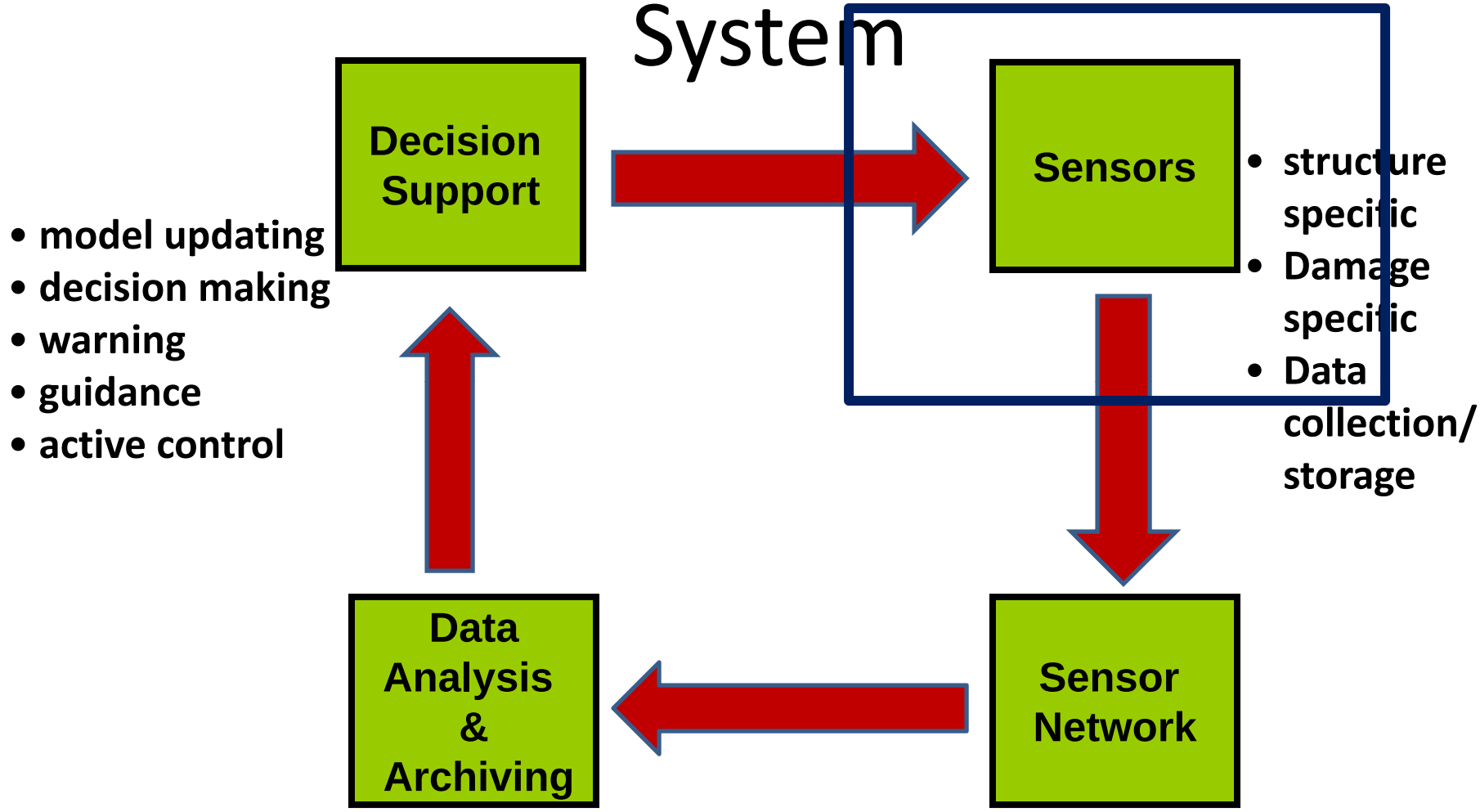
Outline

- Wireless/Wired Monitoring System Design
- Algorithmic Development
- Example Applications
- Decision Support System
- Conclusion

