

Introduction of Smart Structure Technology

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CIVE 497 – CIVE 700: Smart Structure Technology

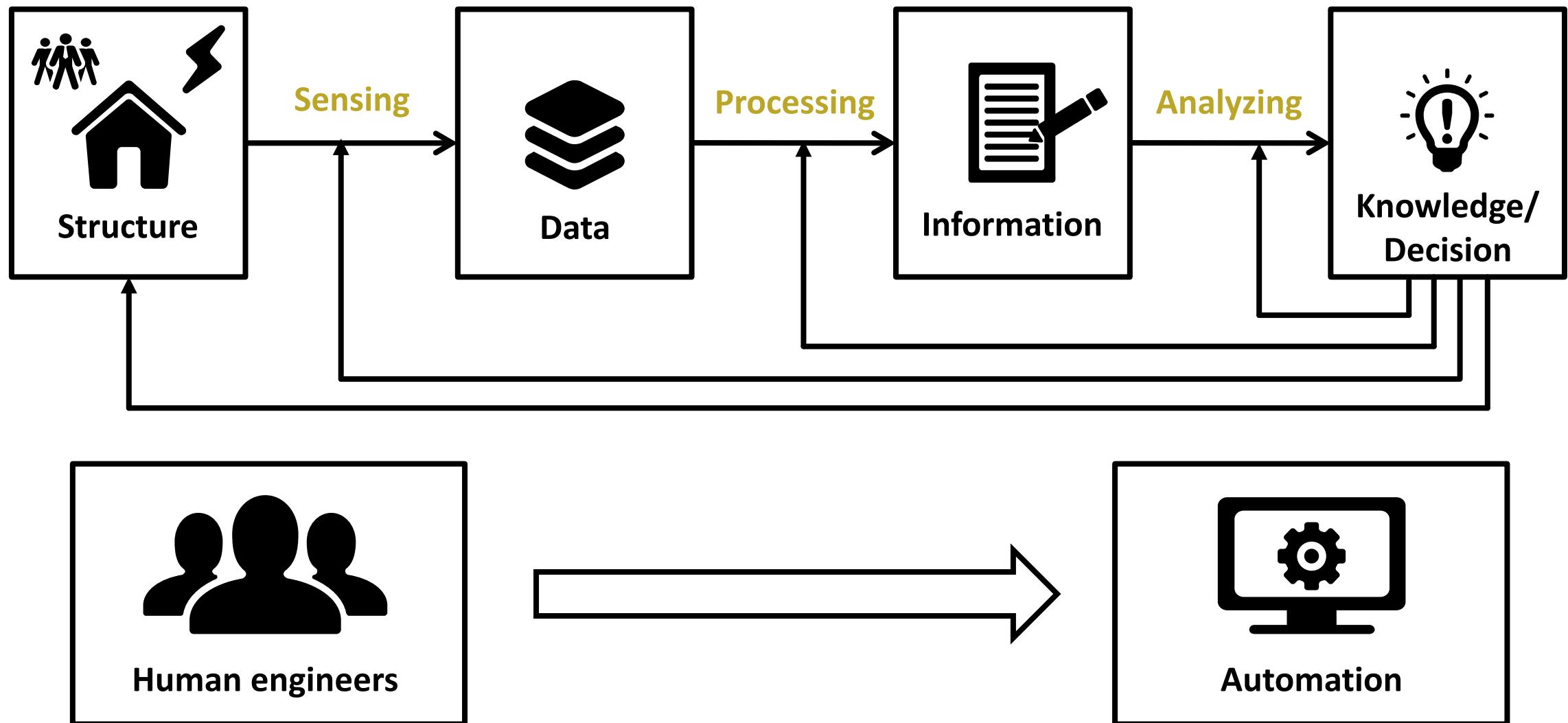


UNIVERSITY OF WATERLOO
FACULTY OF ENGINEERING

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- **Part I: Introduction of Smart Structure Technology**
- **Part II: Review of the Course Syllabus**
- **Part III: Instructor's Prior Research**

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.

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.
- New business models: Manufacturers of large capital investment hardware can charge by the amount of life used instead of a time-based lease.

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** Remaining life



Definition of “Damage”

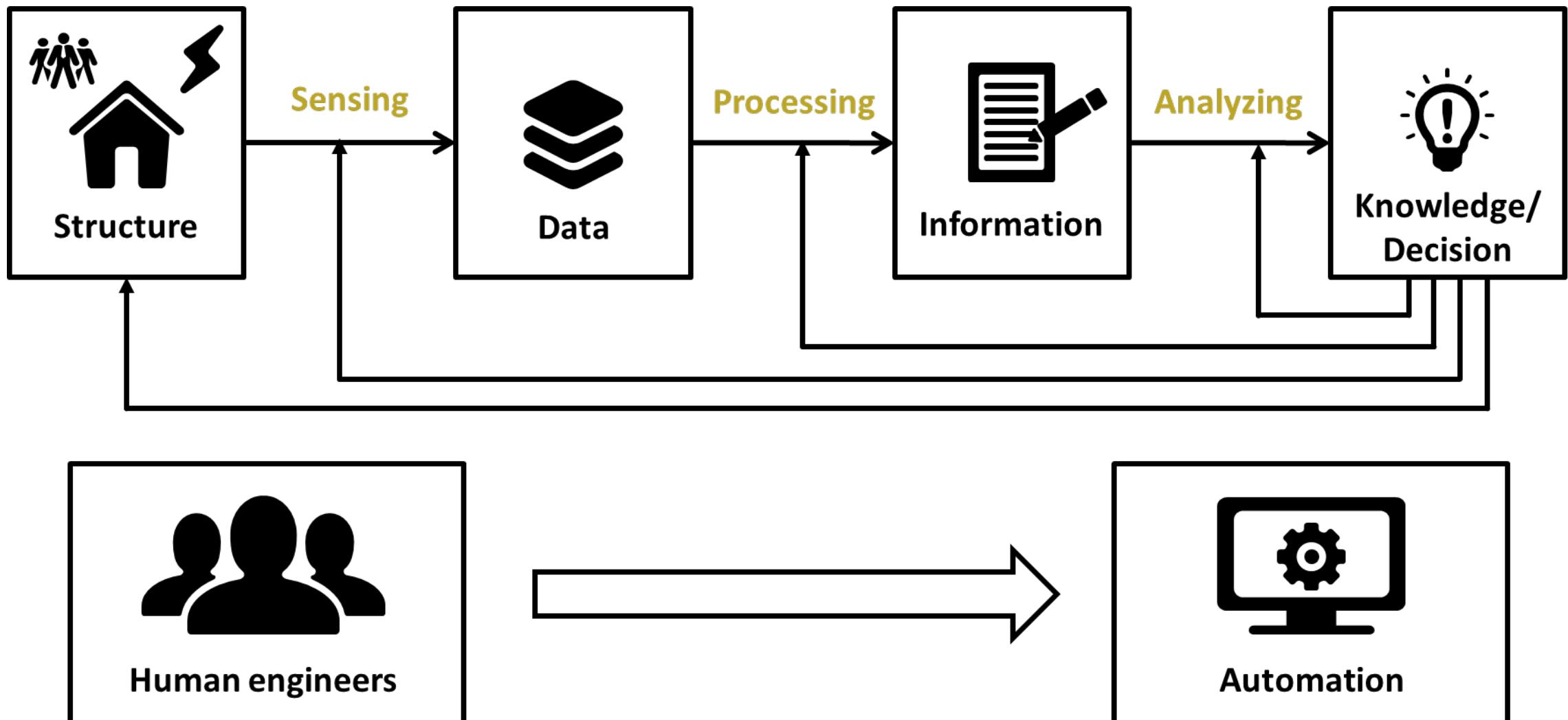
- **Damage** will be defined as changes to the material and/or geometric properties of a structural or mechanical system, including changes to the boundary conditions and system connectivity, that adversely affect the current or future **performance** of that system.
- Examples:
 - crack in mechanical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

