

Introduction of Smart Structure Technology

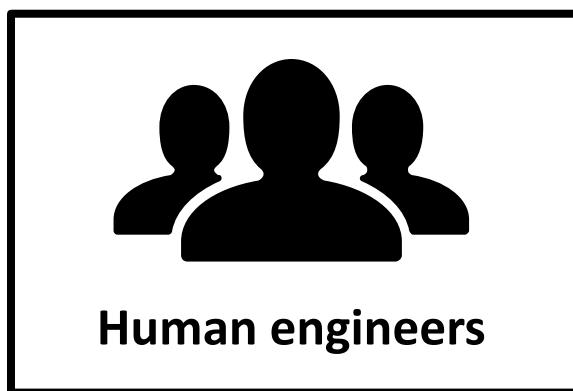
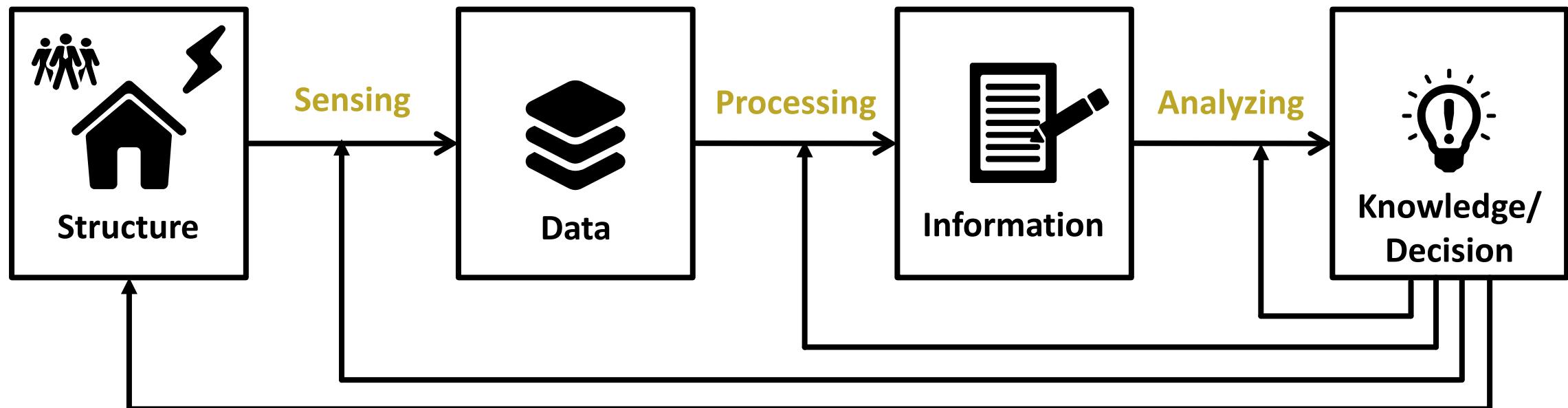
Chul Min Yeum
Assistant Professor
Civil and Environmental Engineering
University of Waterloo, Canada

CIVE 497 – CIVE 700: Smart Structure Technology
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UNIVERSITY OF WATERLOO
FACULTY OF ENGINEERING

Smart Structures and Systems



Smart Sensing and Data Processing



Ultimately, we emulate the activities of civil engineers in a rapid and automated ways with high precision.

Definition of Structural Health Monitoring

- **Structural Health Monitoring** is the process of implementing a damage detection strategy for aerospace, civil and mechanical engineering infrastructure.
- The SHM process involves:
 - The observation of a system over time using periodically sampled dynamic response measurements from an array of sensors.
 - The extraction of damage-sensitive features from these measurements.
 - The statistical analysis of these features is then used to determine the current state of system health.

Definition of “Damage”

- **Damage** will be defined as unwanted changes to the material and/or geometric properties of a structural or mechanical system, including changes to the boundary conditions and system connectivity, that adversely affect the current or future **performance** of that system.
- Examples:
 - crack in mechanical part (stiffness change)
 - scour of bridge pier (boundary condition change)
 - loosening of bolted joints (connectivity change)

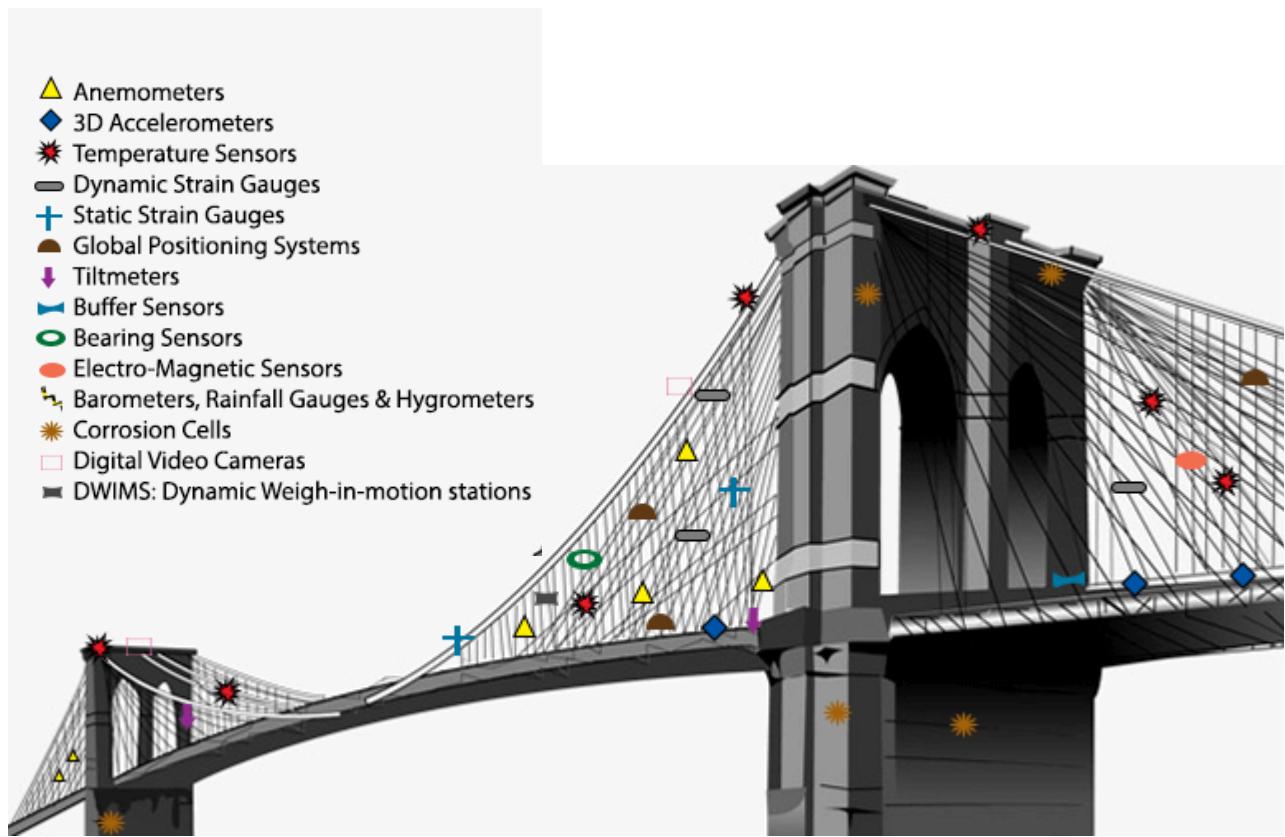
Motivations for Structural Health Monitoring

- Local damage detection methods, referred to as Non-Destructive Evaluation (NDE), are well developed and widely used.
- These methods have difficulty when large surface areas need to be inspected.
- Need more global and automated damage detection methods.
- Economic and life-safety advantage.
- Move from time-based maintenance to condition-based maintenance.

Structural Health Monitoring (SHM) Process

Definition: SHM is a process to monitor and evaluate the safety and integrity of a structural system throughout its life span.

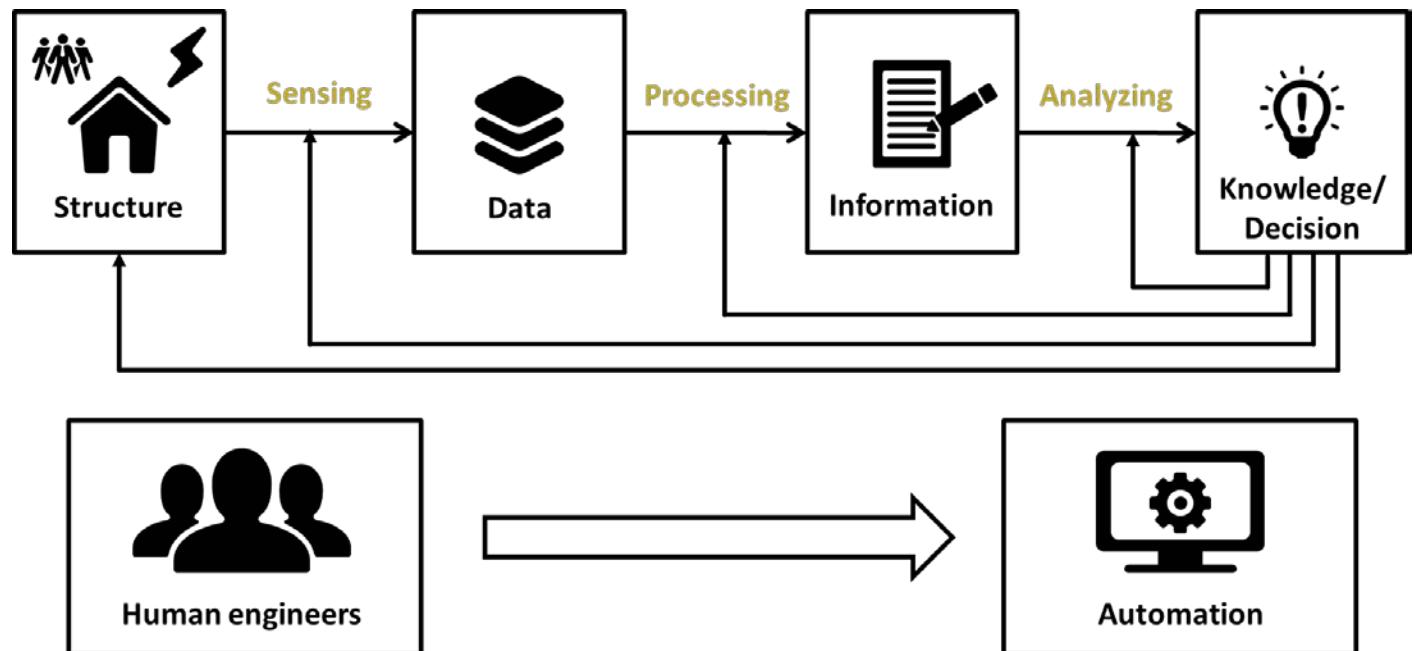
- **Step 1: Define Damage**
- **Step 2: Identify Damage**
- **Step 3: Locate Damage**
- **Step 4: Quantify Damage**
- **Step 5: Predict Conditions**



Smart Structures and Systems

Incorporating advanced technologies in the fields of

- Non-destructive evaluation
- Structural health monitoring
- Structural assessment
- Structural control
- Smart structure materials
- Construction management



Passive and Active Sensors

- **Passive sensors** are only used to detect energy when the naturally or artificially occurring energy is available.
- **Active sensors** have its own energy source to interact with objects.