Structural Monitoring System



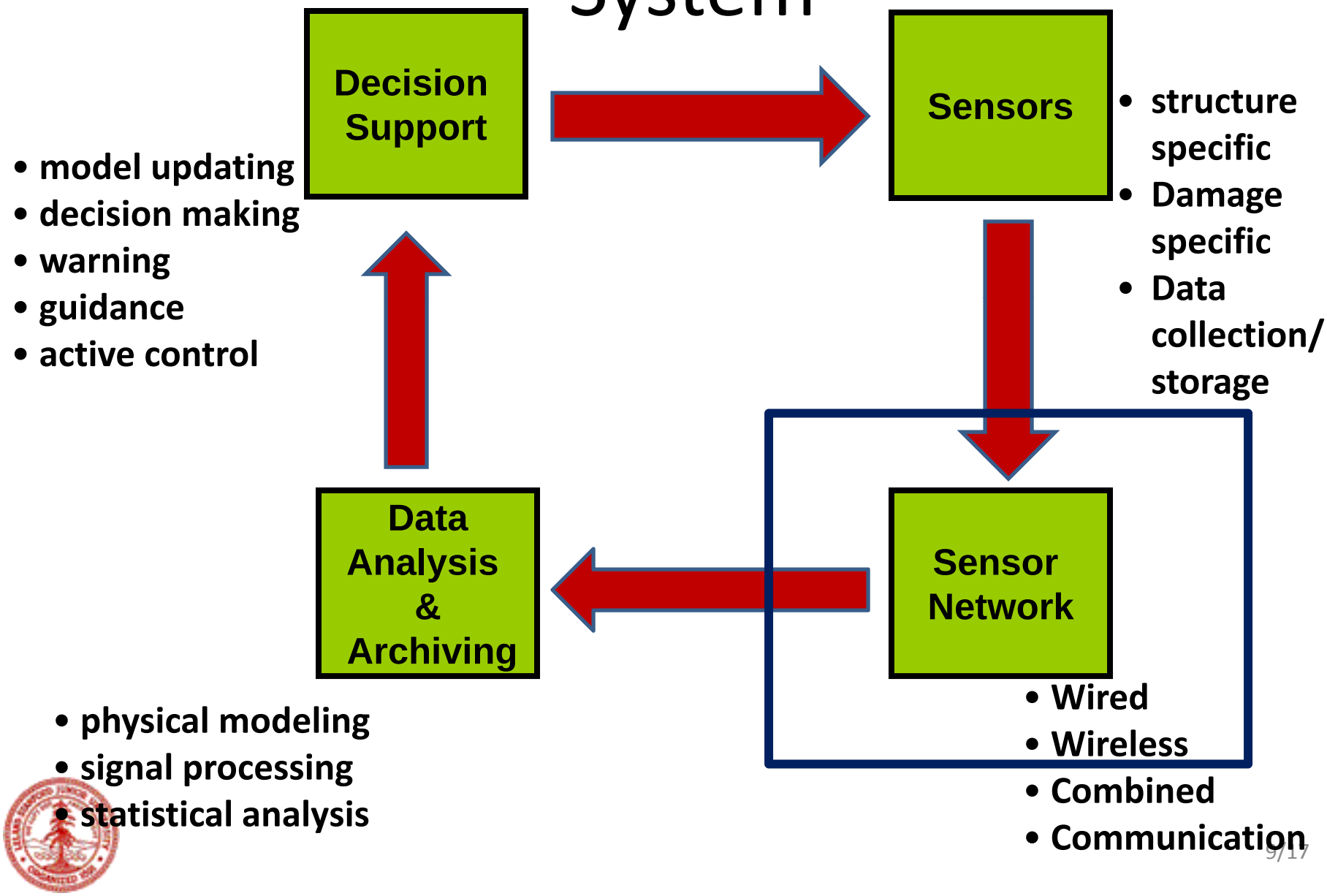
The Smart Structural Monitoring System



Damage-Specific Sensors

Currently Available		Still needed
Wired sensors	Wireless/Wired sensors	Crack
Fiber optic sensors	Accelerometers	Corrosion
High definition digital cameras	Strain gages	Displacement
Laser interferometers	GPS	Materials specific
Laser scanner	Tilt meters	
Deep penetration radar	Temperature	
	Humidity	
	Corrosion	
	Anemometers	

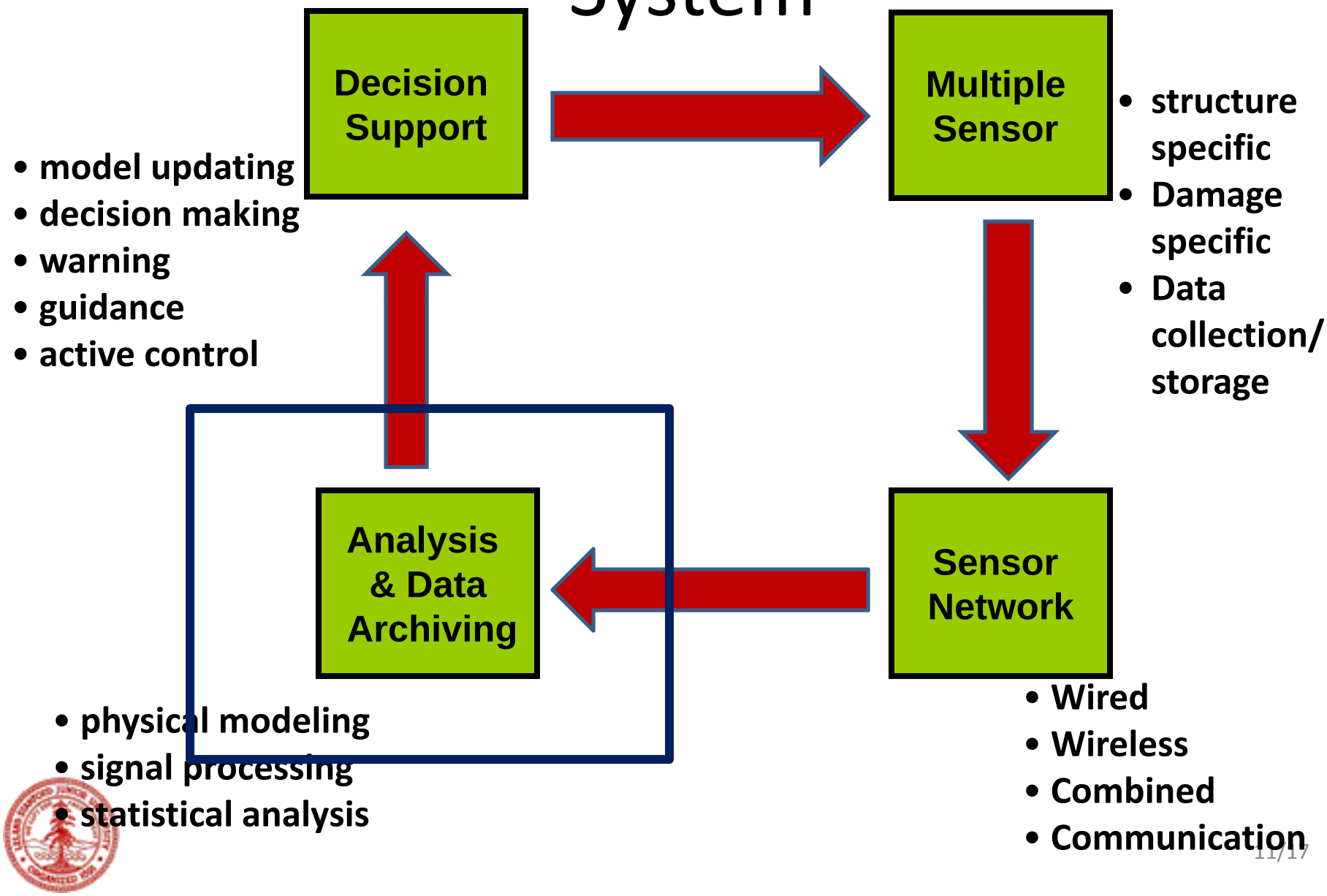
The Smart Structural Monitoring System



Sensor Networks

- Wireless vs. wired
- Advantages of wireless systems
  - Scalable
  - Ease of installation
  - Portability
  - Lower cost
- Challenges
  - Potential signal loss
  - Communication barriers

The Smart Structural Monitoring System



Types of Algorithm

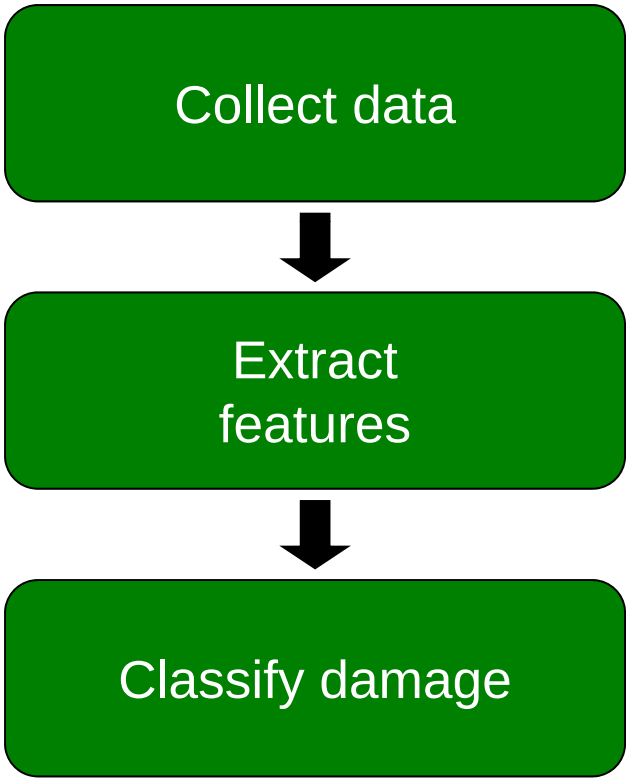
- **Device control**
  - Wake up
  - Database structure
  - Baseline collection
    - By time
    - By season
    - By temperature
    - By humidity
  - Synchronization
    - Hardware – internal clock
    - Software – pre -& post synchronization