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

Smart Structures and Systems



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

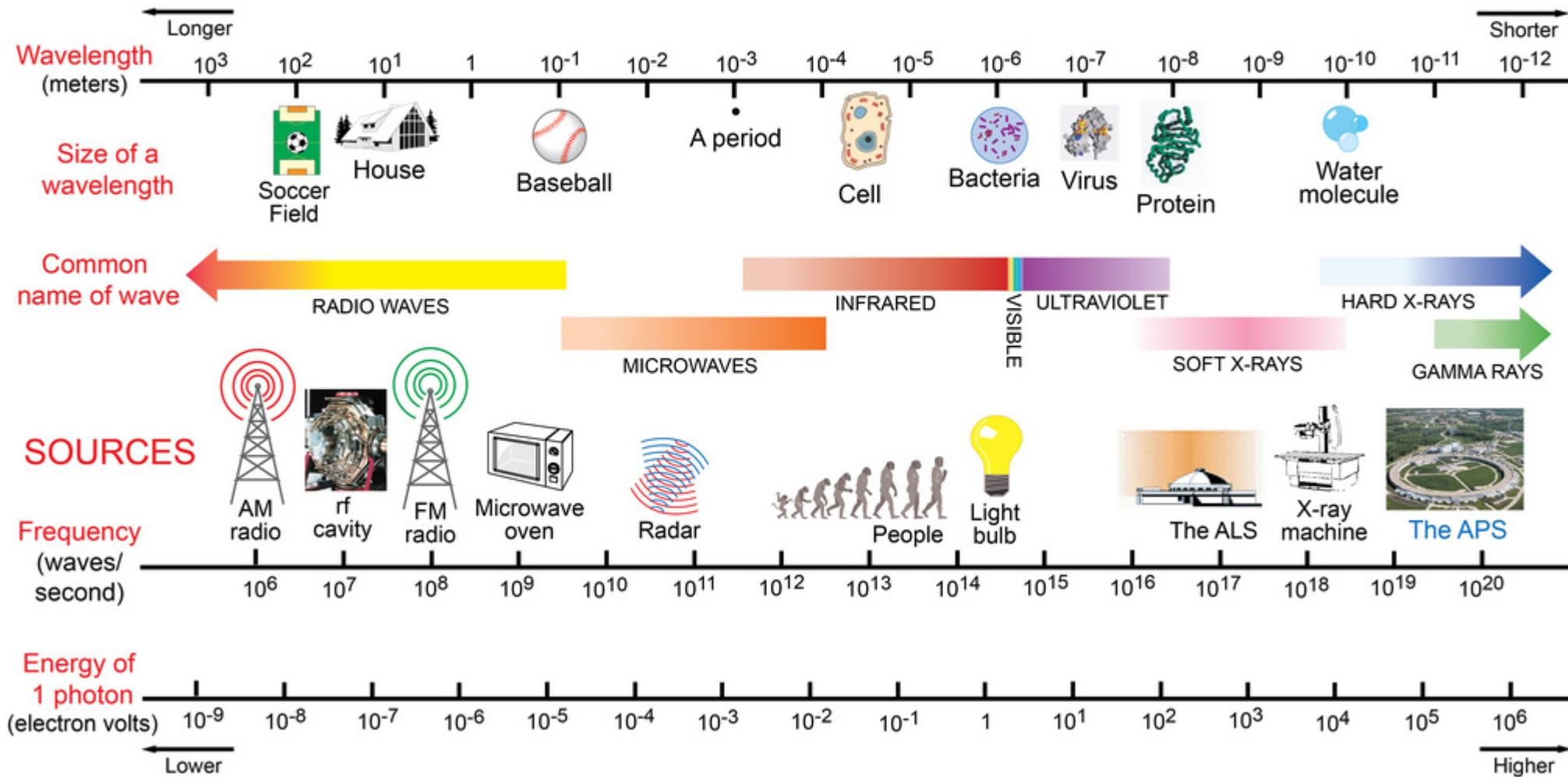
**Active
sensor**



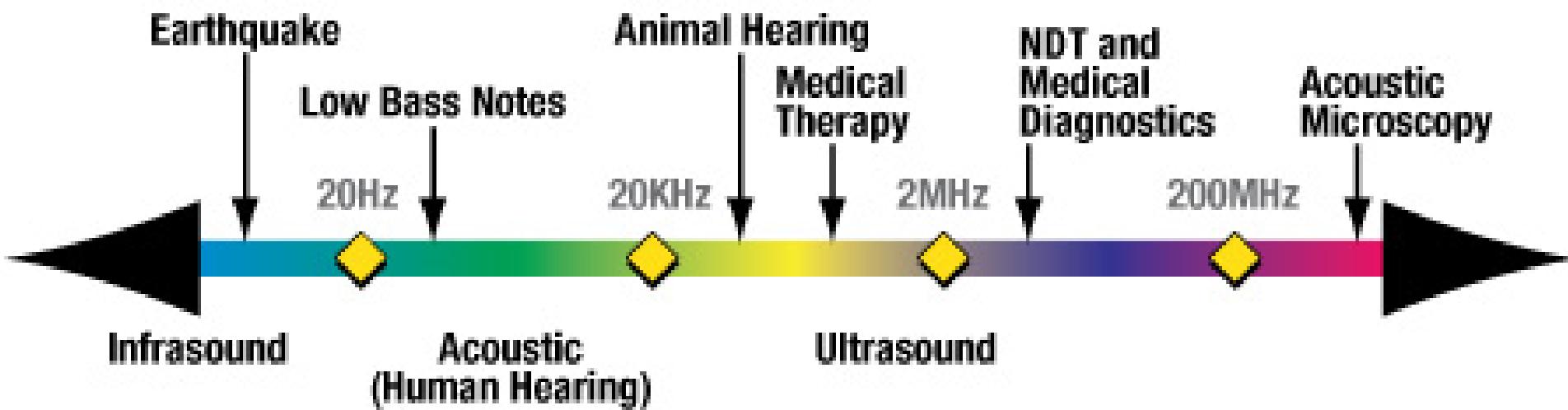
Thermometer

Electromagnetic Spectrum

THE ELECTROMAGNETIC SPECTRUM

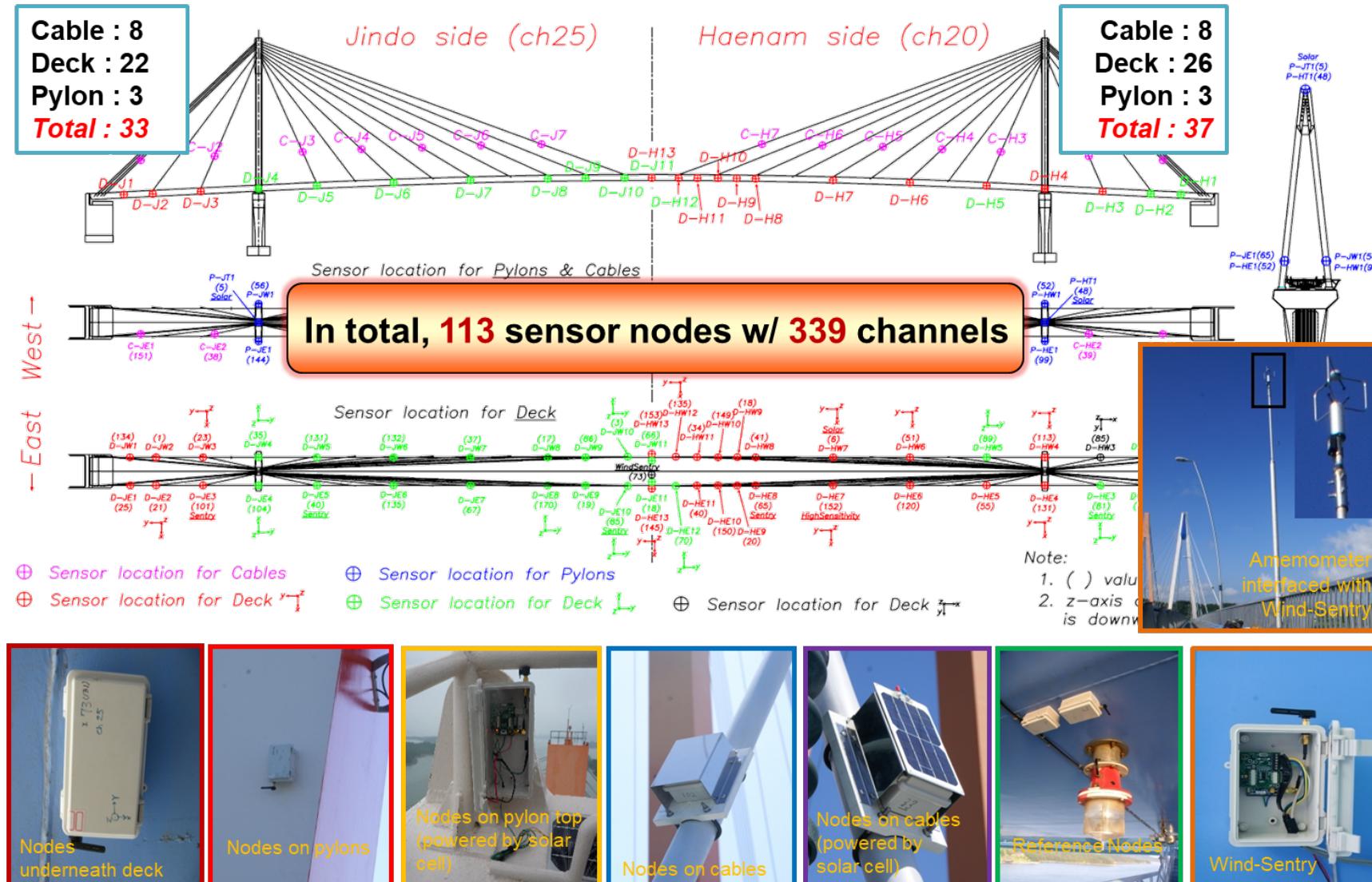


Mechanical Vibration

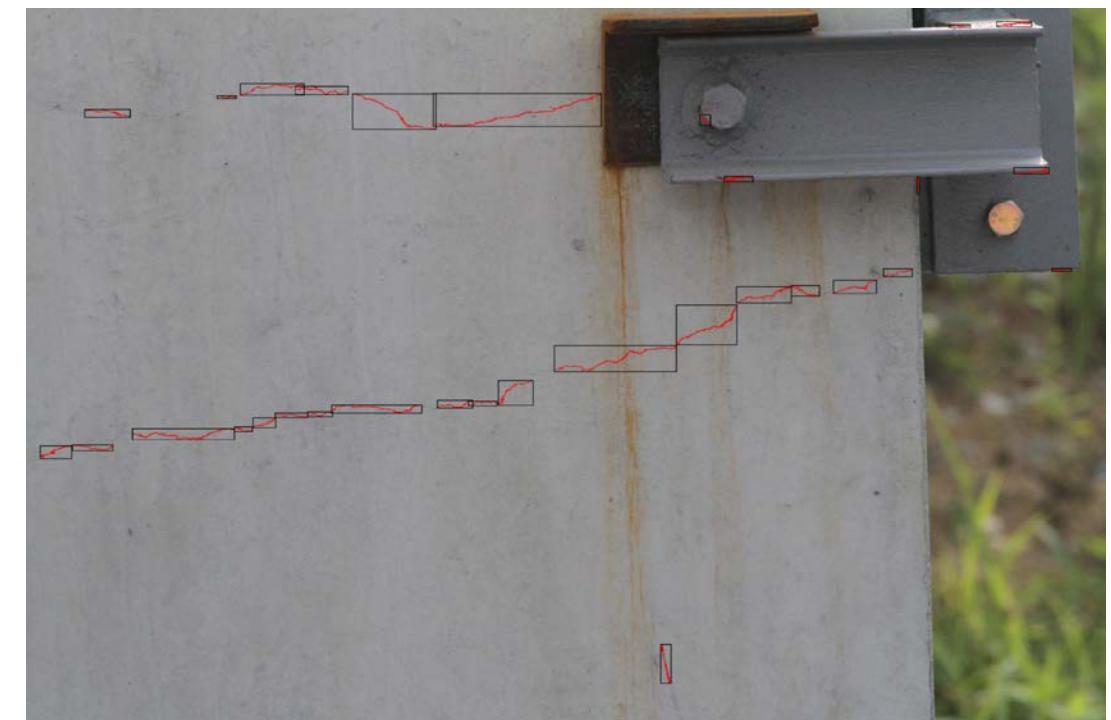
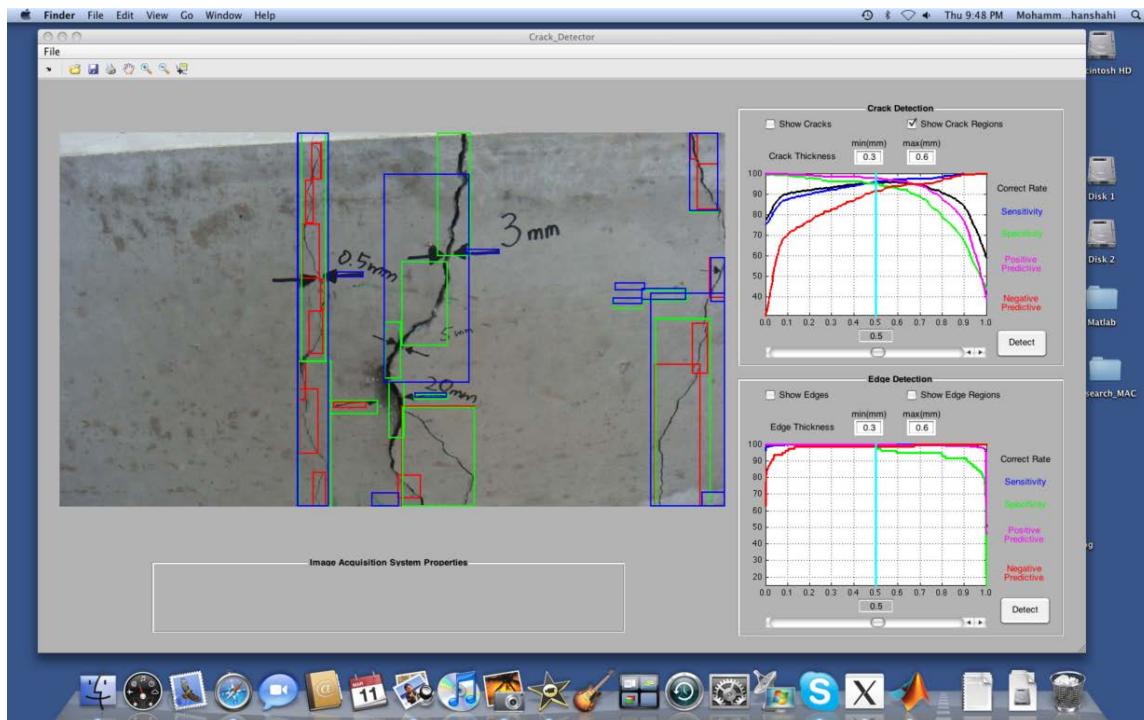


Applications of Smart Structure Technology in Civil Engineering

Structural Engineering: Wireless Monitoring of a Cable-Stayed Bridge



Structural Engineering: Visual Inspection – Crack Detection



Jahanshahi, M. R., Masri, S. F., Padgett, C. W., & Sukhatme, G. S. (2013). An innovative methodology for detection and quantification of cracks through incorporation of depth perception. *Machine vision and applications*, 24(2), 227-241.