GPS



Camera



Accelerometer



Thermometer



Interac



Stethoscope



Smoke detector



IR-camera

Passive
sensor



Scanner



Camera + flash



Kinect



Ultrasound



X-ray



Measuring laser

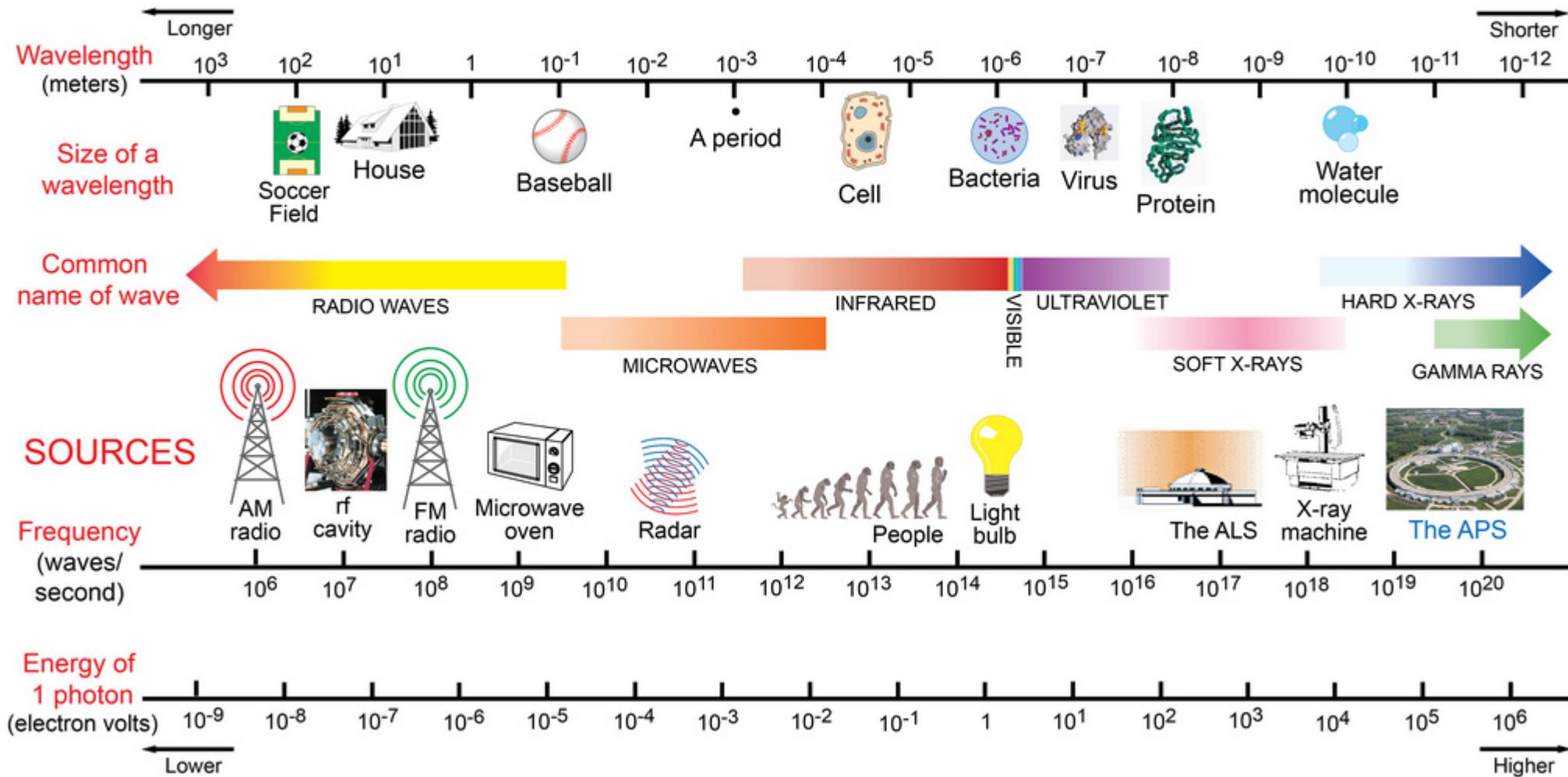
Active
sensor



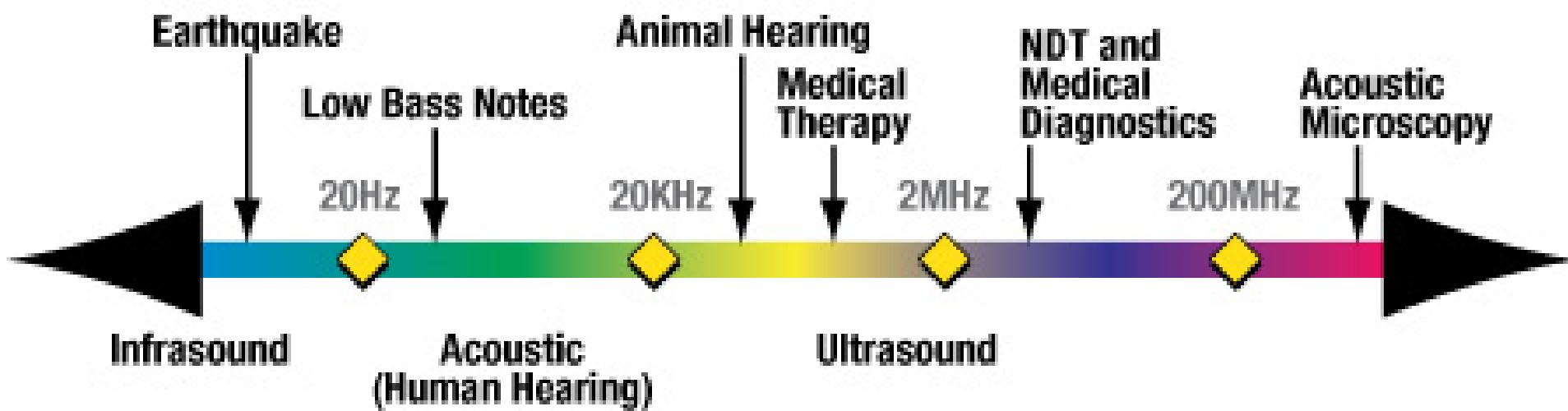
Thermometer

Electromagnetic Spectrum

THE ELECTROMAGNETIC SPECTRUM

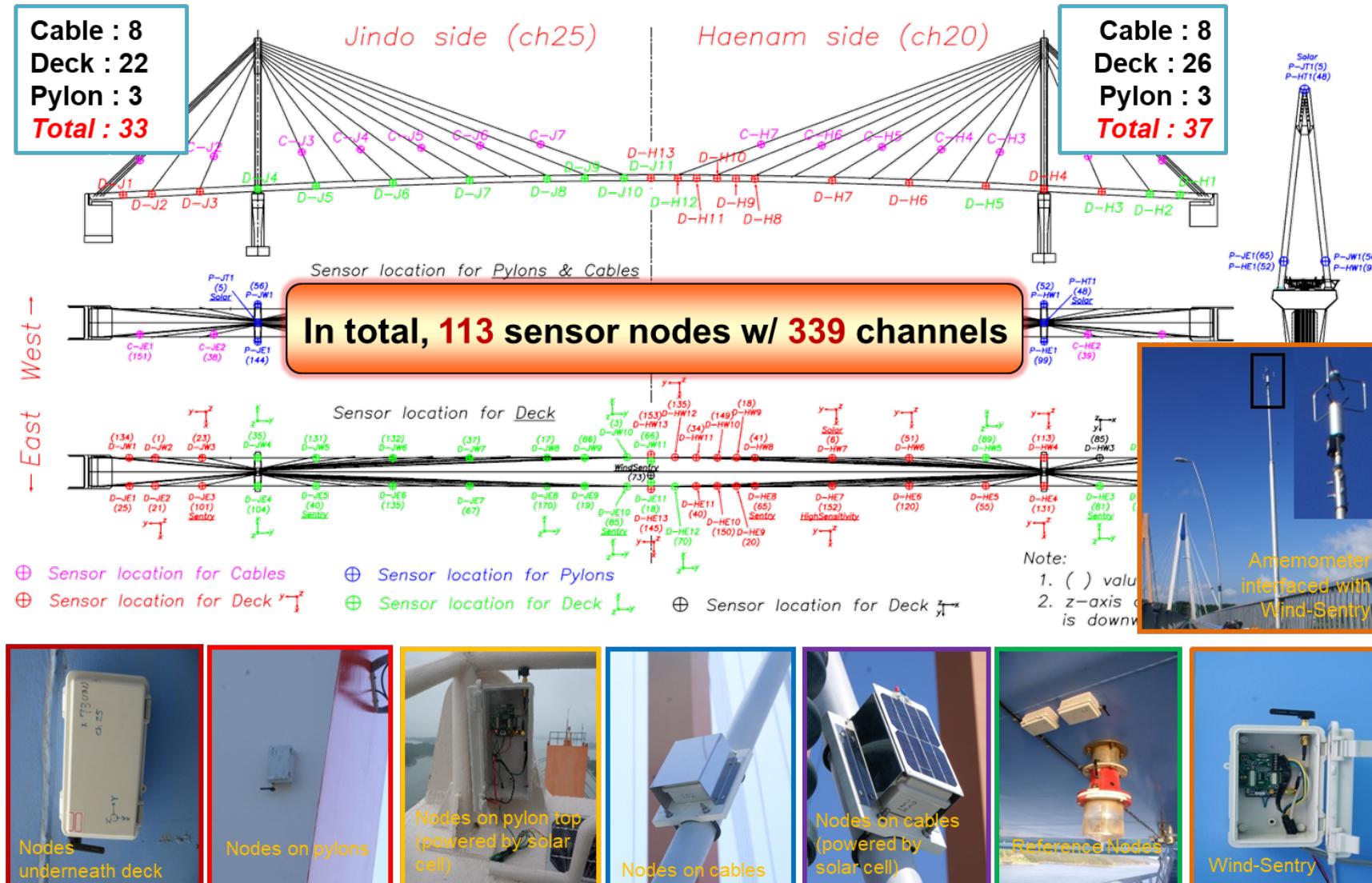


Mechanical Vibration

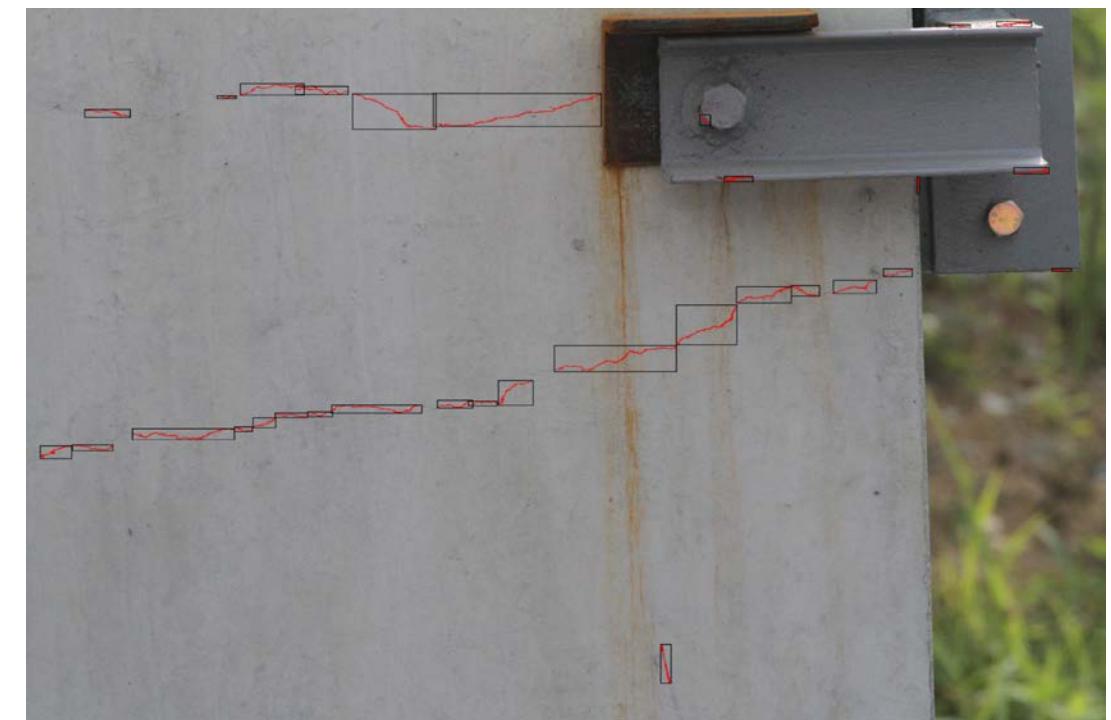
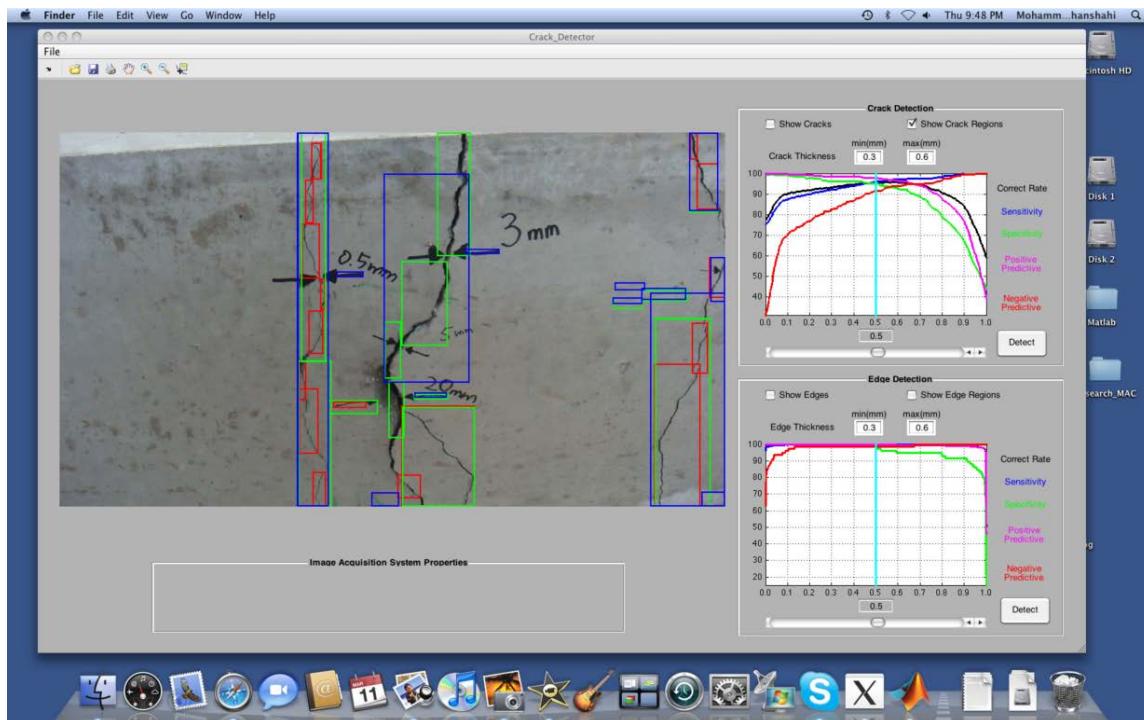


Applications of Smart Structure Technology in Civil Engineering

Structural Engineering: Wireless Monitoring of a Cable-Stayed Bridge



Structural Engineering: Visual Inspection – Crack Detection