- **Damage diagnosis– statistical pattern recognition methods**
  - AR/ARMA/ARX
    - Hypothesis testing
    - Gaussian Mixture Modeling- GMM
  - Wavelet Based – Haar and Morelet wavelets
    - Comparison of wavelet energies at high scales
    - Gaussian Mixture Modeling
  - Rotation - to drift -to damage

Damage Detection Using Statistical Signal Processing

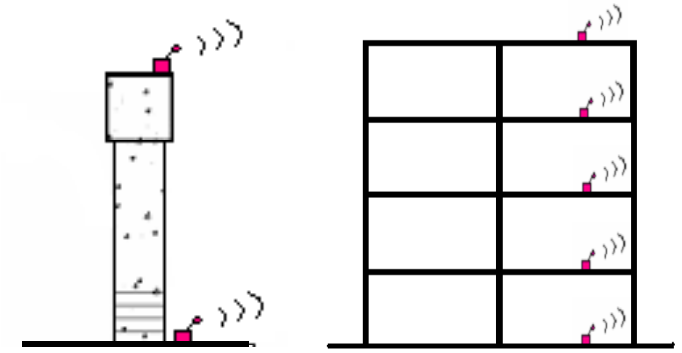
- **Main approach**
  - Use single sensor pre- and post- damage measurements
  - Combine information from multiple sensors
  - Computationally efficient - local micro-processing
  - Independent of the sensor – can be used with acceleration, strain, etc.
  - Scalable with increased sensor density
  - Reduces amount of transmitted data – power saving

Steps in Damage Diagnosis



Statistics Based

- ARX
- AR
- GMM
- Wavelet
- Change point detection



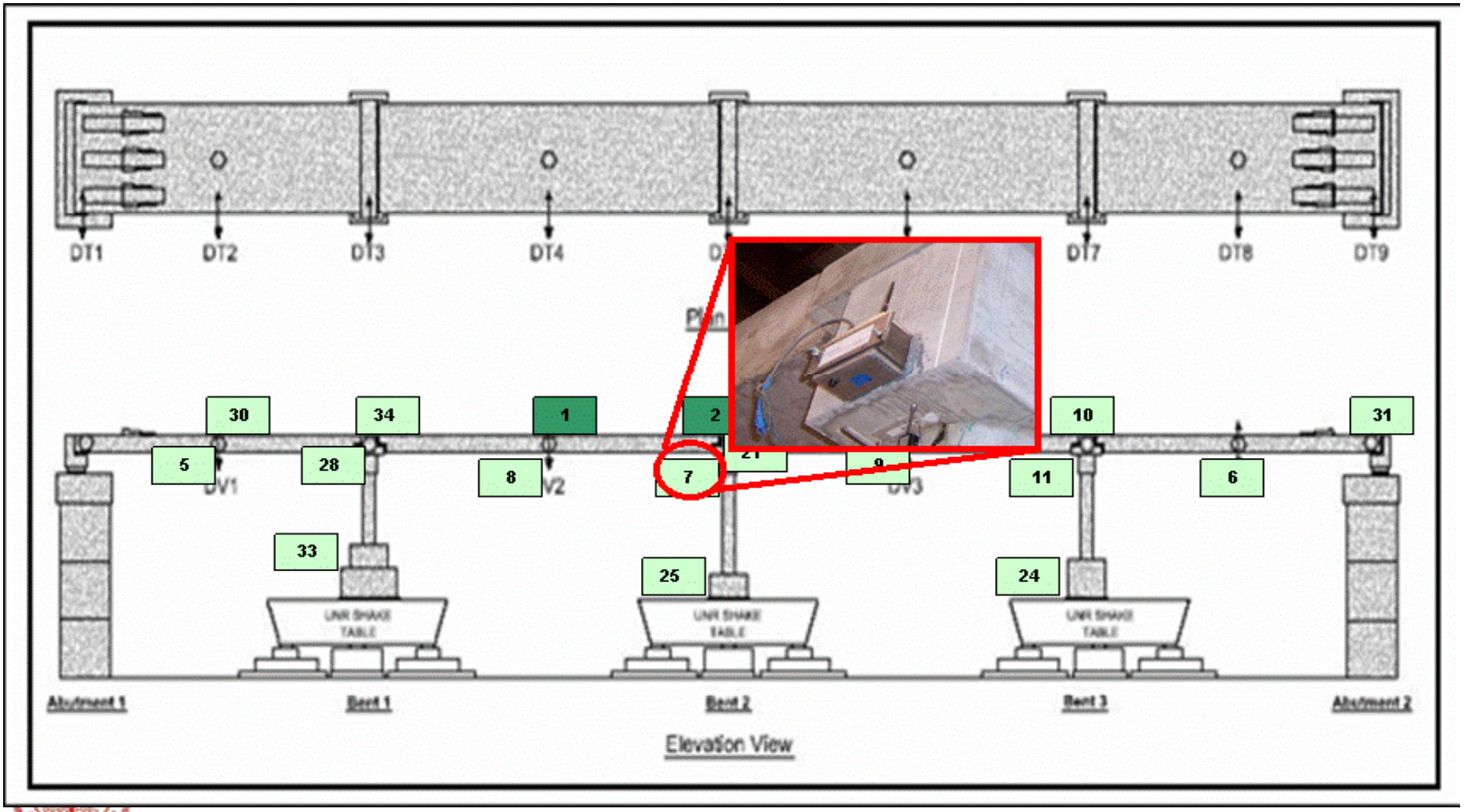
Examples

- Using stationary vibration signals –
  - AR with information criteria testing
  - AR with Gaussian Mixture Model
- Using non-stationary vibration signals – e.g. earthquake motions