Structural Engineering: Bridge Deck Assessment Robot



degradation, and the visual condition of the bridge and transmit it to a mobile command.

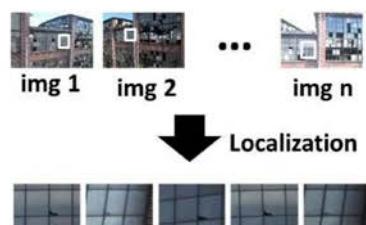
Structural Engineering: Visual Inspection – Façade Inspection using UAVs



Step 1. Image collection



Step 2. Orthophoto generation



Step 3. ROI localization

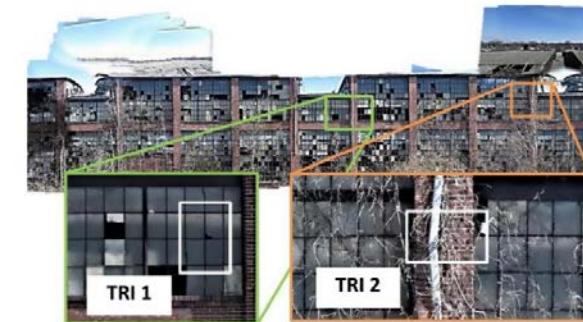
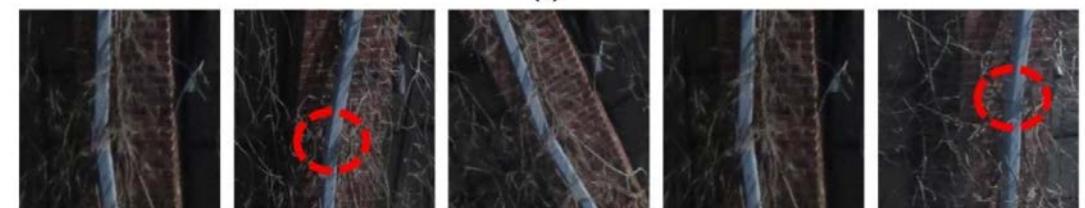


Figure 7. Selection of two sample TRIs (TRI 1 and TRI 2) on the orthophoto.



(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

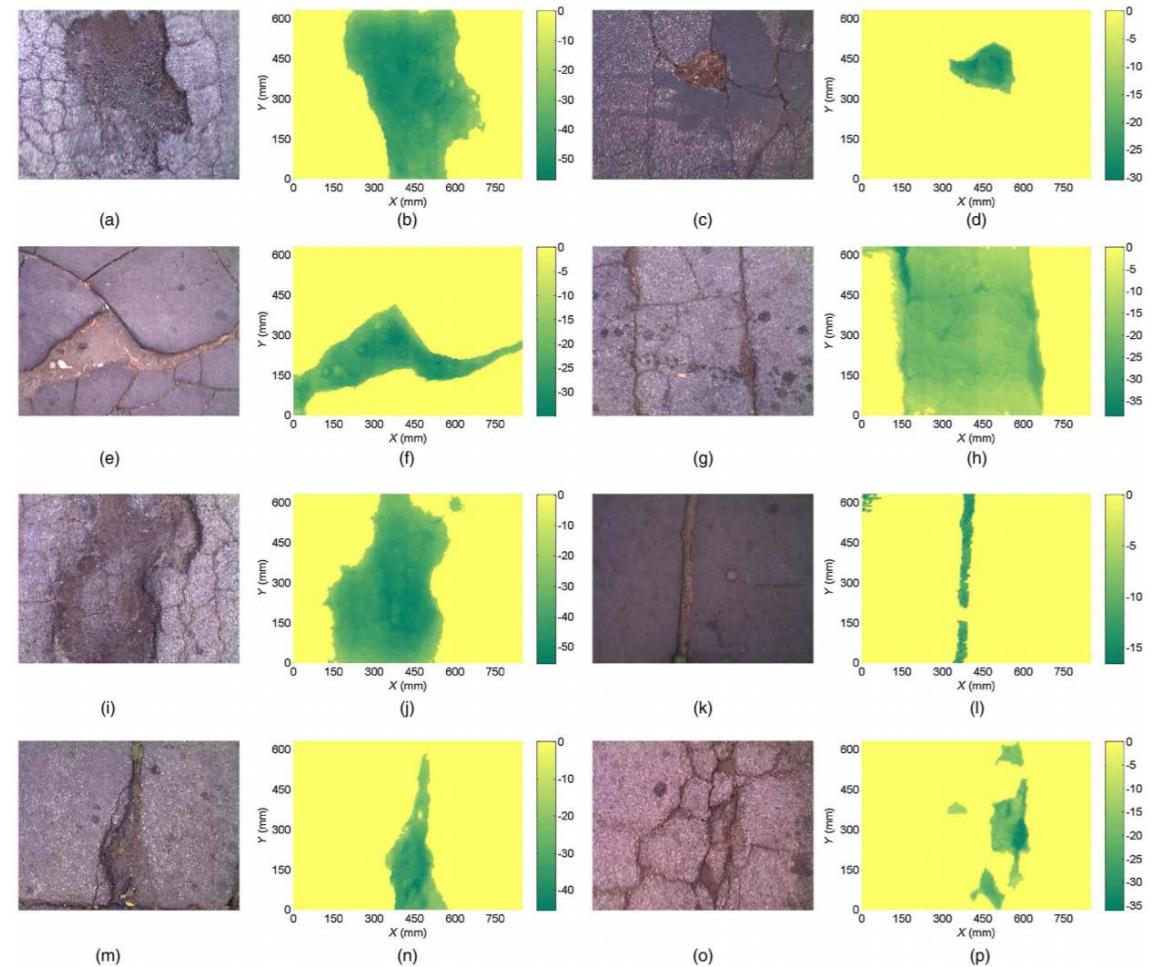
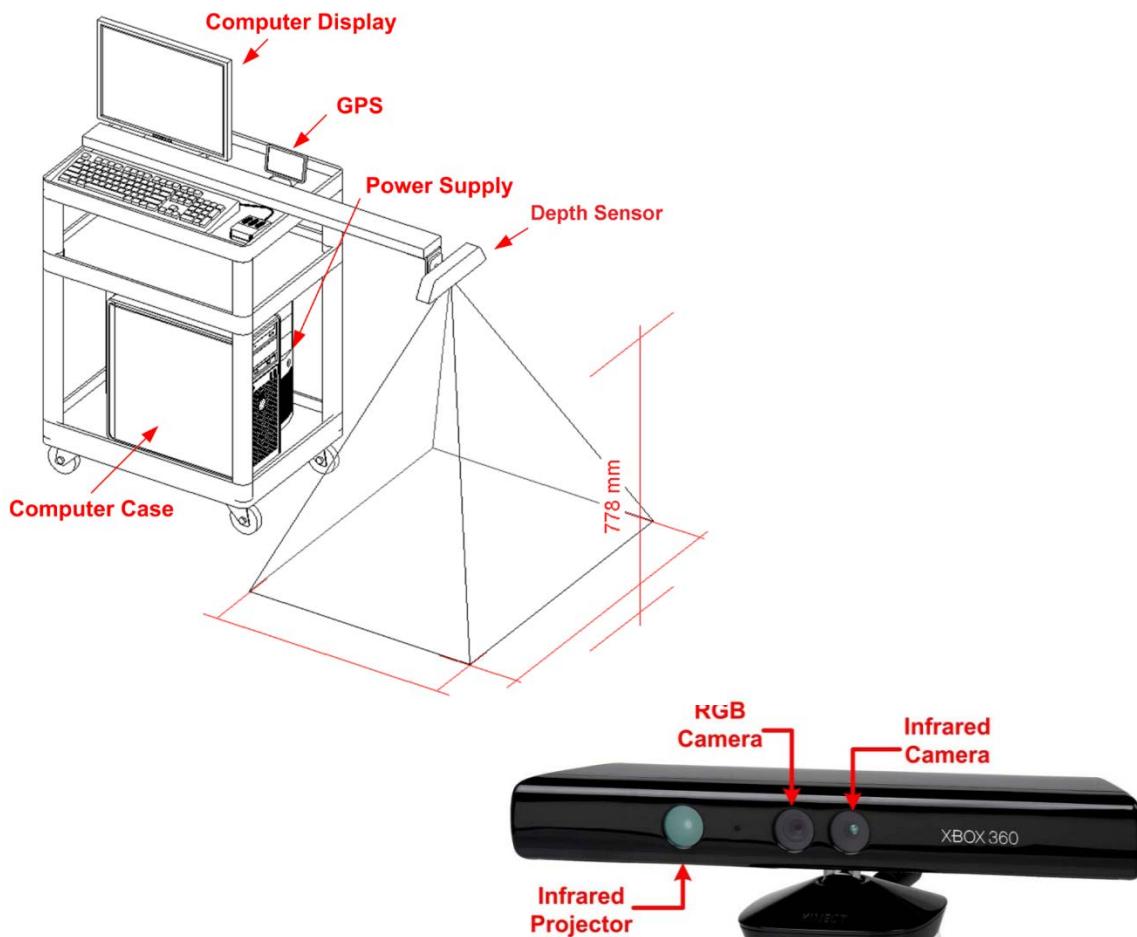
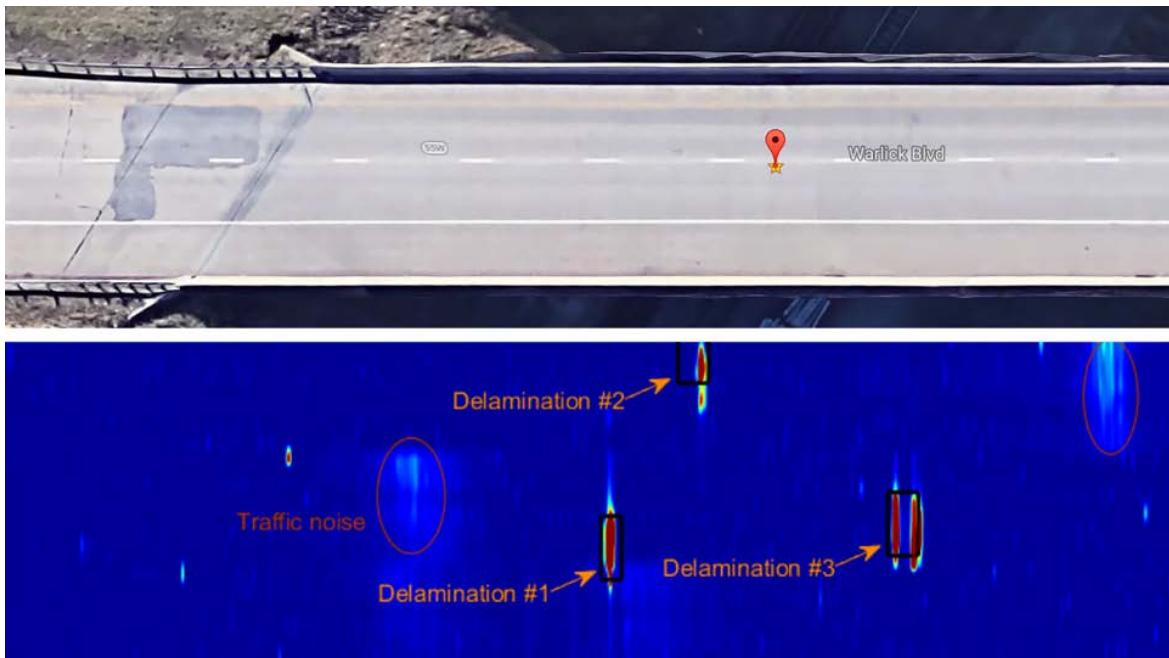