Structural Engineering: Bridge Deck Assessment Robot



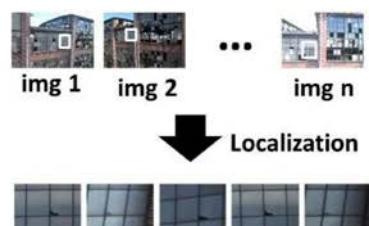
Structural Engineering: Visual Inspection – Façade Inspection using UAVs



Step 1. Image collection



Step 2. Orthophoto generation



Step 3. ROI localization

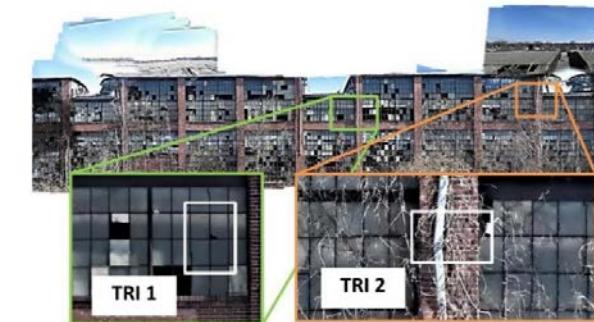
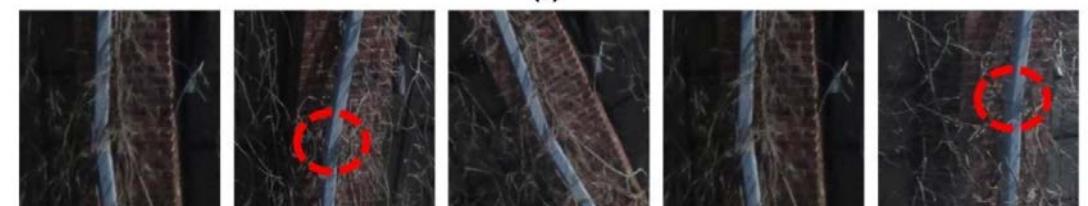


Figure 7. Selection of two sample TRIs (TRI 1 and TRI 2) on the orthophoto.



(a)



(b)

Figure 8. Localized ROIs corresponding to TRI 1 in (a) and TRI 2 in (b): The hairline vertical crack on a window pane in TRI 1 and damage on a drainage pipe in TRI 2 are only visible in specific ROIs and those damage locations are marked with a red dotted line.