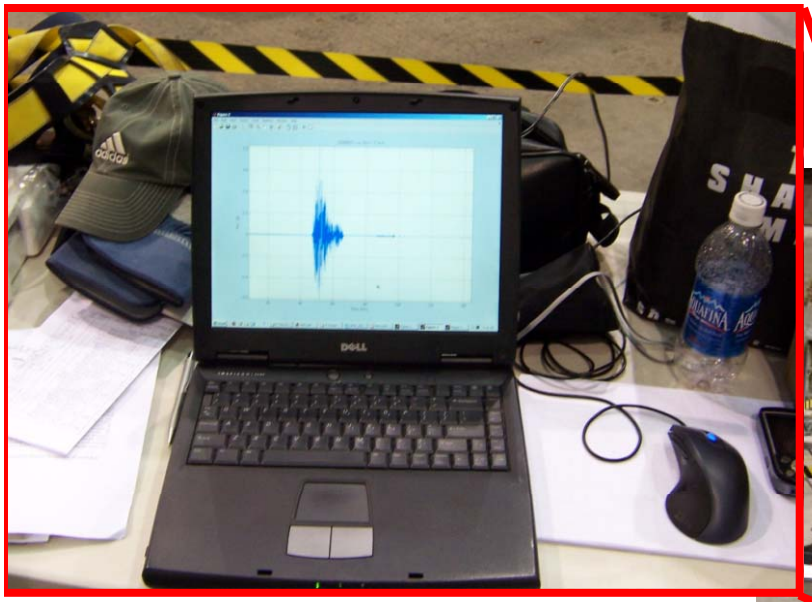
NEES – UNR Project-¼ Scale Bridge Test

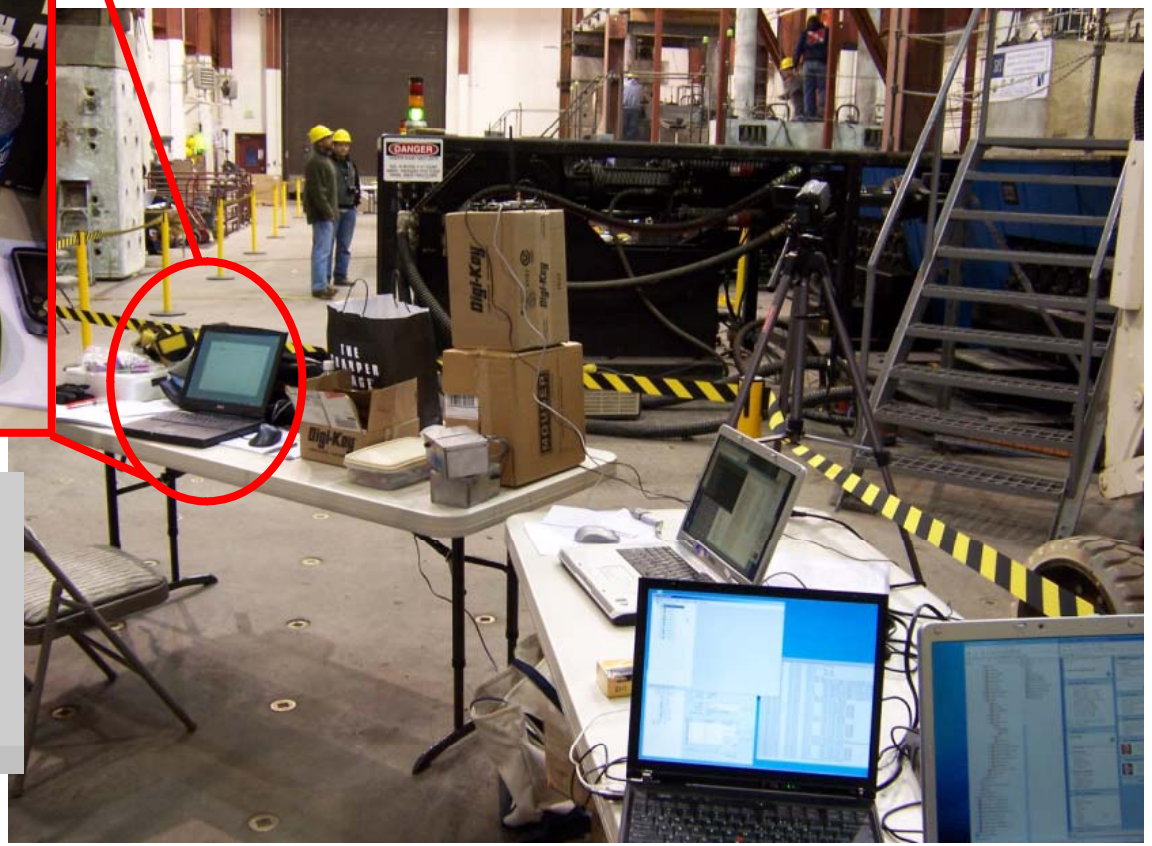
AR & Gaussian Mixture Algorithm

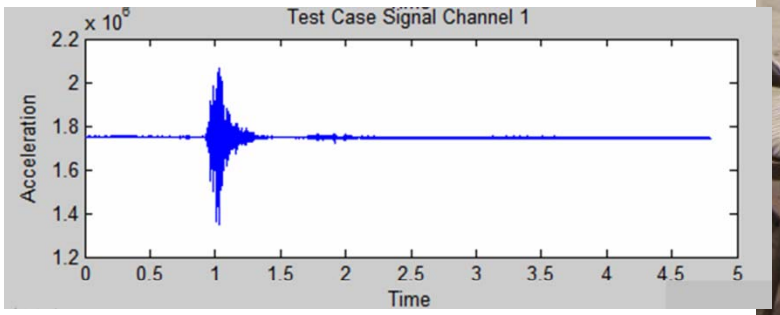
(Nair & Kiremidjian, 2006)



Decision Support System







Test Schedule – 4-span Bridge Test at UNR

Complete test schedule for shake table tests

Test No.	Test Date	Motion Level	Test Type	Motion PGA (g)		Estimated D_{max} (in)						Notes
						Pier 1		Pier 2		Pier 3		
				Trans.	Long.	Trans.	Long.	Trans.	Long.	Trans.	Long.	
WN01	Feb. 12, 2007		White Noise (Trans.)									
WN02			White Noise (Long.)									
1A		1	W/Restrainer1	-	0.09							
1B		1	W/Restrainer2	-	0.09							
1C		1	Longitudinal	-	0.09							
1D		1	Biaxial	0.075	0.09	0.40	0.40	0.30	0.40	0.24	0.40	
WN11			White Noise (Trans.)									
WN12			White Noise (Long.)									
2		2	Biaxial	0.15	0.18	0.70	1.00	0.60	0.95	0.60	1.00	
WN21	Feb. 13, 2007		White Noise (Trans.)									
WN22			White Noise (Long.)									
3		3	Biaxial	0.25	0.30	0.80	1.40	0.80	1.60	0.90	1.60	
WN31			White Noise (Trans.)									
WN32			White Noise (Long.)									
4A		4	W/Restrainer1		0.60							
4B		4	W/Restrainer2	-	0.60							
4C		4	Longitudinal	-	0.60							
4D		4	Biaxial	0.50	0.60	1.60	2.65	1.50	2.60	1.50	2.70	
WN41	Feb. 15, 2007		White Noise (Trans.)									
WN42			White Noise (Long.)									
5		5	Biaxial	0.75	0.90	2.50	3.40	2.35	3.40	2.80	3.40	
WN51			White Noise (Trans.)									
WN52			White Noise (Long.)									
6		6	Biaxial	1.00	1.20	3.60	4.20	3.60	4.20	3.85	4.30	
WN61			White Noise (Trans.)									
WN62			White Noise (Long.)									
7		7	Biaxial	1.33	1.60	5.00	5.70	4.90	5.70	6.00	5.75	