Fig. 6. Defect detection and depth quantification: (a), (c), (e), (g), (i), (k), (m), and (o) are the images of the defects, and (b), (d), (f), (h), (j), (l), (n) and (p) are the corresponding depth maps, respectively

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

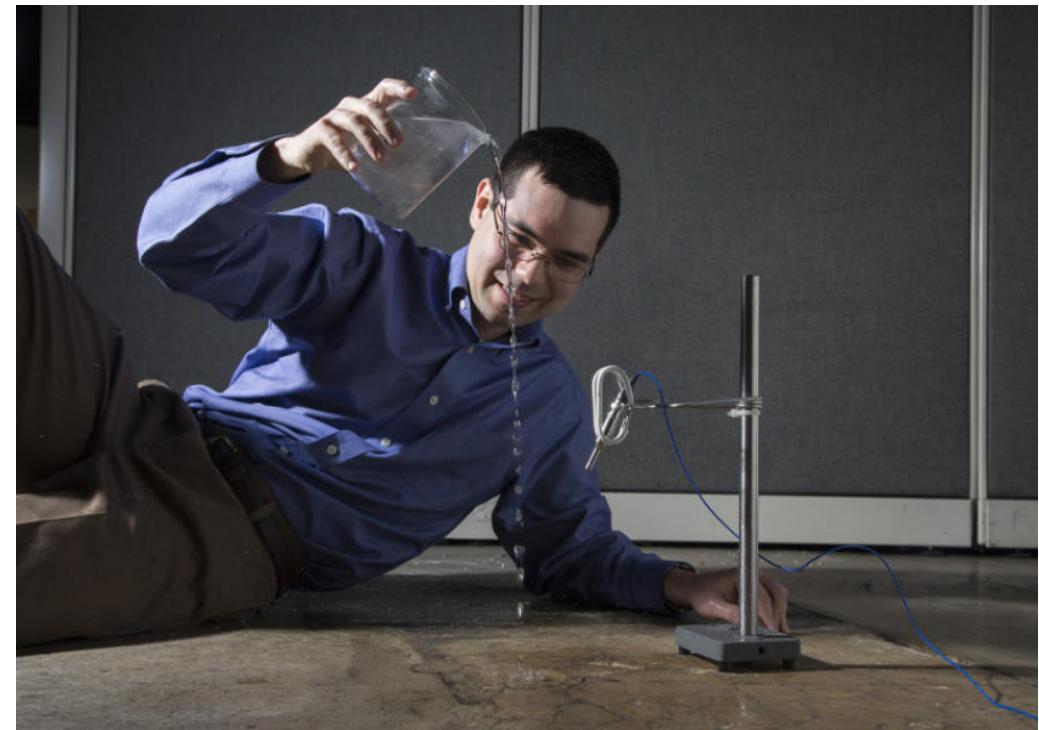
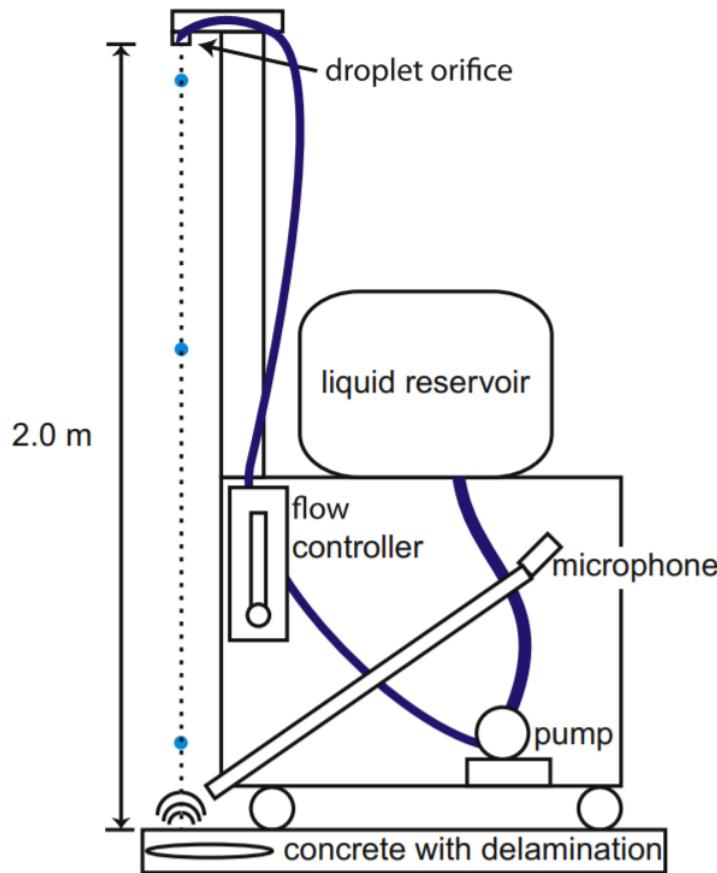


<https://go.unl.edu/ic7w>



<https://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>

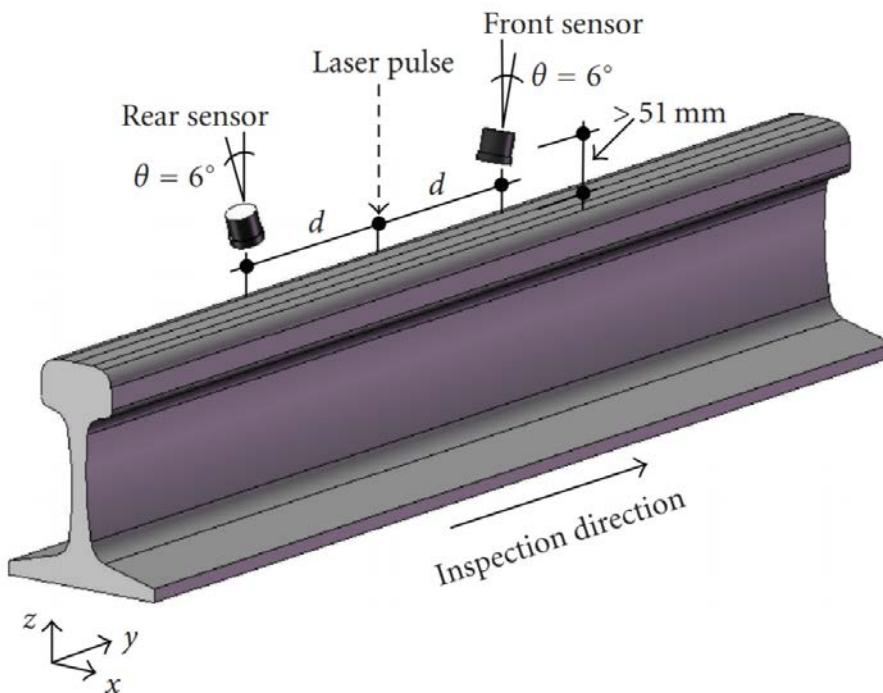
Structural Engineering: Robotic for Structural Assessment



Structural Engineering: Video Surveillance of Vehicle Clearance



Structural Engineering: Rail Inspection using Non-contact Ultrasonic Transducers



(a)