Structural Engineering: Visual Inspection – 3D Pavement Inspection

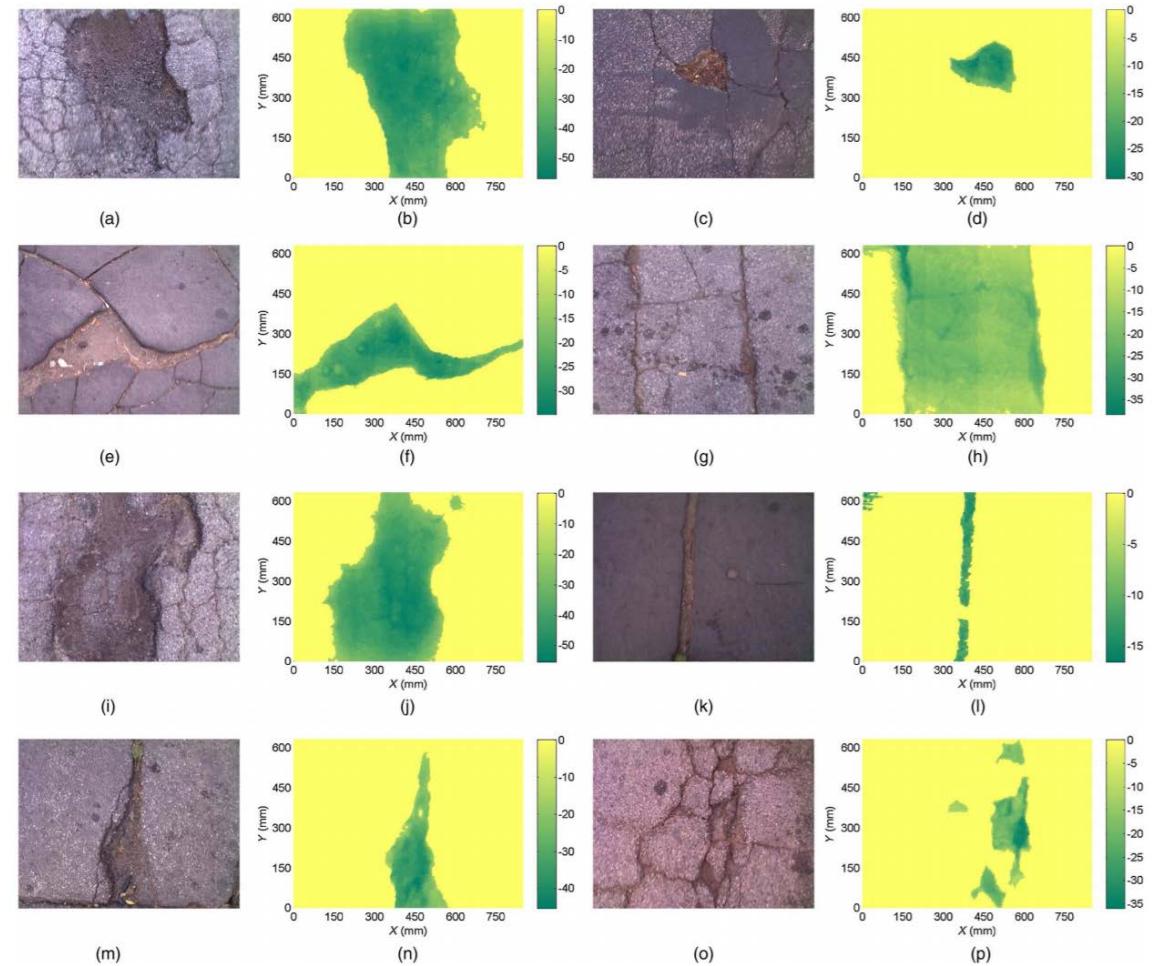
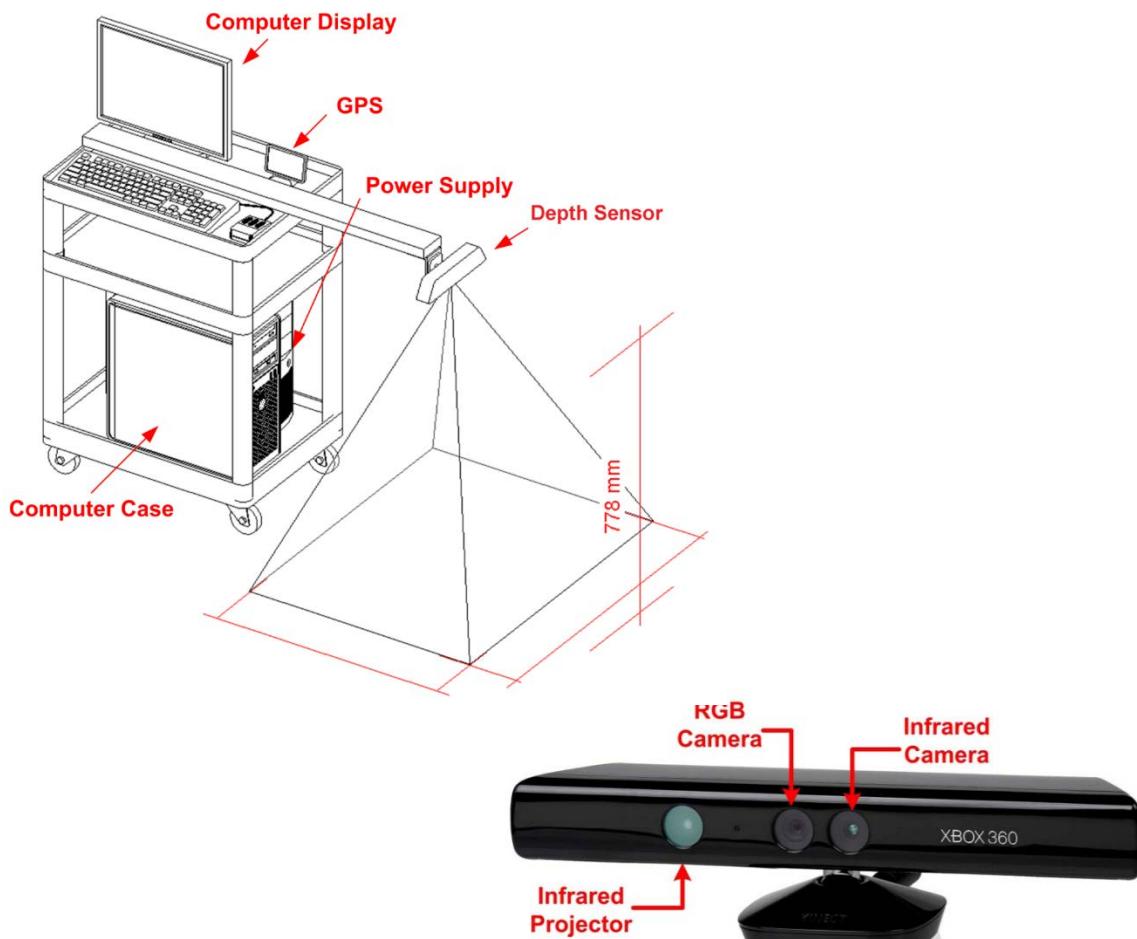
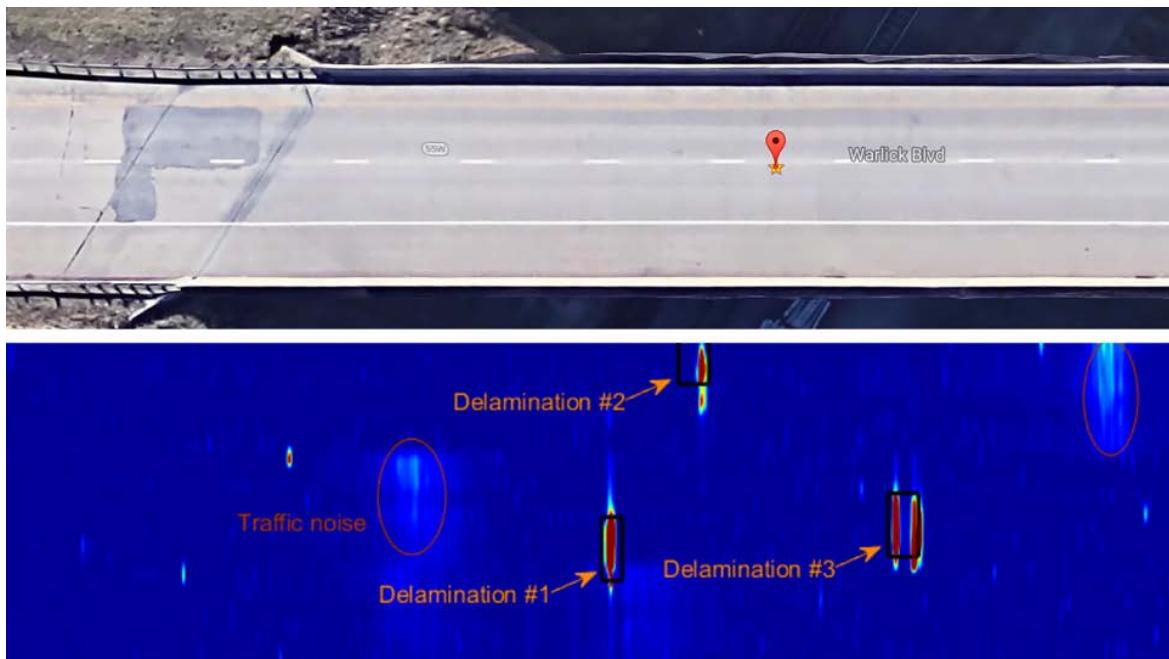


Fig. 6. Defect detection and depth quantification: (a), (c), (e), (g), (i), (k), (m), and (o) are the images of the defects, and (b), (d), (f), (h), (j), (l), (n) and (p) are the corresponding depth maps, respectively

Jahanshahi, M. R., Jazizadeh, F., Masri, S. F., & Becerik-Gerber, B. (2013). Unsupervised Approach for Autonomous Pavement-Defect Detection and Quantification Using an Inexpensive Depth Sensor. *Journal of Computing in Civil Engineering*, 27(6), 743–754.

Structural Engineering: Delamination Detection using Acoustic Analysis



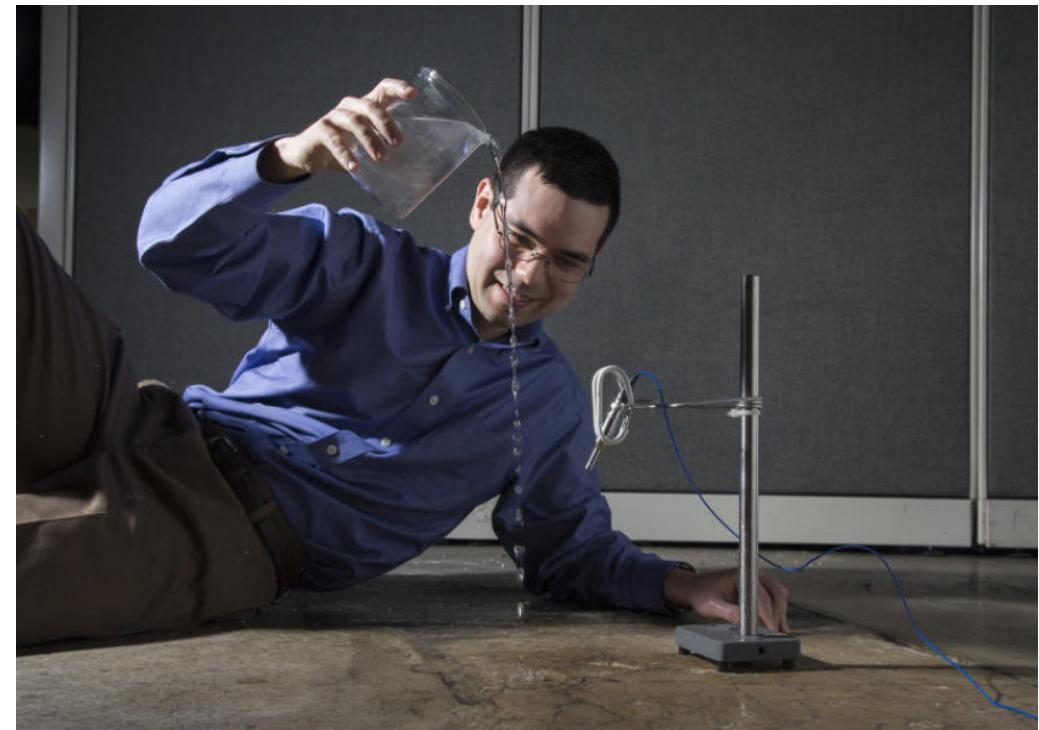
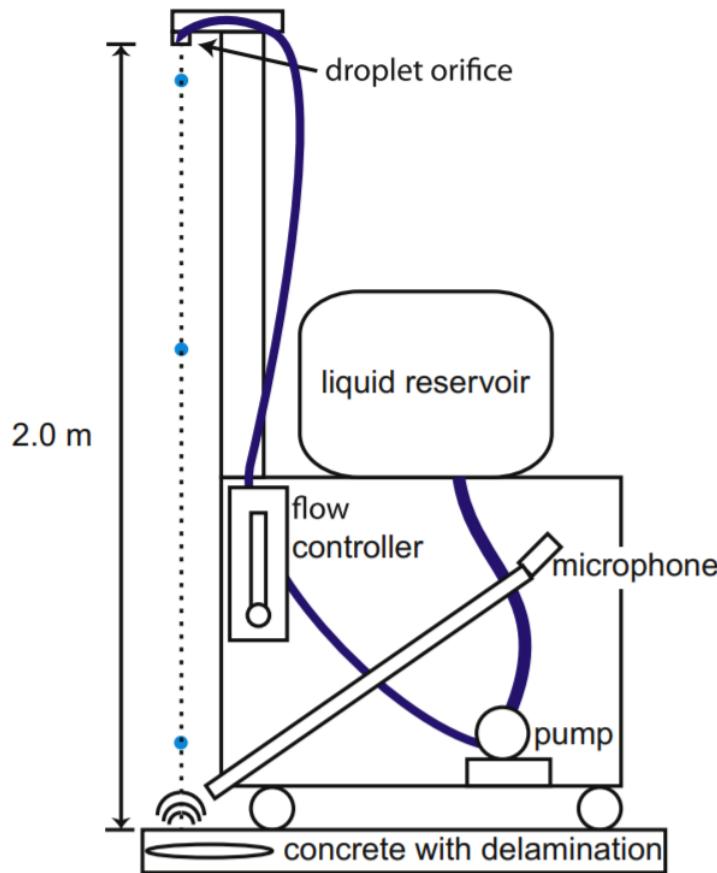
<https://go.unl.edu/ic7w>



https://www.youtube.com/watch?v=GPfPdk_t7gk

<https://news.unl.edu/newsrooms/today/article/how-acoustics-can-be-an-early-warning-system-for-bridges/>