Baseline Signals

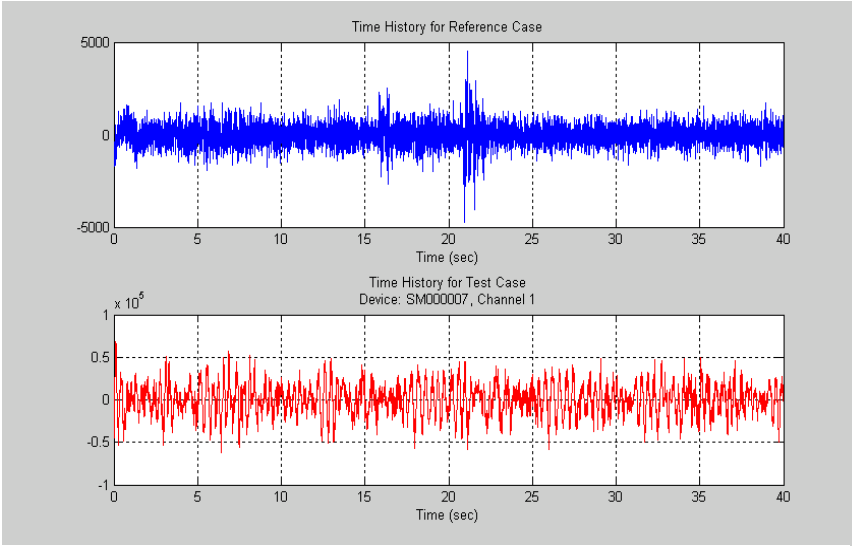
Minor cracks at base of column

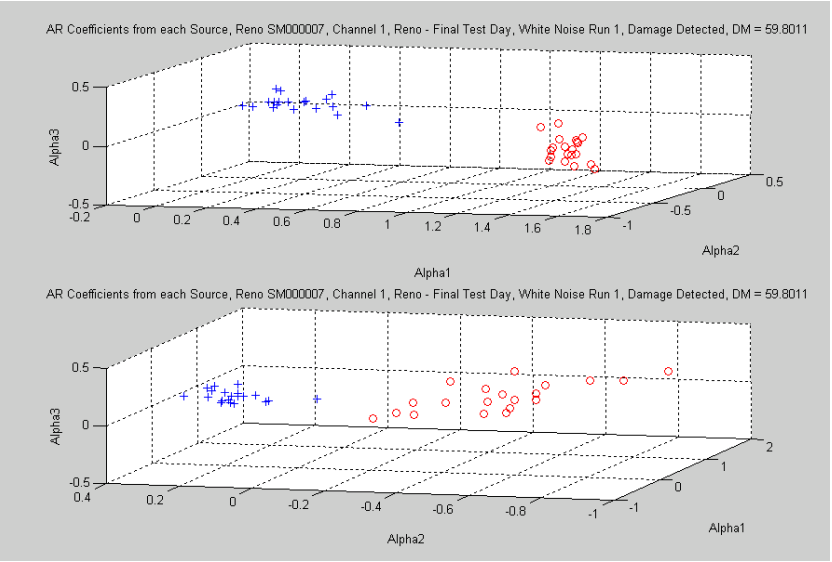
Major cracks at base of col. & spalling

Concrete spalling and exposure or rebar

Rebar buckling/ breaking; concrete pouring out of core

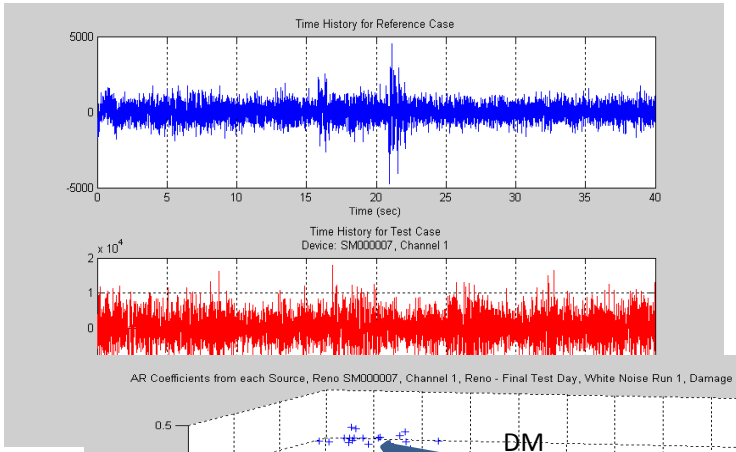
Final Test – White Noise

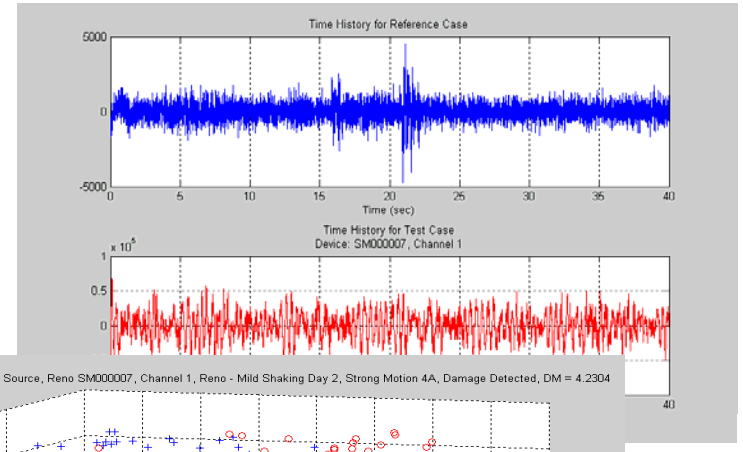


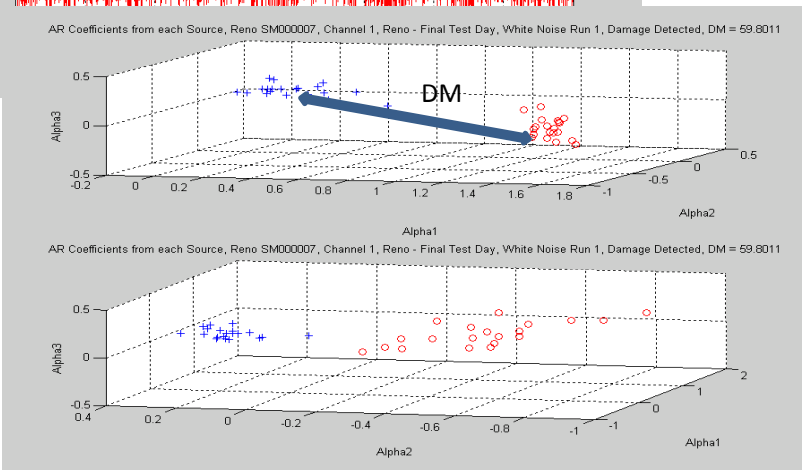


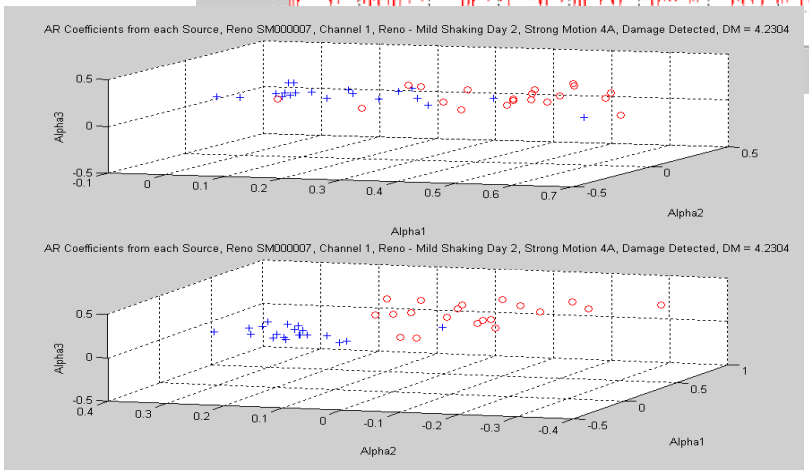