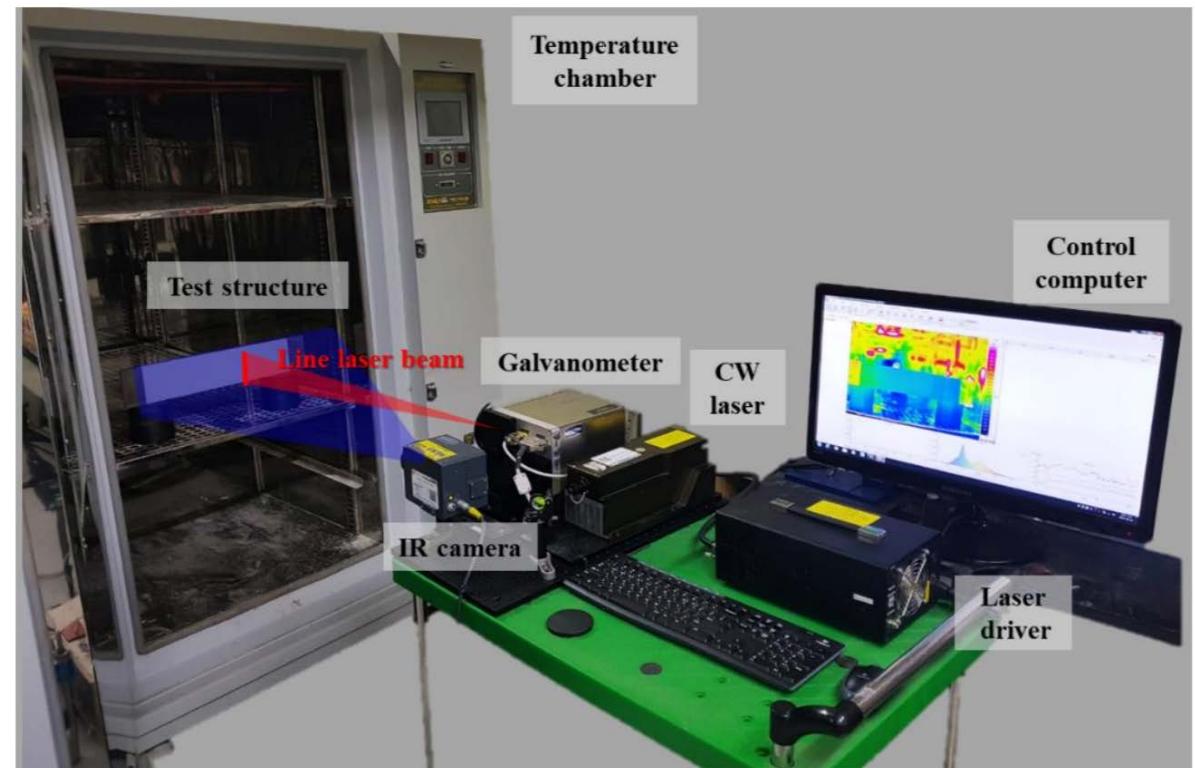
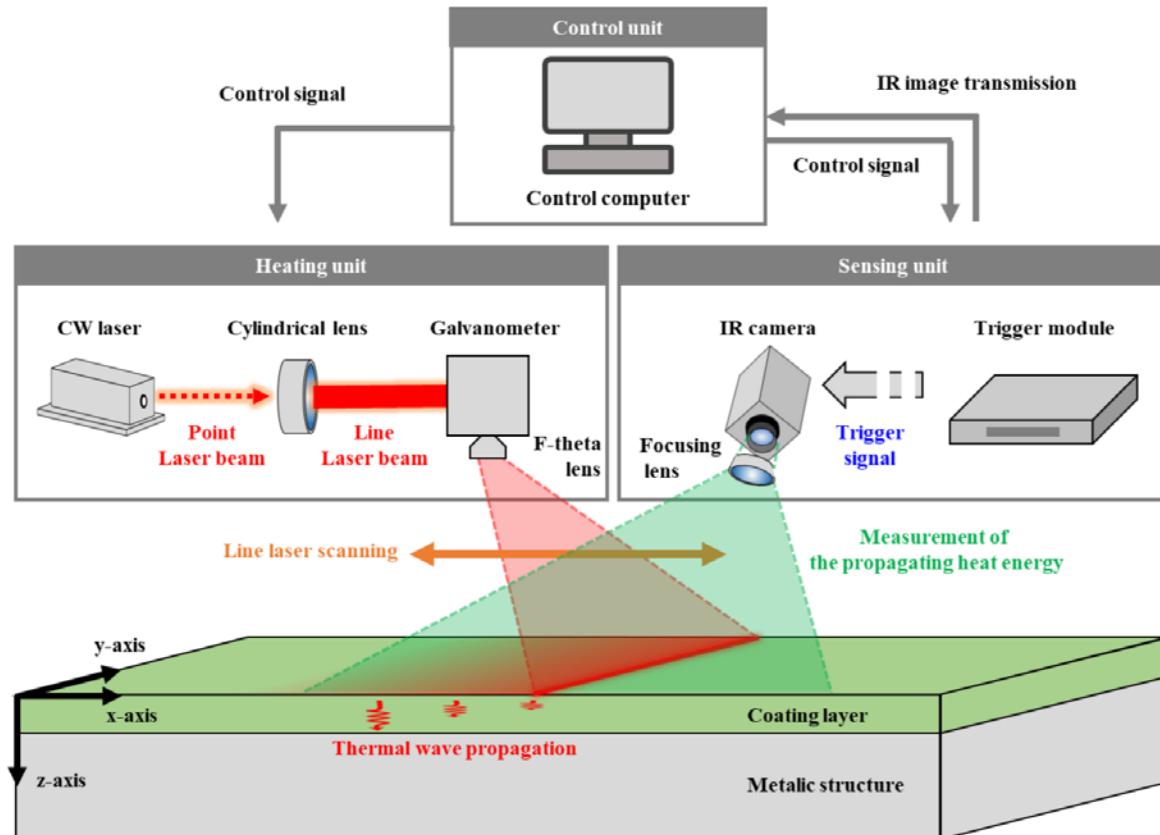


(b)

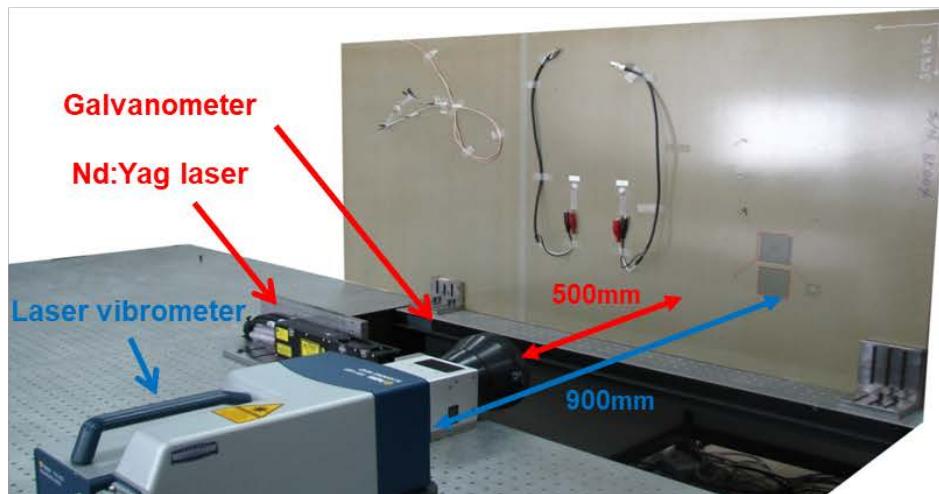
FIGURE 10: (a) Test site near Gettysburg, Pennsylvania. (b) Photo of the latest inspection prototype tested in the field.

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

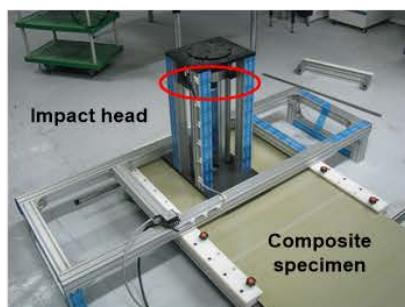
Structural Engineering: Coating Thickness Quantification using Laser Thermography



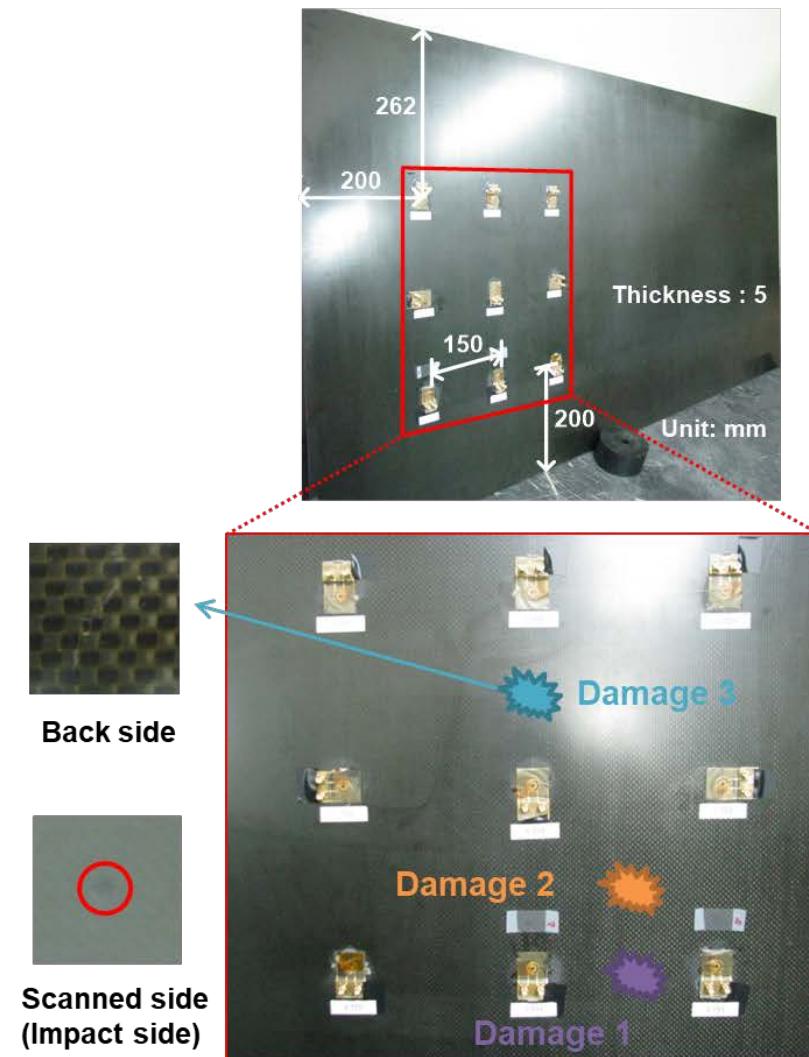
Structural Engineering: Delamination Detection using Piezoelectric Sensors