Structural Engineering: Acoustic Impact-Echo Investigation of Concrete Delamination



- <https://www.sciencedaily.com/releases/2012/10/121022162701.htm>
- Mazzeo, B. A., Patil, A. N., & Guthrie, W. S. (2012). Acoustic impact-echo investigation of concrete delaminations using liquid droplet excitation. *NDT & E International*, 51, 41–44. <https://doi.org/10.1016/j.ndteint.2012.05.007>

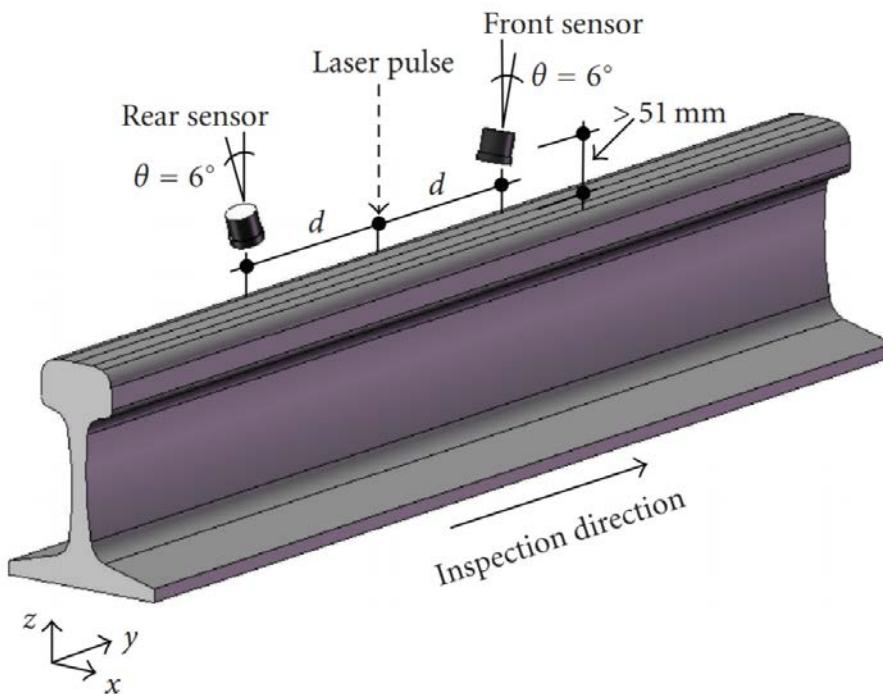
Structural Engineering: Robotic for Structural Assessment



Structural Engineering: Video Surveillance of Vehicle Clearance



Structural Engineering: Rail Inspection using Non-contact Ultrasonic Transducers



(a)

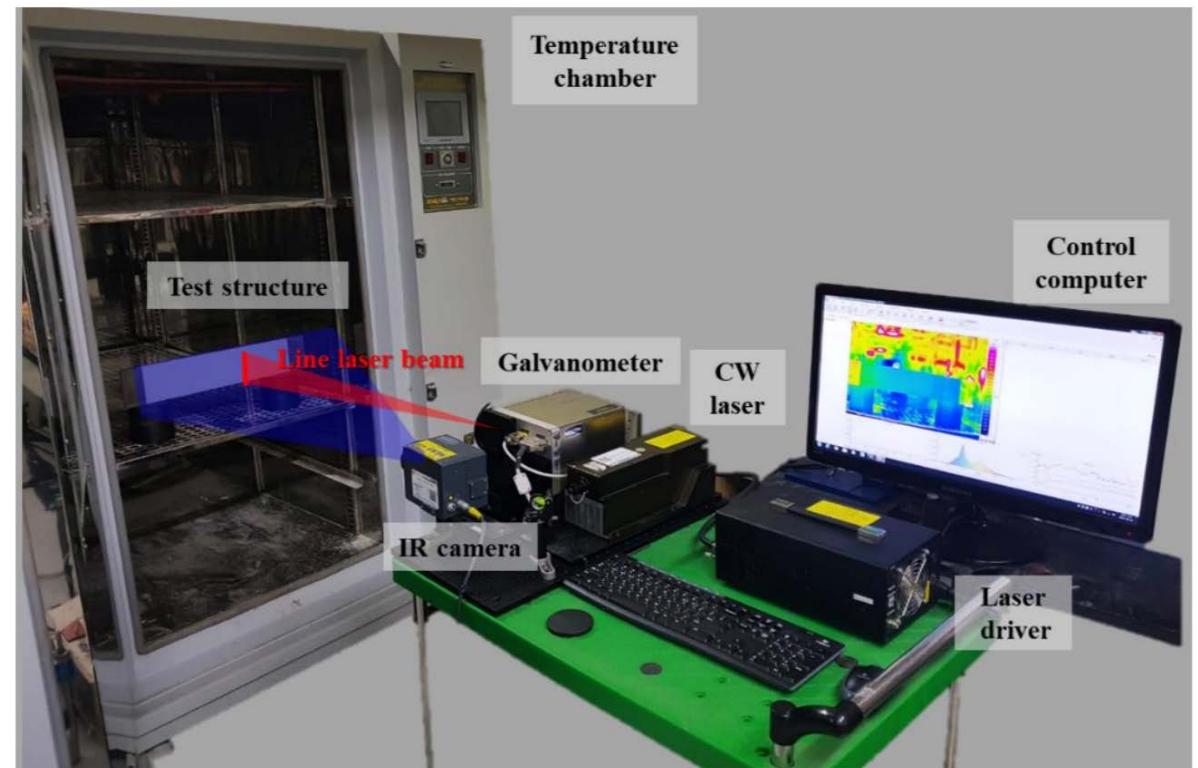
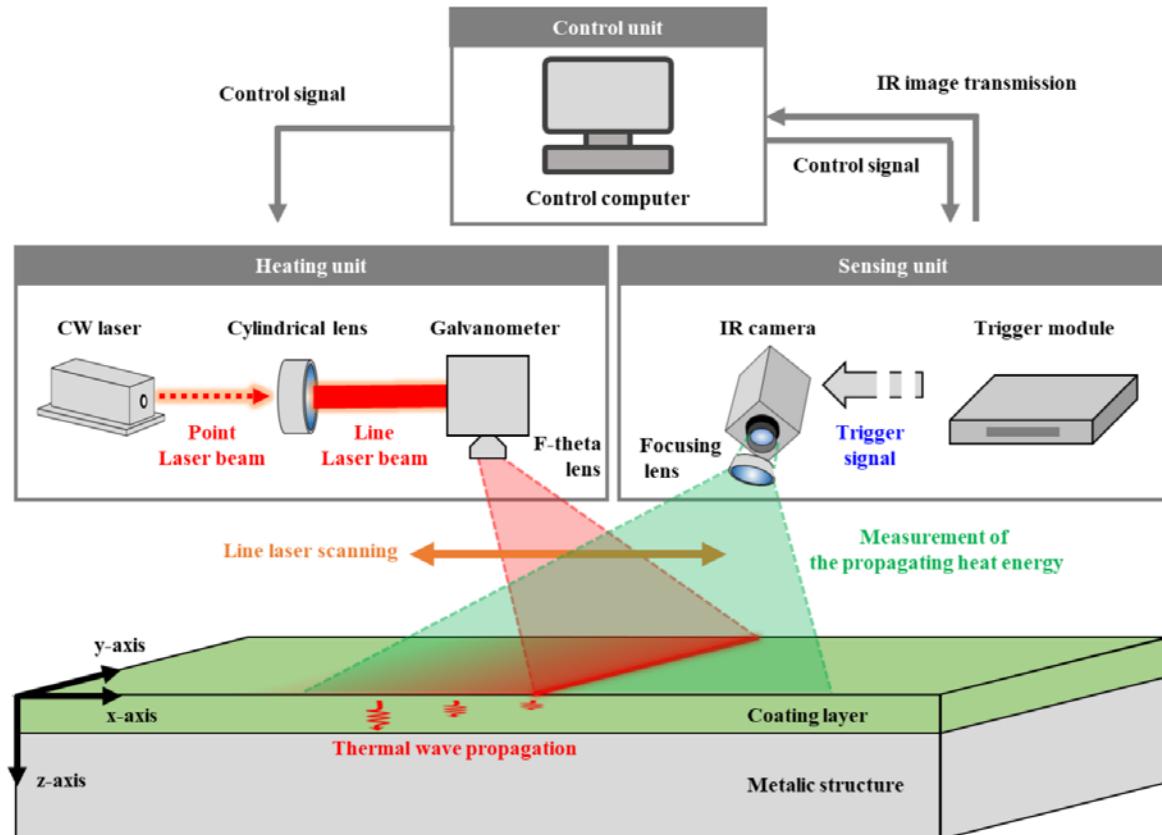


(b)

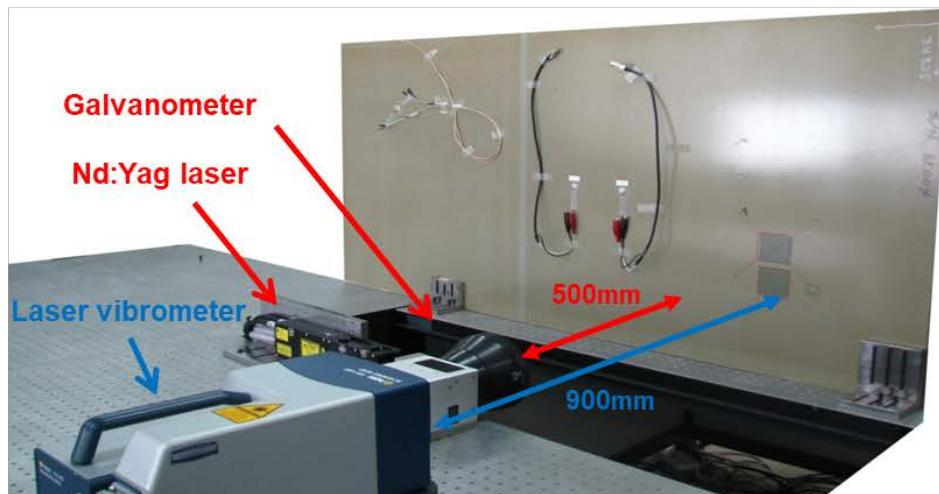
FIGURE 10: (a) Test site near Gettysburg, Pennsylvania. (b) Photo of the latest inspection prototype tested in the field.