Test	Damage Measure
Reno - Setup Day DC1 and DC2	baseline
Mild Shaking Day 1, White Noise	21.05
Mild Shaking Day 2, White Noise 21	36.79
Mild Shaking Day 3, White Noise 41	56.97
Final Test Day, White Noise Run 51	**59.80**

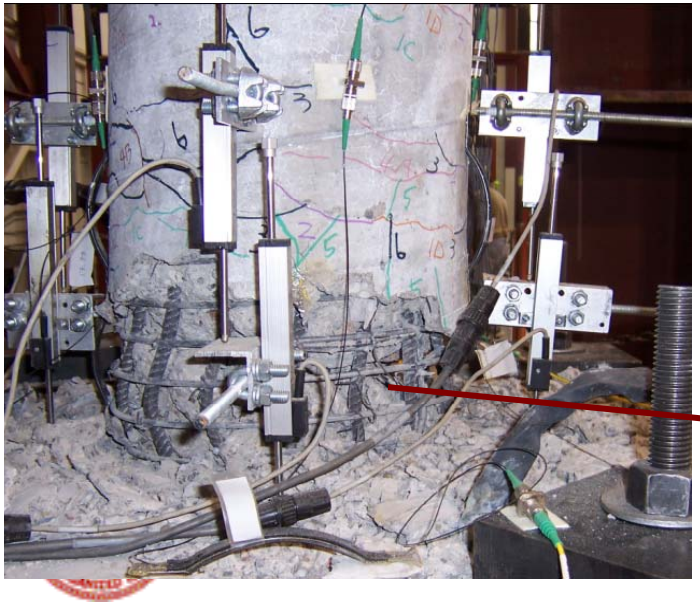
Column Device











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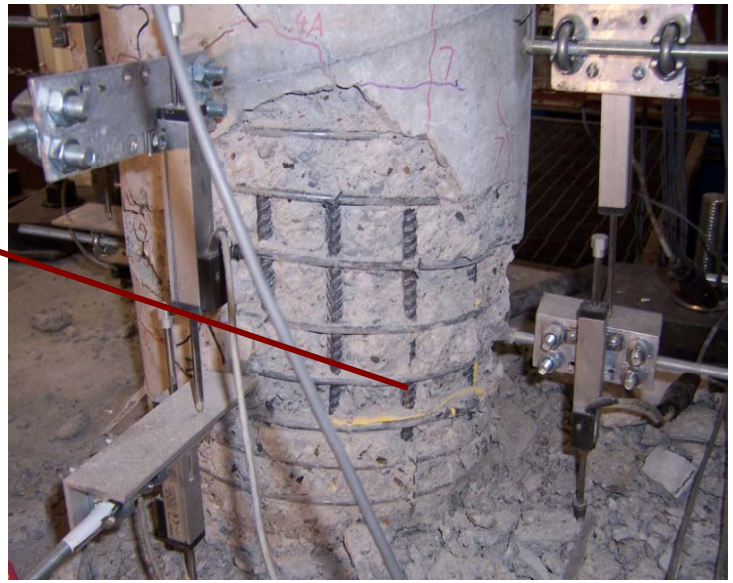
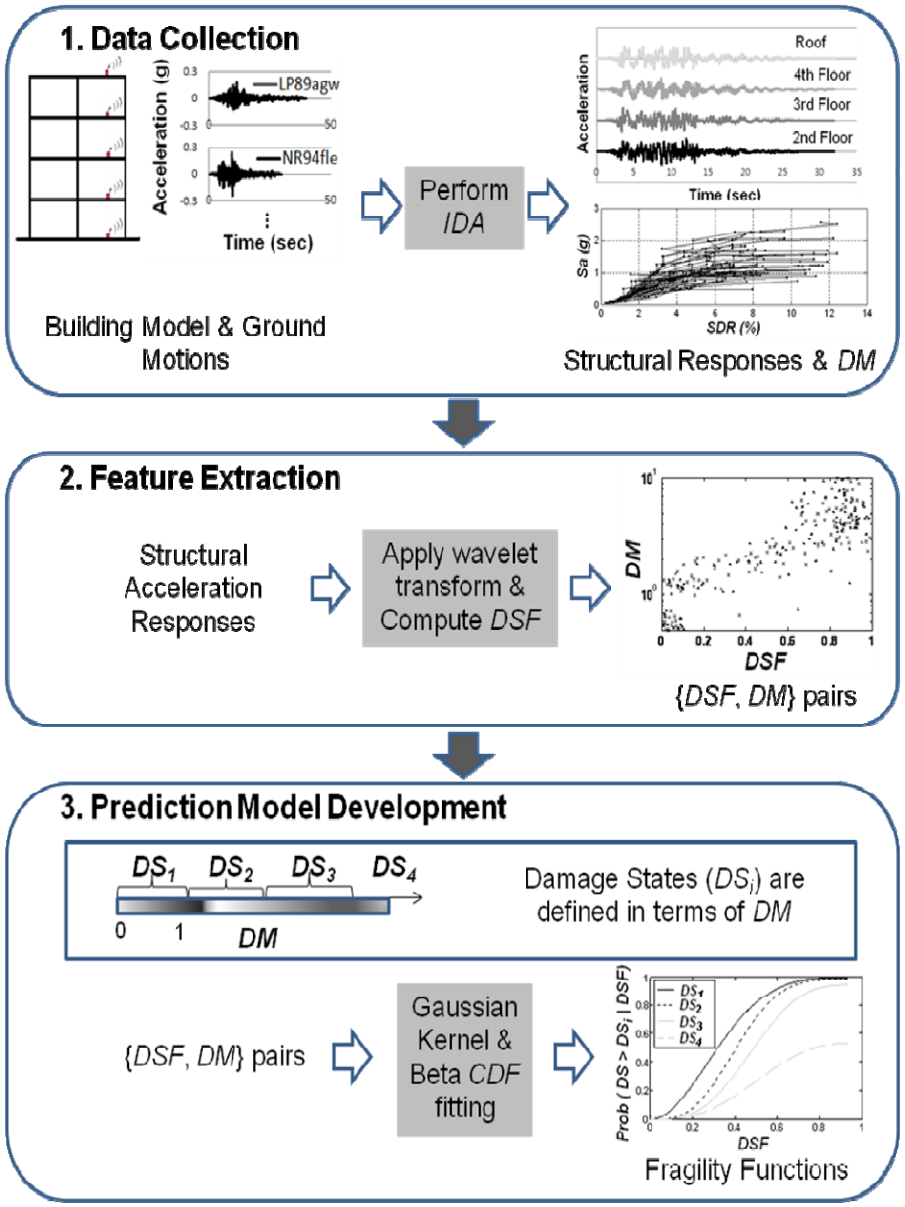