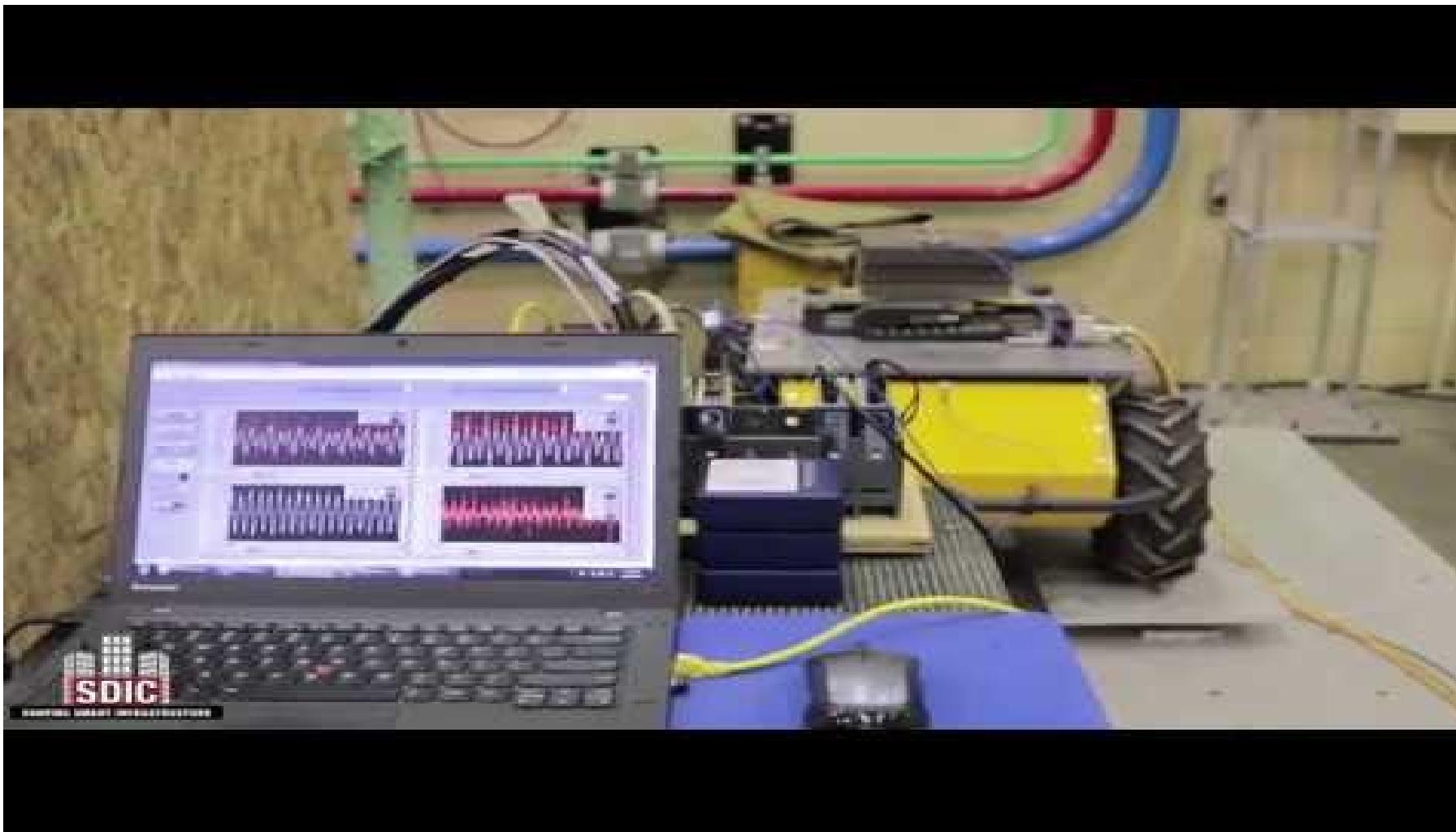
Low velocity impact test



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

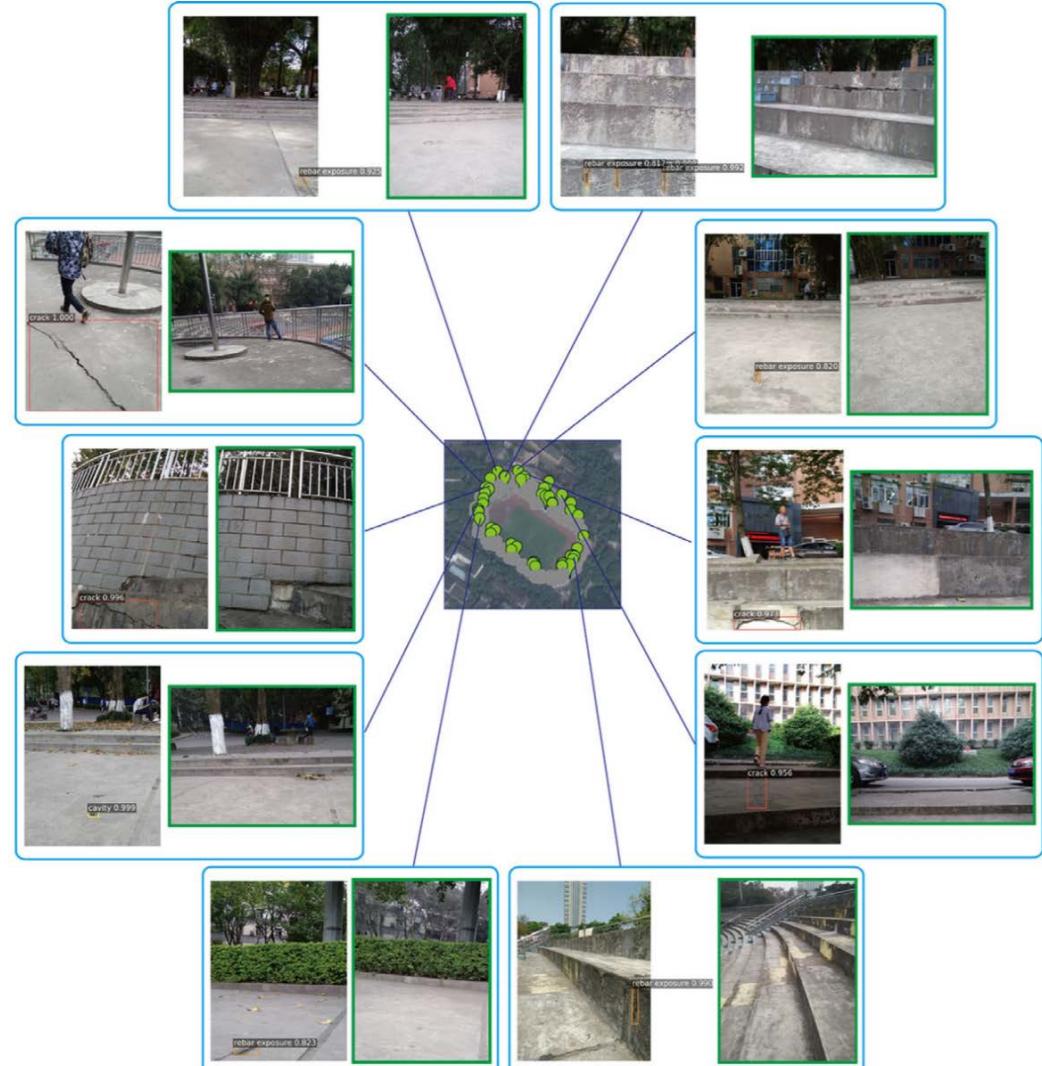
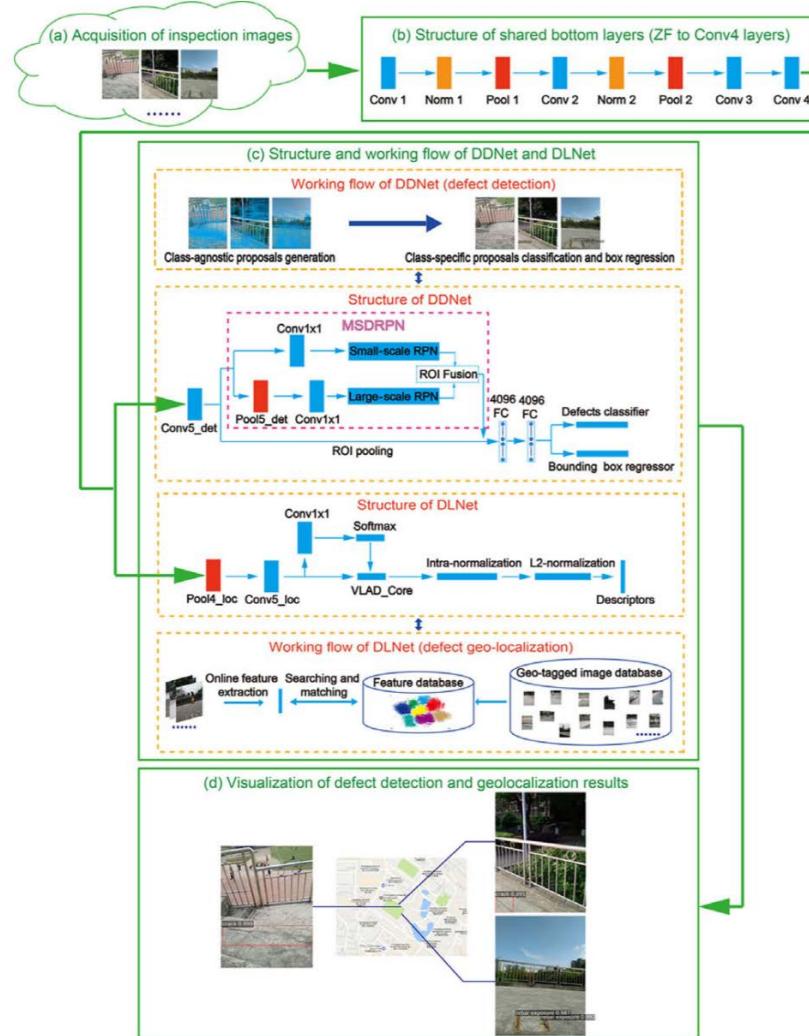