<https://www.youtube.com/watch?v=wqKzrFeYEU8>

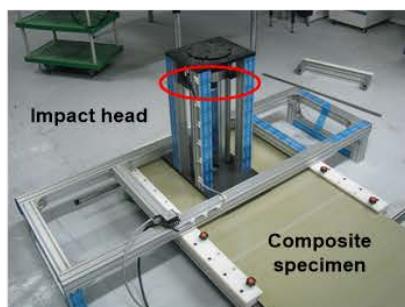
Structural Engineering: Coating Thickness Quantification using Laser Thermography



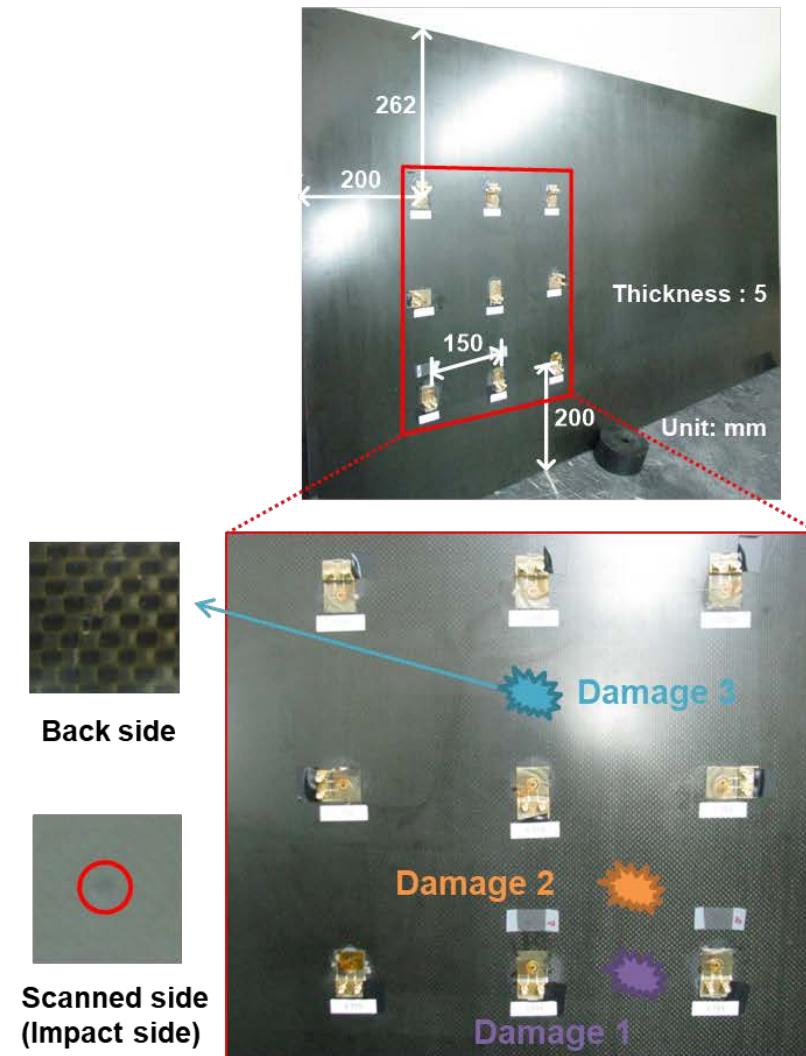
Structural Engineering: Delamination Detection using Piezoelectric Sensors



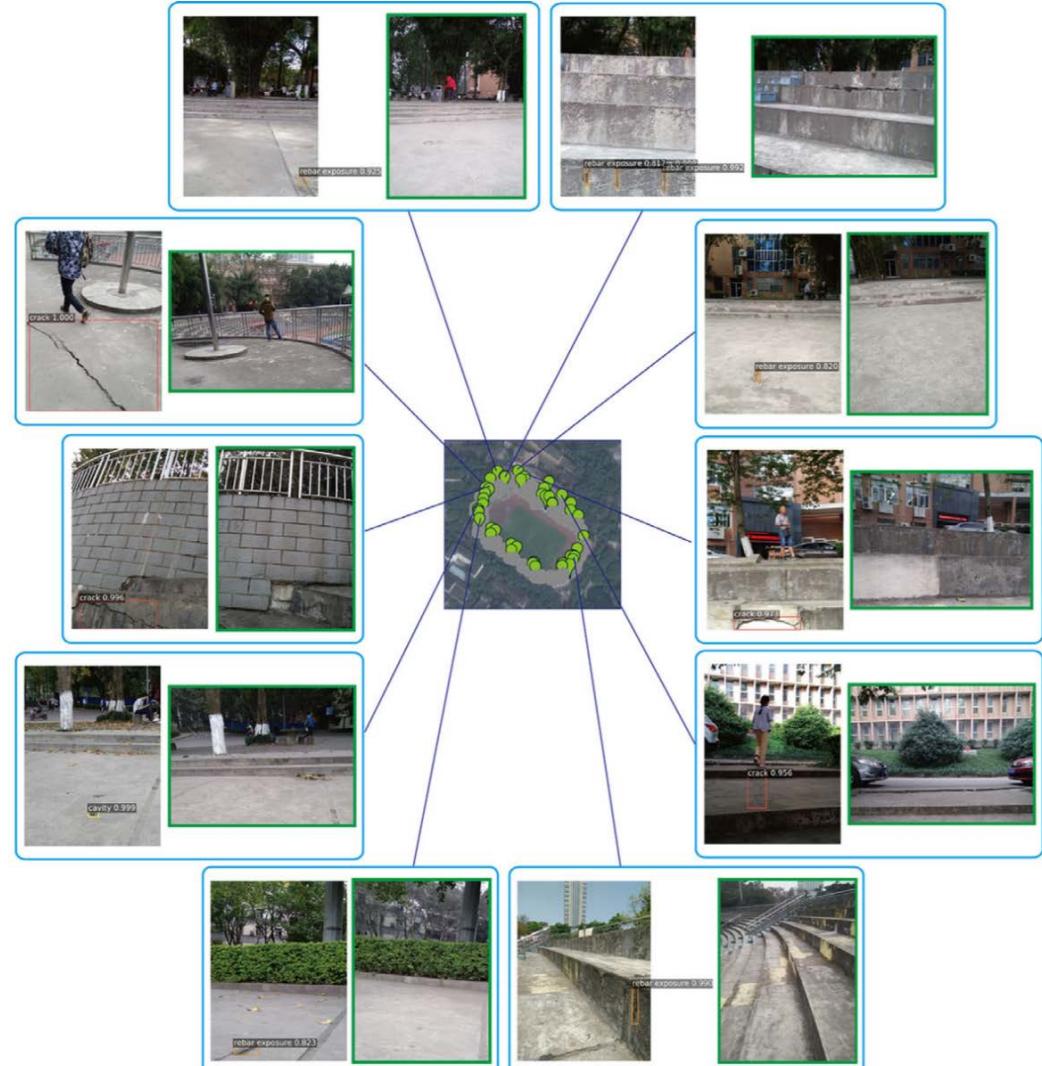
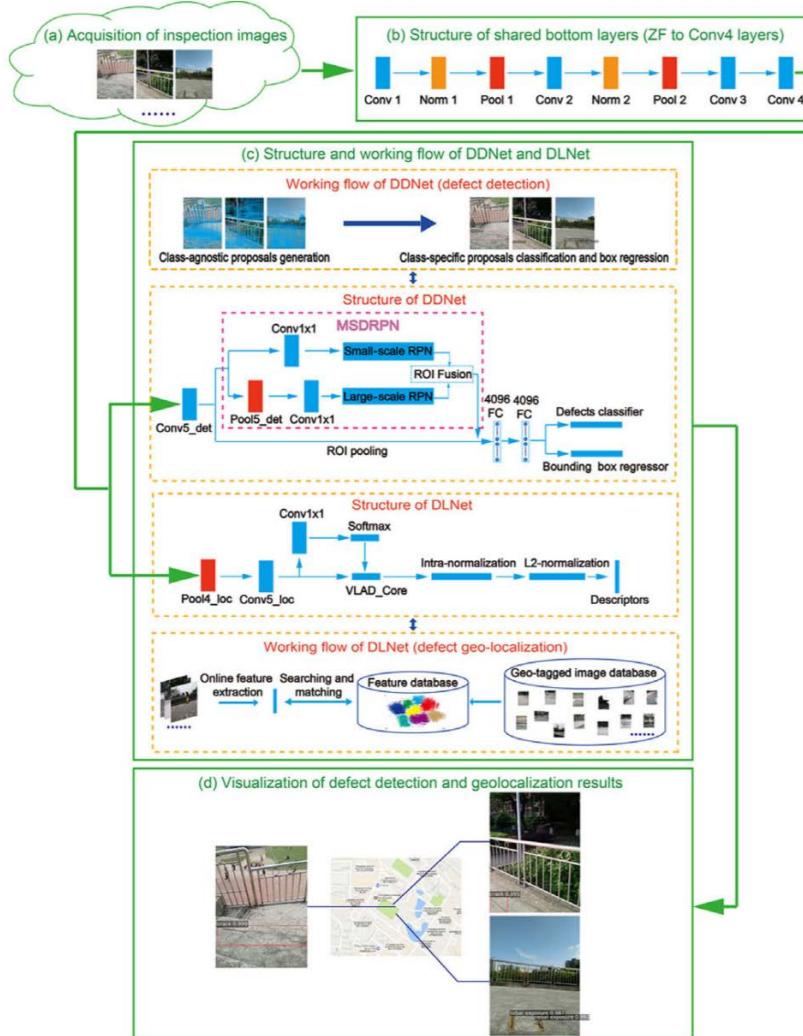
Low velocity impact test



A low velocity impact with a 1cm radius steel cone-shape tip is used to produce delamination.