Example of Wavelet Damage Diagnosis

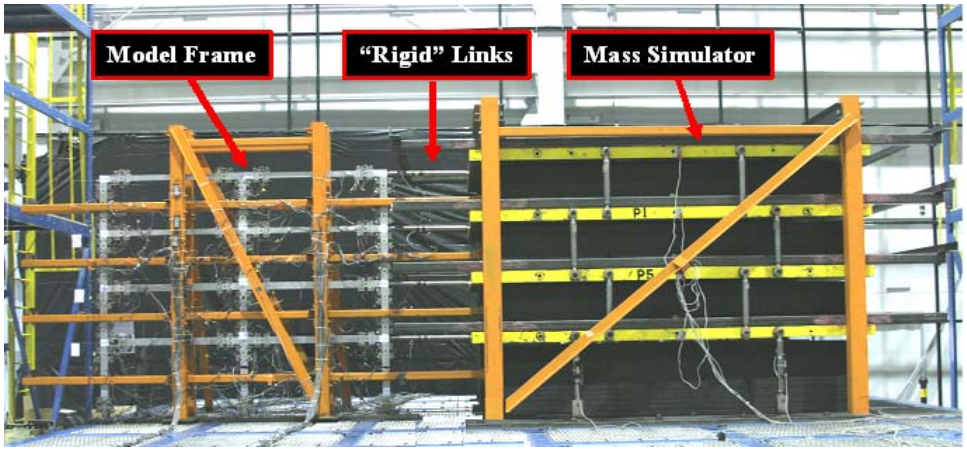
(Noh et al., 2011)

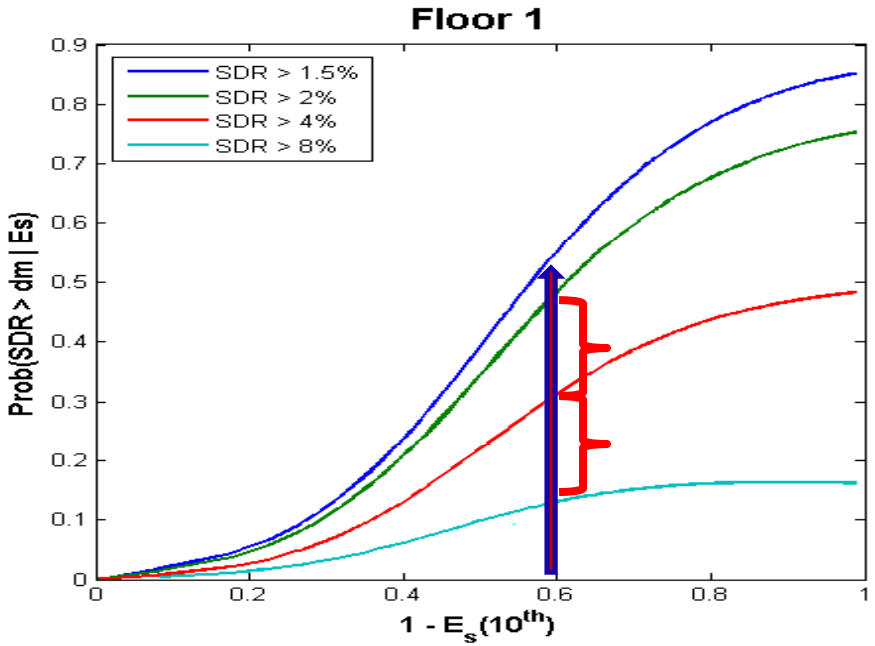
- Feature from wavelet energies of signal
- Used with non-stationary signals – e.g. earthquake response motions
- Develop fragilities for rapid damage indication



NEES 4 Story Steel Frame

Wavelet Based Algorithm

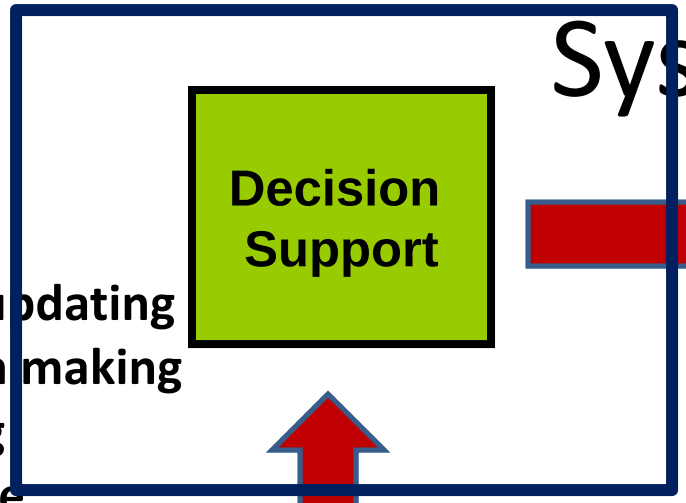




- Scaled structural system tests – Stanford/SUNY Buffalo
- Development of fragility functions in terms of structural response parameters obtainable from real time measurements – wavelet based fragilities

(Noh, Lignos, Nair and Kiremidjian 2011)