Structural Engineering: Autonomous Vehicle for Structural Control and Assessment



<https://www.youtube.com/watch?v=TS2KWmGCsnQ>

Structural Engineering: Image Registration



Material Engineering: Self-Healing Concrete

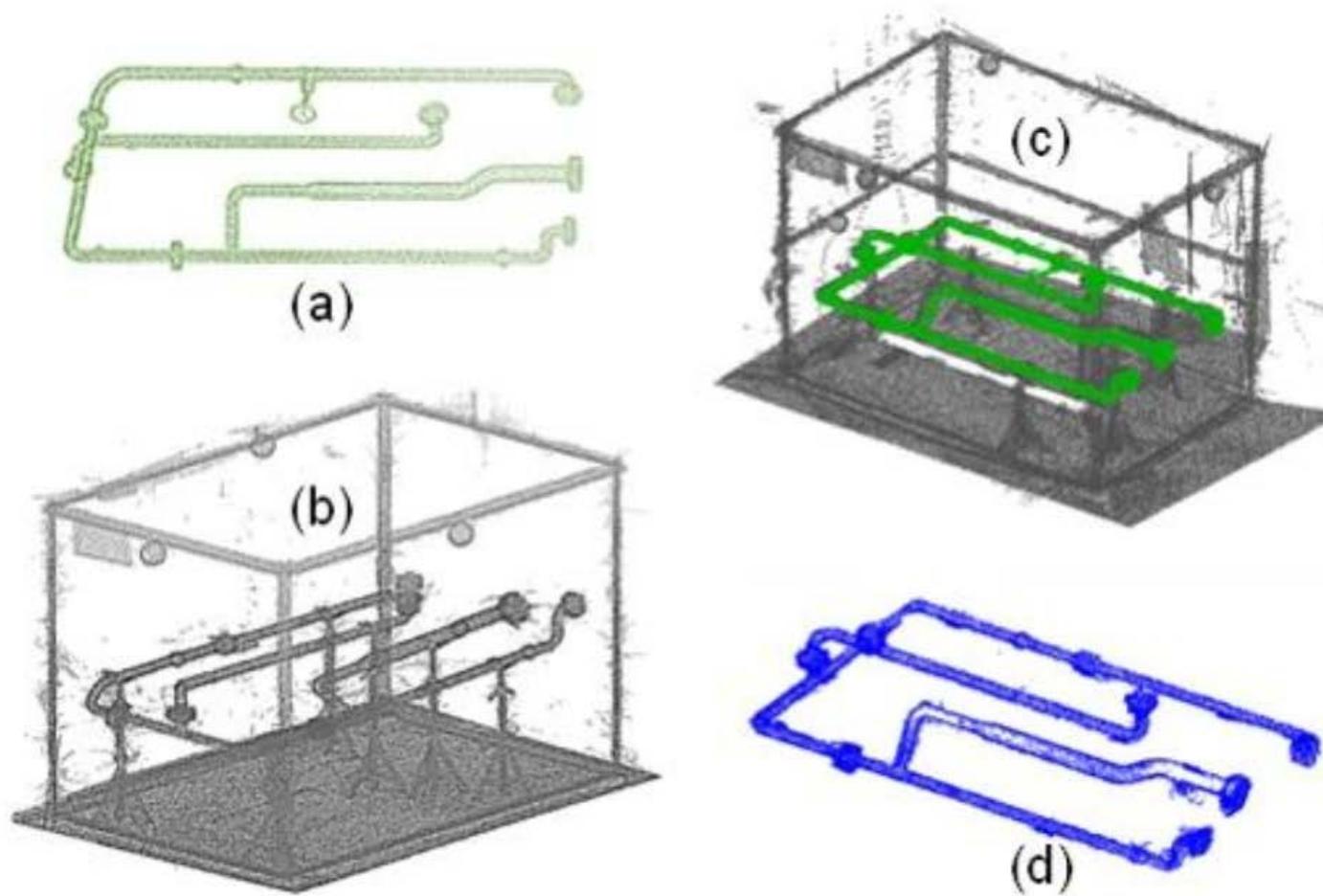


Material Engineering: Shape Alloy

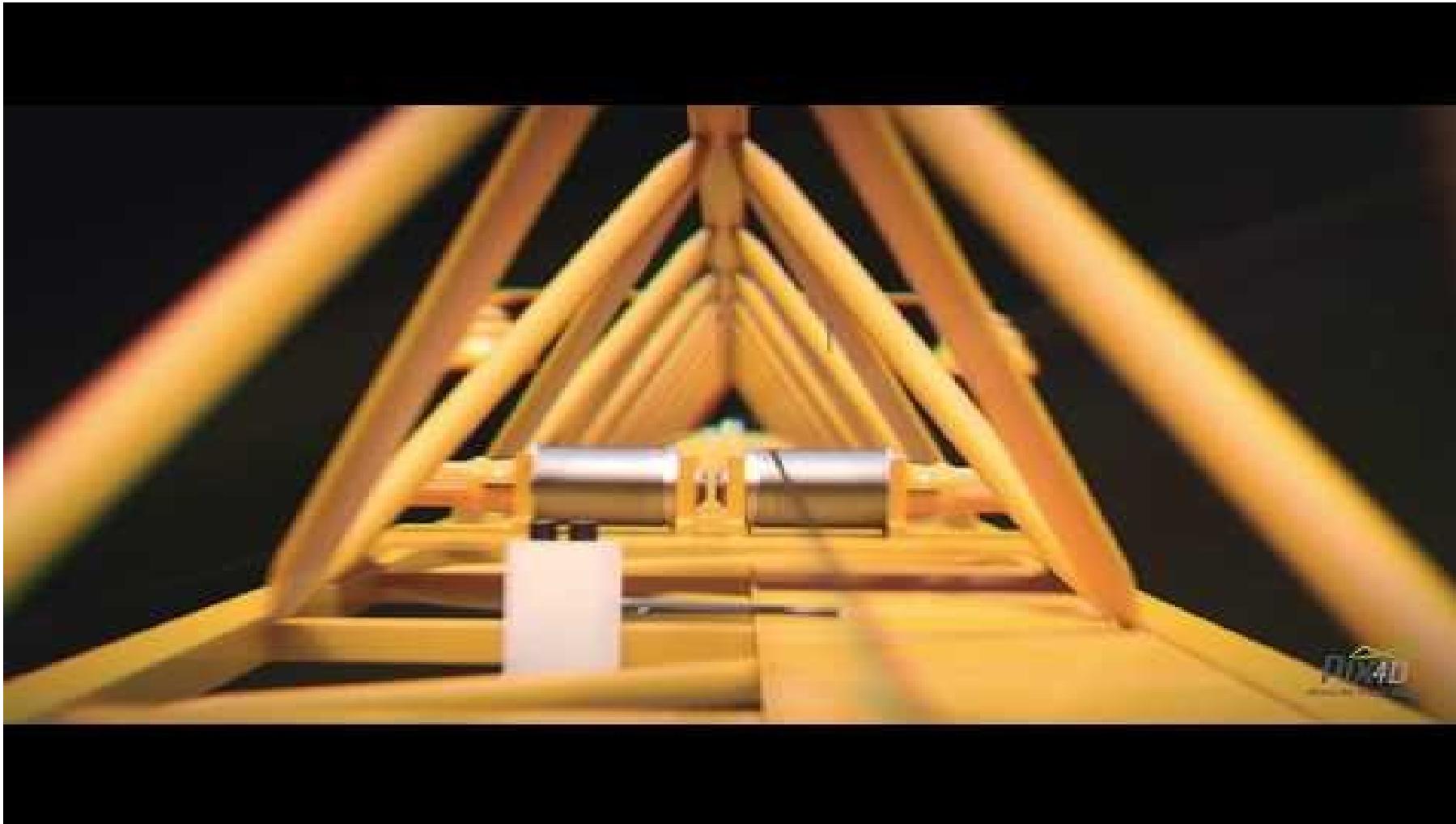


<https://youtu.be/-K57cbOhA5g>

Construction Engineering: Automated construction state estimation

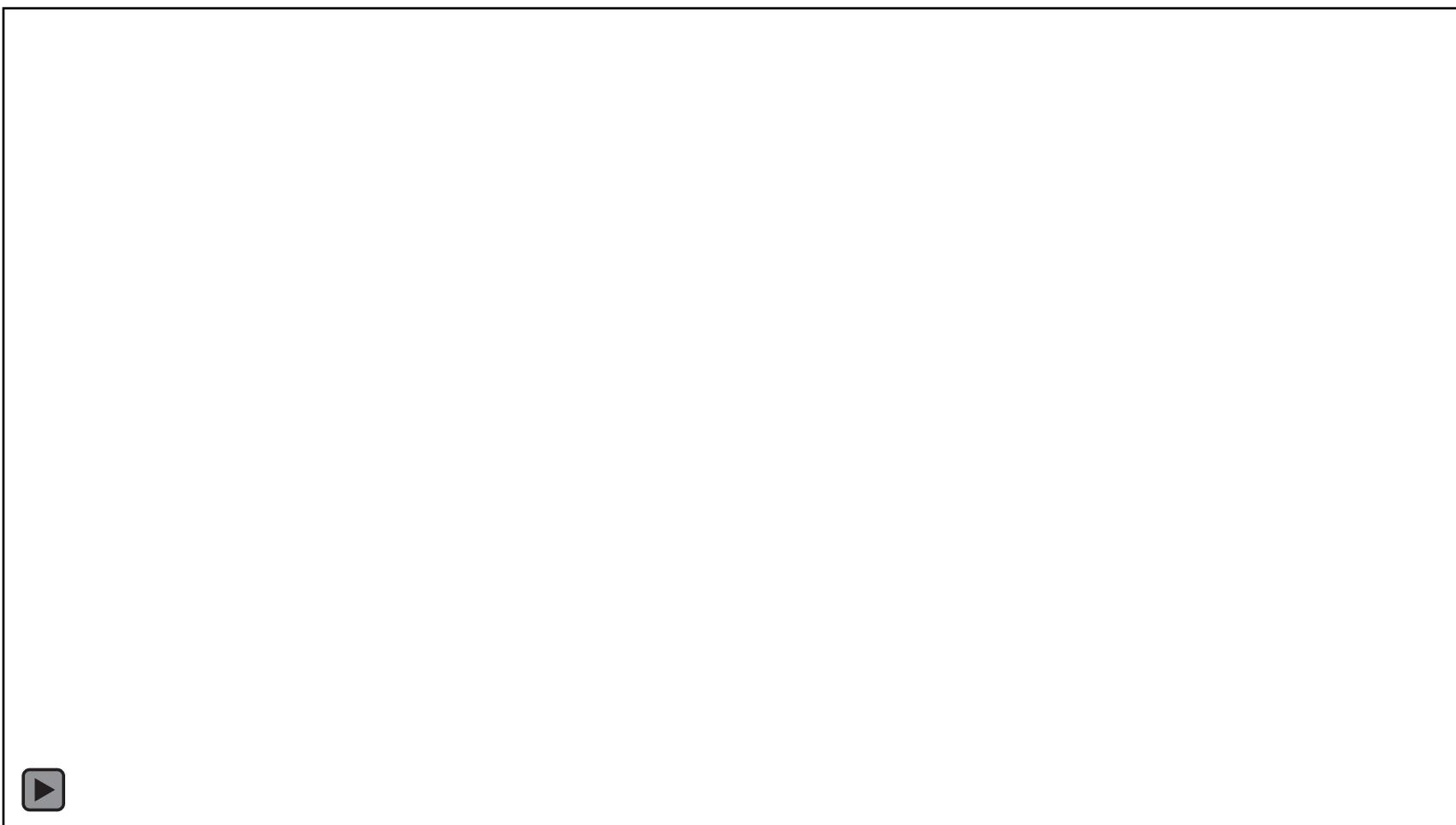


Construction Engineering: Crane Camera Solution (Pix4D)



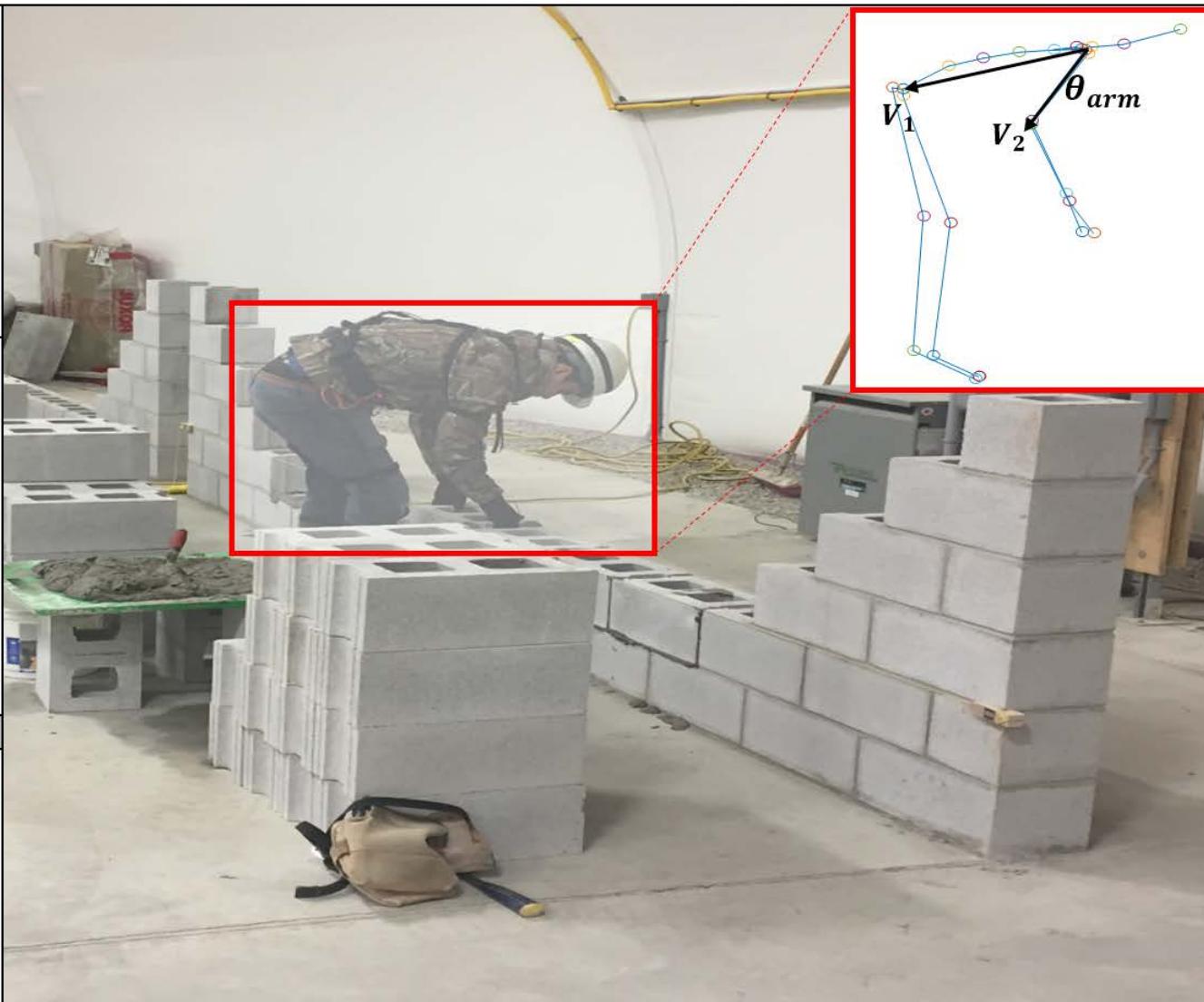
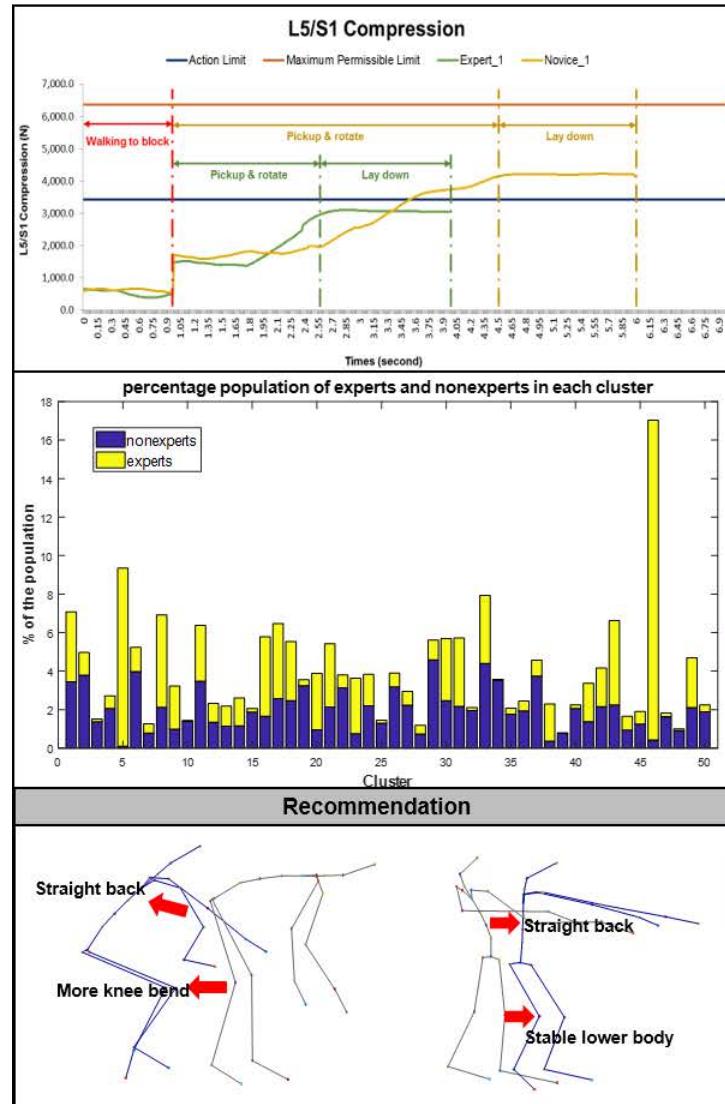
<https://youtu.be/wZazAliljKw>