Structural Engineering: Image Registration



Structural Engineering: Crowdsourcing to Enable Lifecycle Infrastructure



Smart Material: Self-Healing Pavement

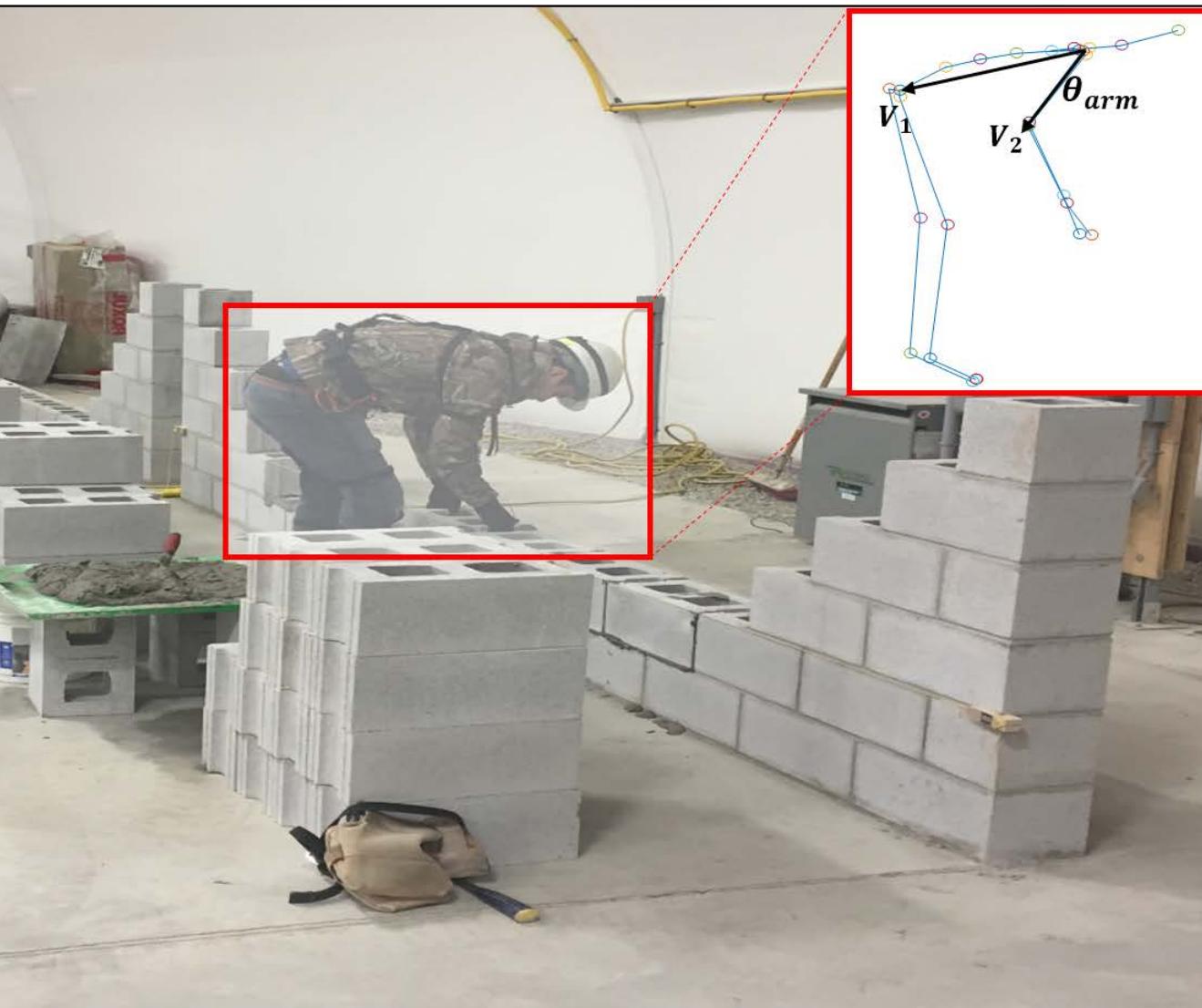
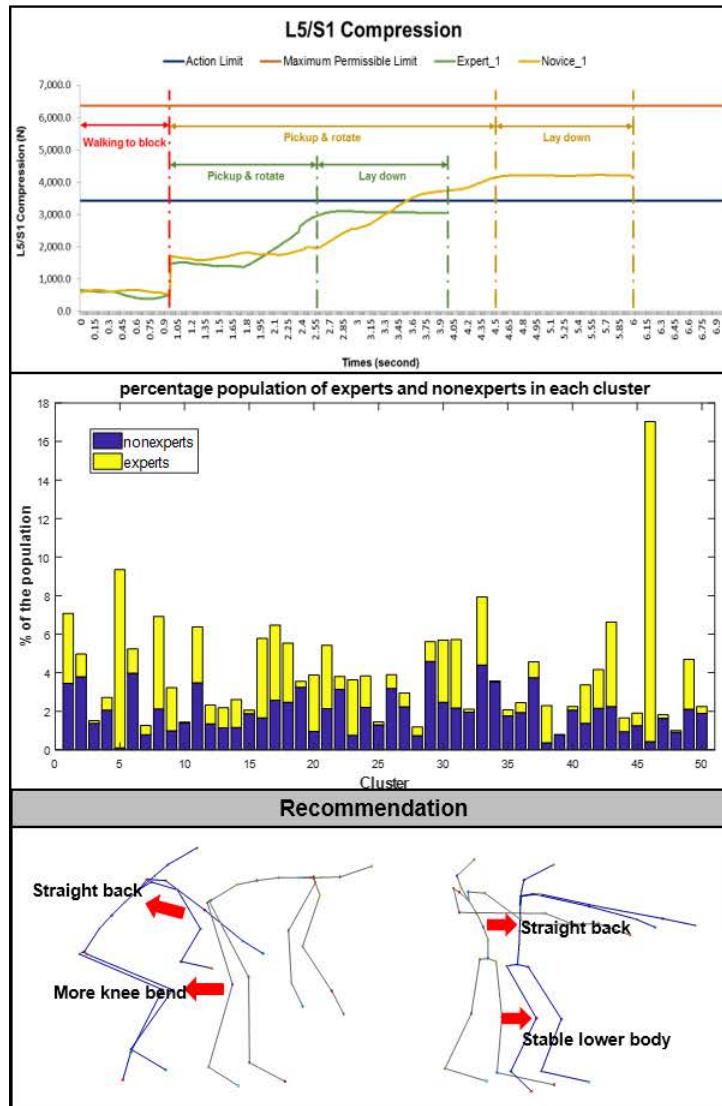


https://www.youtube.com/watch?v=XpKlvMB_c7o&feature=emb_logo&ab_channel=uwaterloo

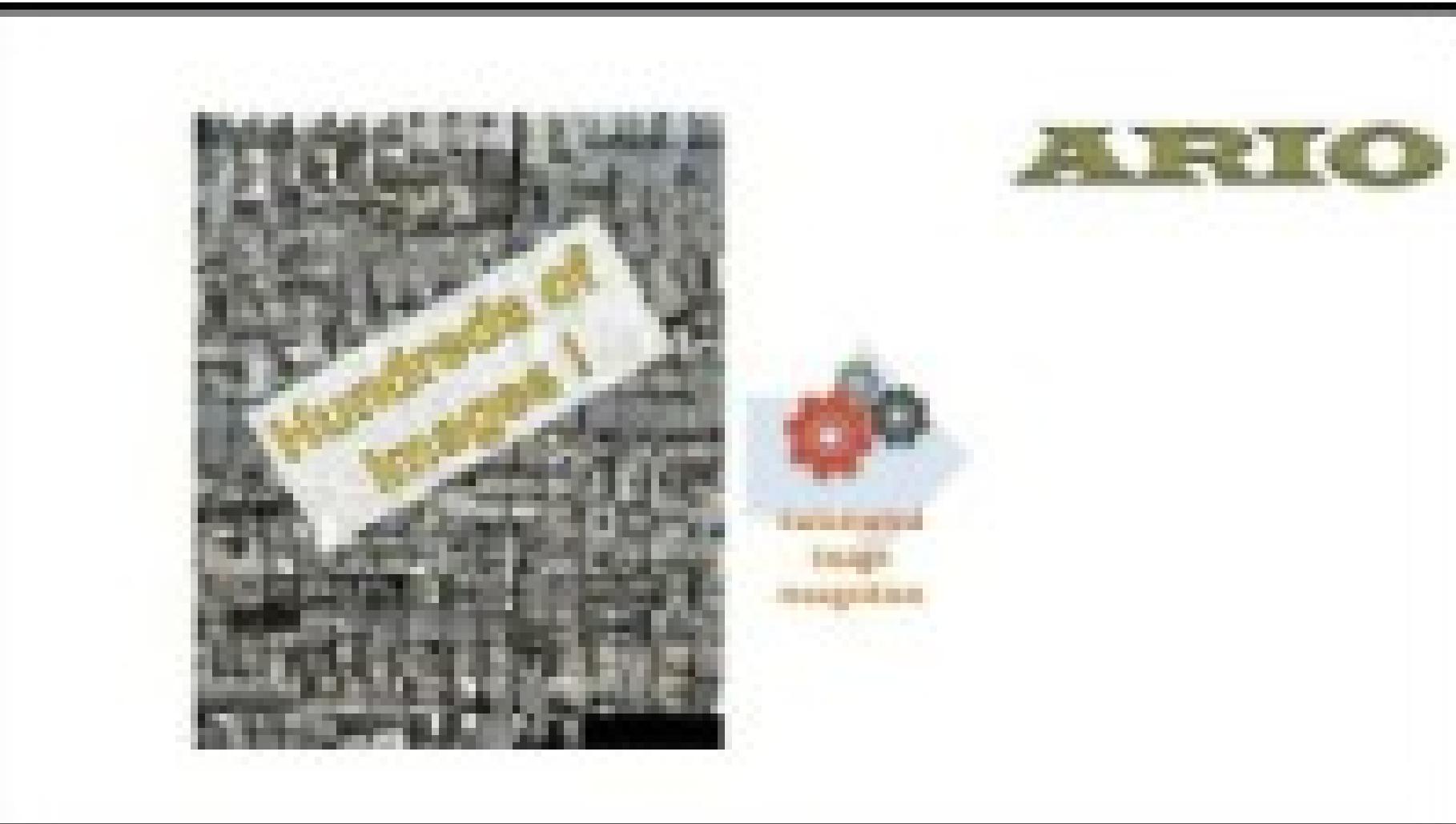
Construction Engineering: Crane Camera Solution (Pix4D)