The Smart Structural Monitoring System



Decision Support

- model updating
- decision making
- warning
- guidance
- active control

Multiple Sensor

- structure specific
- Damage specific
- Data collection/ storage

Sensor Network

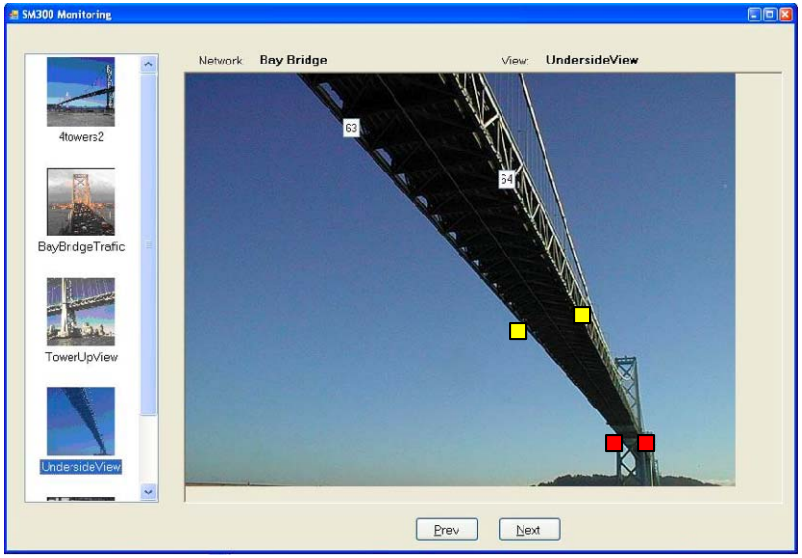
- Wired
- Wireless
- Combined
- Communication

Analysis & Data Archiving

- physical modeling
- signal processing
- statistical analysis

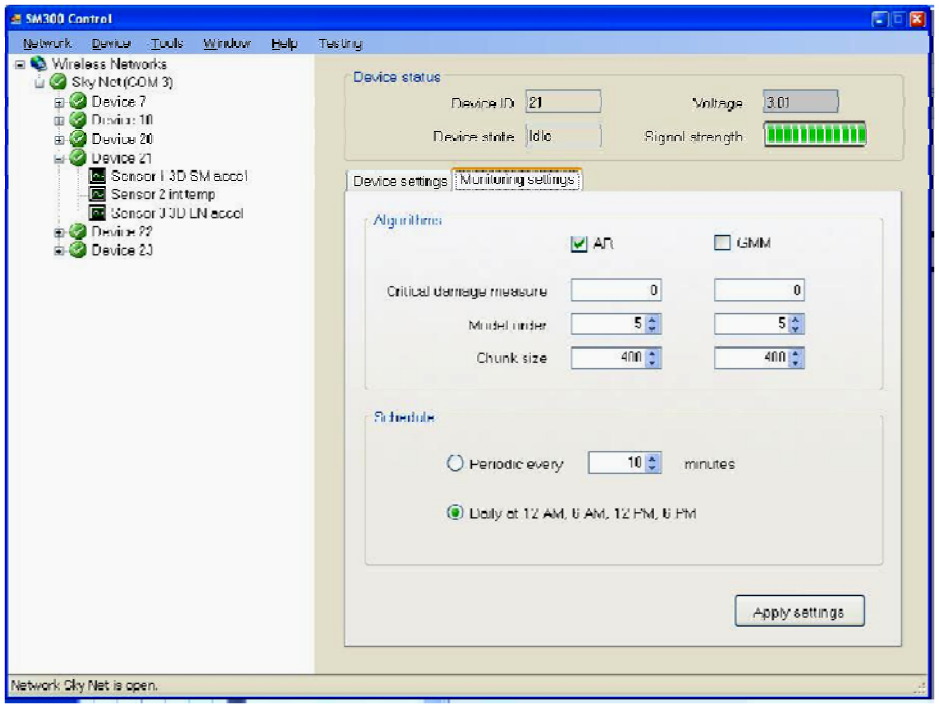
Decision Support System

- Visual representation of the structure
- Visual representation locations of the wireless system
- Interface to wireless network
- System command and control center
- Display results of monitoring analyses
- Issue alerts



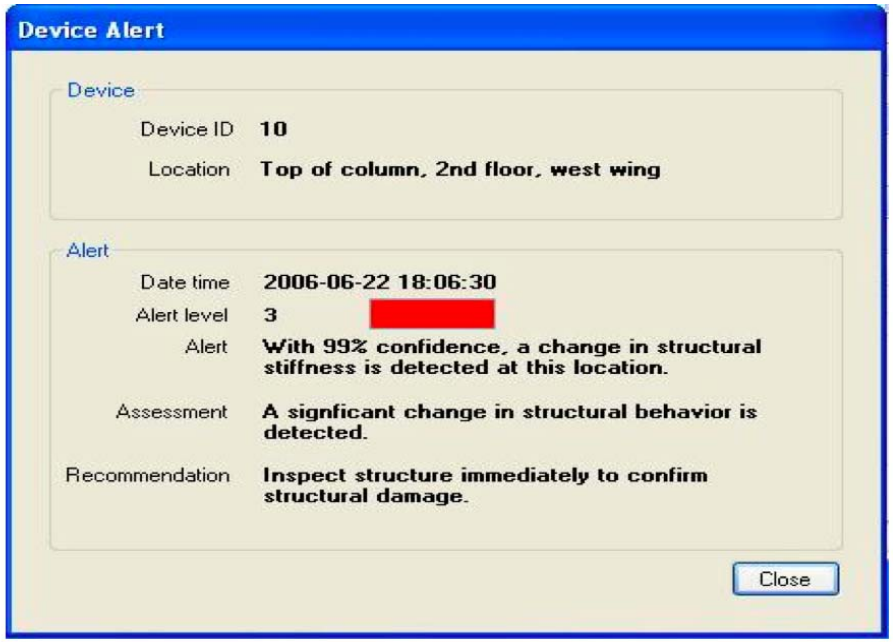
Components of a Decision Support System

- Monitor the sensor
- Monitor the sensor communications system
- Serve as the communications environment between manager and system
  - Initial set-up
  - Modifications of system parameters
  - Modifications of monitoring settings
- Serve as the information delivery environment
  - Periodic queries
  - Following a major event



Decision Support System

- Provide support for decision making for follow-on actions
- Enable web services for
  - wide distribution of alerts and other information
  - remote access by operators and other users.



Conclusion

- Wireless monitoring systems – inevitable part of the future
- Few applications in Europe, Asia and the US
- Must combine structural with other monitoring systems, e.g.
  - Building environmental/energy/lighting/security monitoring
  - Bridge, highway, tunnel, pipeline, transmission line, etc. management systems
- Key to success is providing information and decision support, not just data

Need for Full-scale and Field Testing

- Objectives
  - Systematic damage at different levels
  - Different damage patterns
  - Different damage sequences

NIED – E-Defense Test
5-Story Full Scale RC Building,
August, 2011

Acknowledgement

- National Science Founcdation
- National Institute of Standards and Technology

- **Students**

Dr. E. Straser ‘98	**Dr. K. Nair ‘07**
A.Kotapalli ‘99	**Allen Cheung**
N. Mastroleon ‘00	**Dr. H- Y Noh ‘11**
C. Charistis ‘03	

Thank You!