Construction Engineering: Craft Worker Health and Productivity Improvement

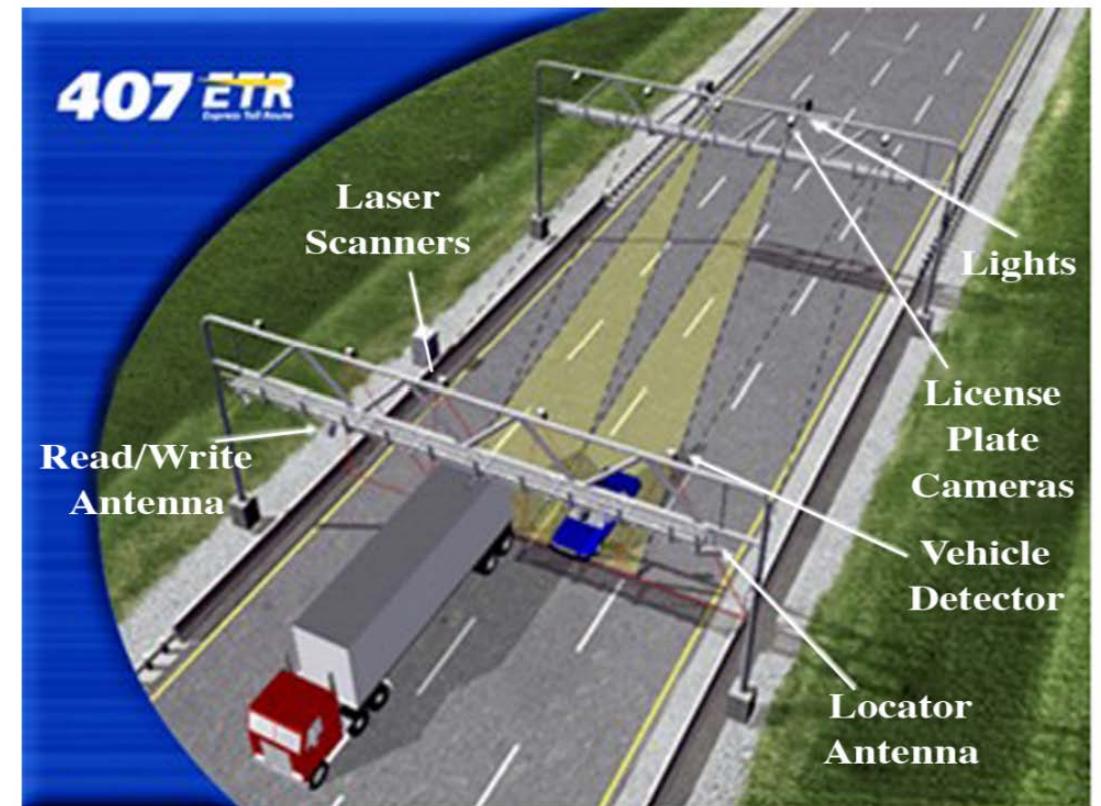


Earthquake Engineering: Post-Disaster Reconnaissance



- Yeum, C. M., Dyke, S. J., Benes, B., Hacker, T., Ramirez, J., Lund, A., & Pujol, S. (2018). Postevent Reconnaissance Image Documentation Using Automated Classification. *Journal of Performance of Constructed Facilities*, 33(1), 04018103.
- <https://youtu.be/aKlj7sRVBv8>

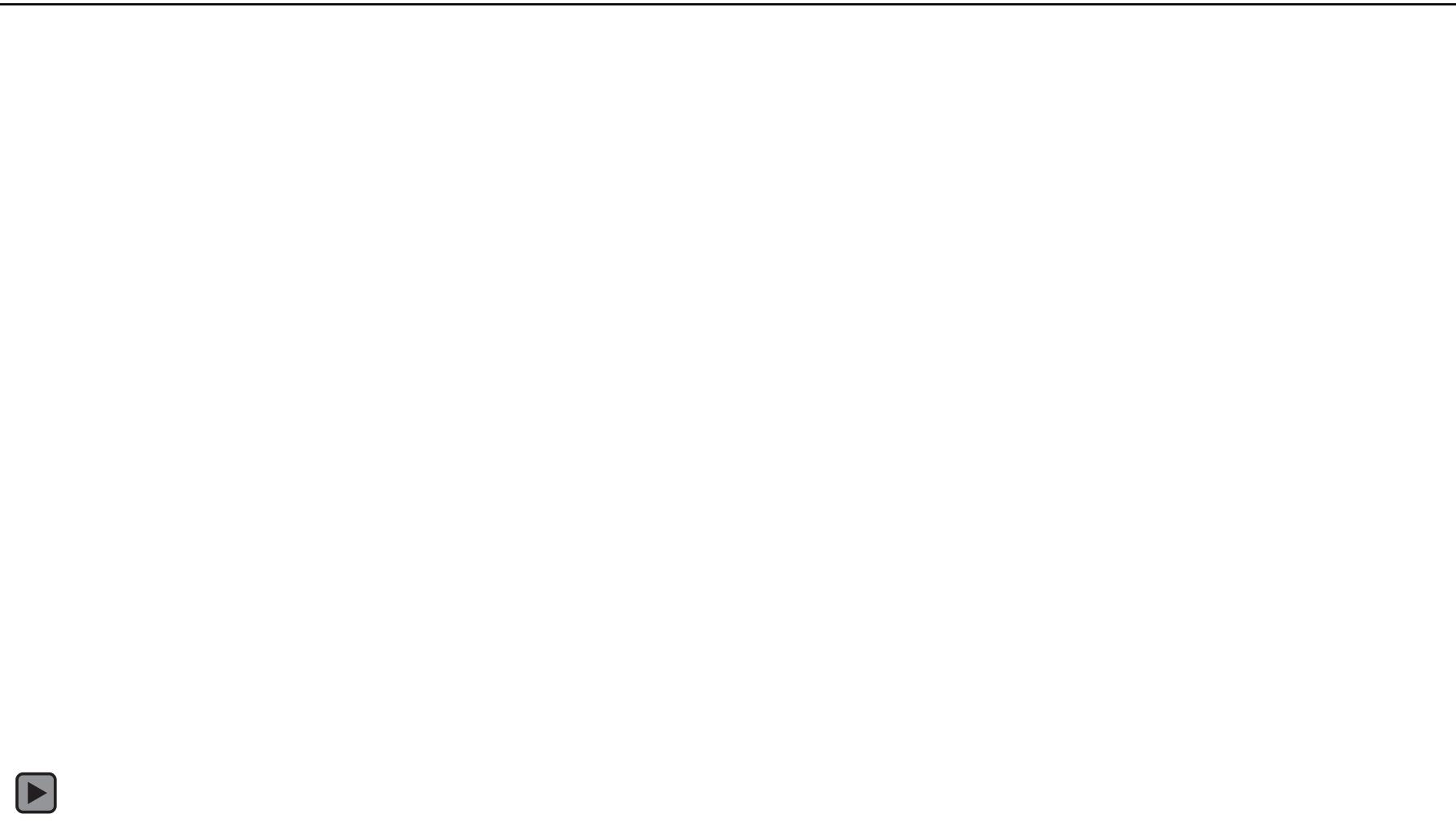
Transportation Engineering: License Plate Estimation



Transportation Engineering: Driver Distraction Monitoring

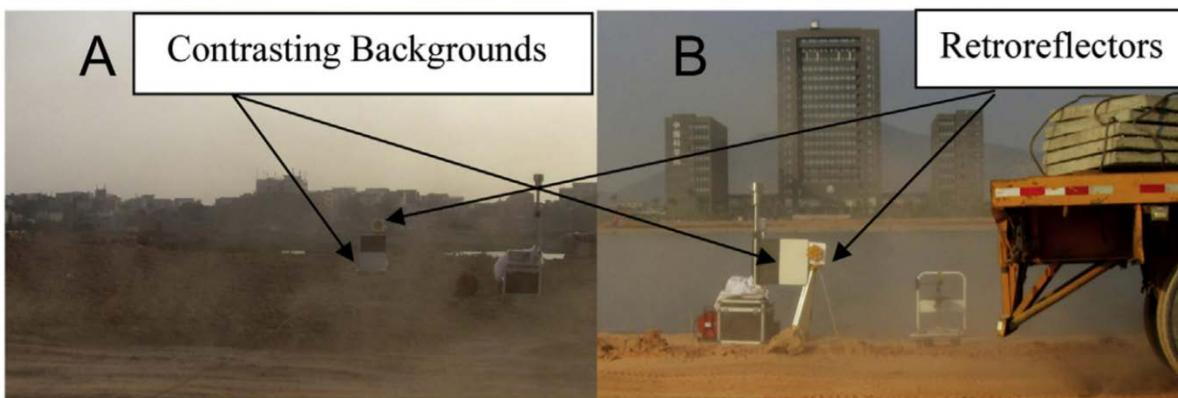
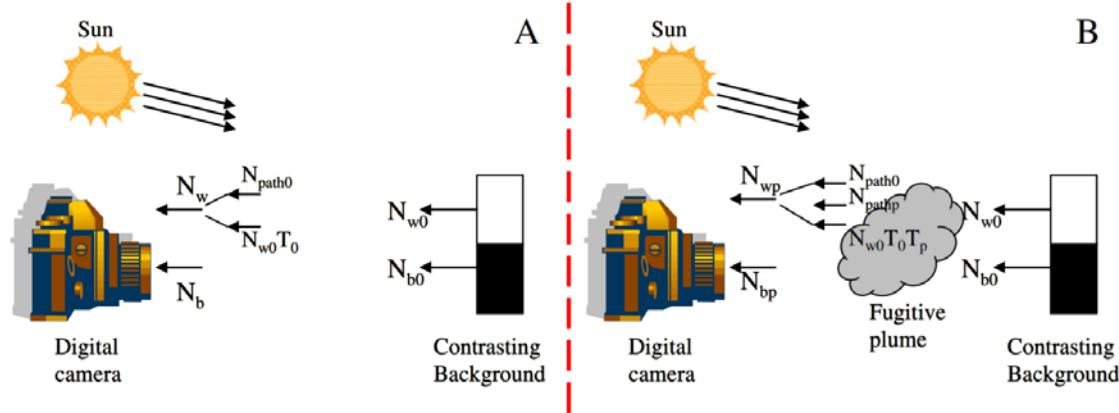


Environmental Engineering: Air Quality Monitoring (Breathe Cam)



- <https://www.cmu.edu/homepage/health/2014/fall/observable-air.shtml>
- https://www.youtube.com/watch?time_continue=1&v=rV21uP9XcFg

Environmental Engineering: Visual Opacity of Fugitive Plumes



<https://youtu.be/tNse9hYYEBc>

Surveying: Photogrammetry



Surveying: Mobile Mapping Solution



Smart Structures and Systems