Construction Engineering: Action Recognition in Construction Sites

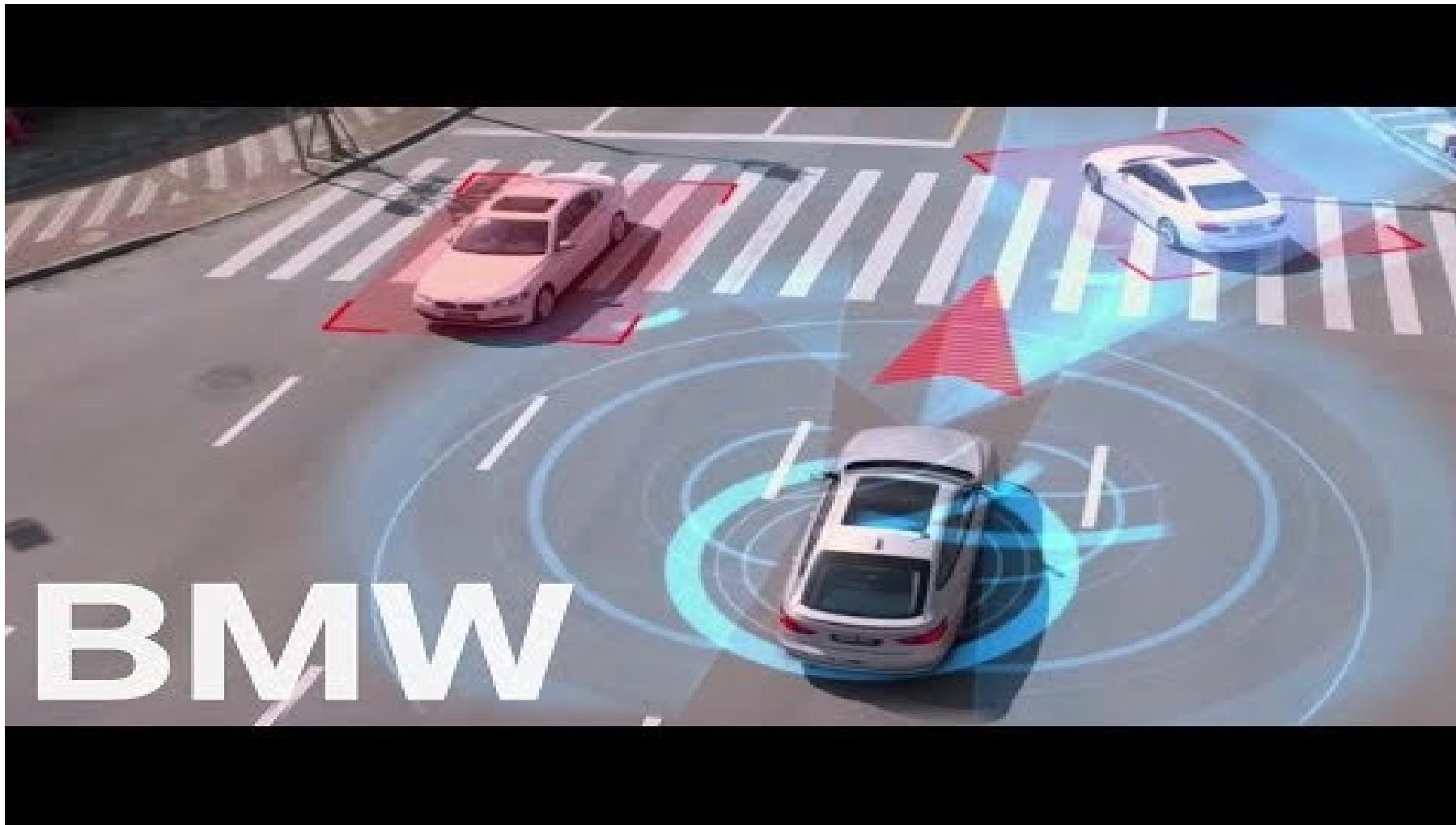


Golparvar-Fard, M., Heydarian, A., & Niebles, J. C. (2013). Vision-based action recognition of earthmoving equipment using spatio-temporal features and support vector machine classifiers. *Advanced Engineering Informatics*, 27(4), 652–663.

Construction Engineering: Craft Worker Health and Productivity Improvement



Transportation Engineering: Autonomous Vehicle



<https://youtu.be/xsQvq4WIUYU>

Earthquake Engineering: Social Media Data Analysis

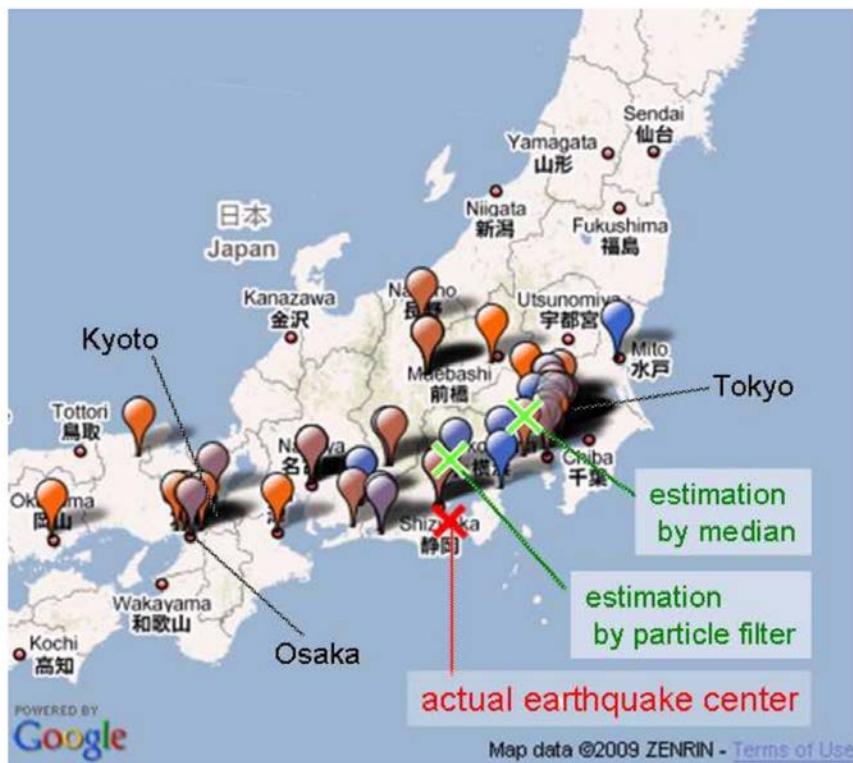
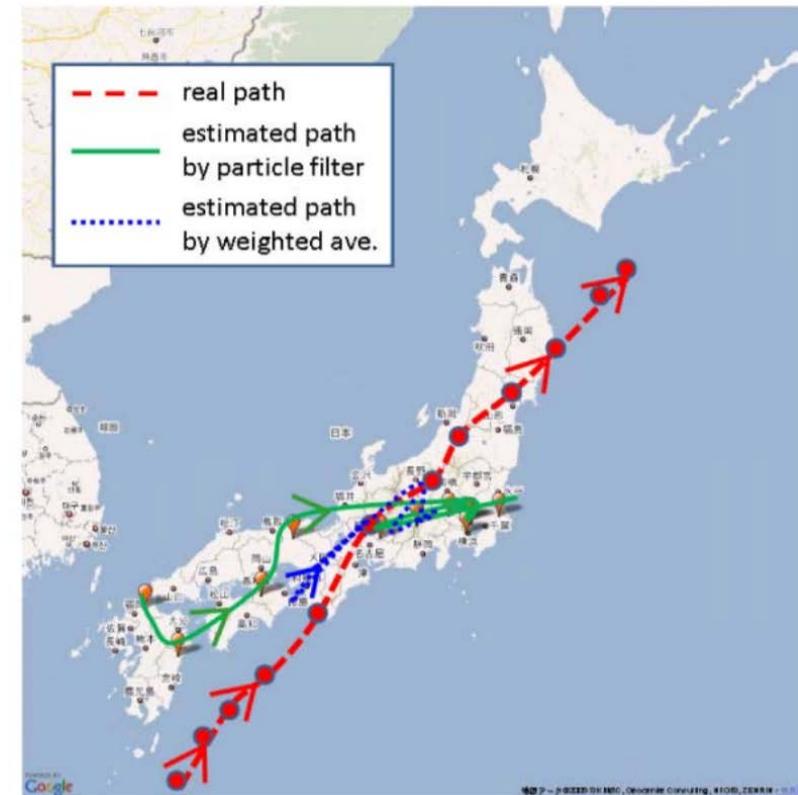


Figure 9: Earthquake location estimation based on tweets. Balloons show the tweets on the earthquake. The cross shows the earthquake center. Red represents early tweets; blue shows later tweets.

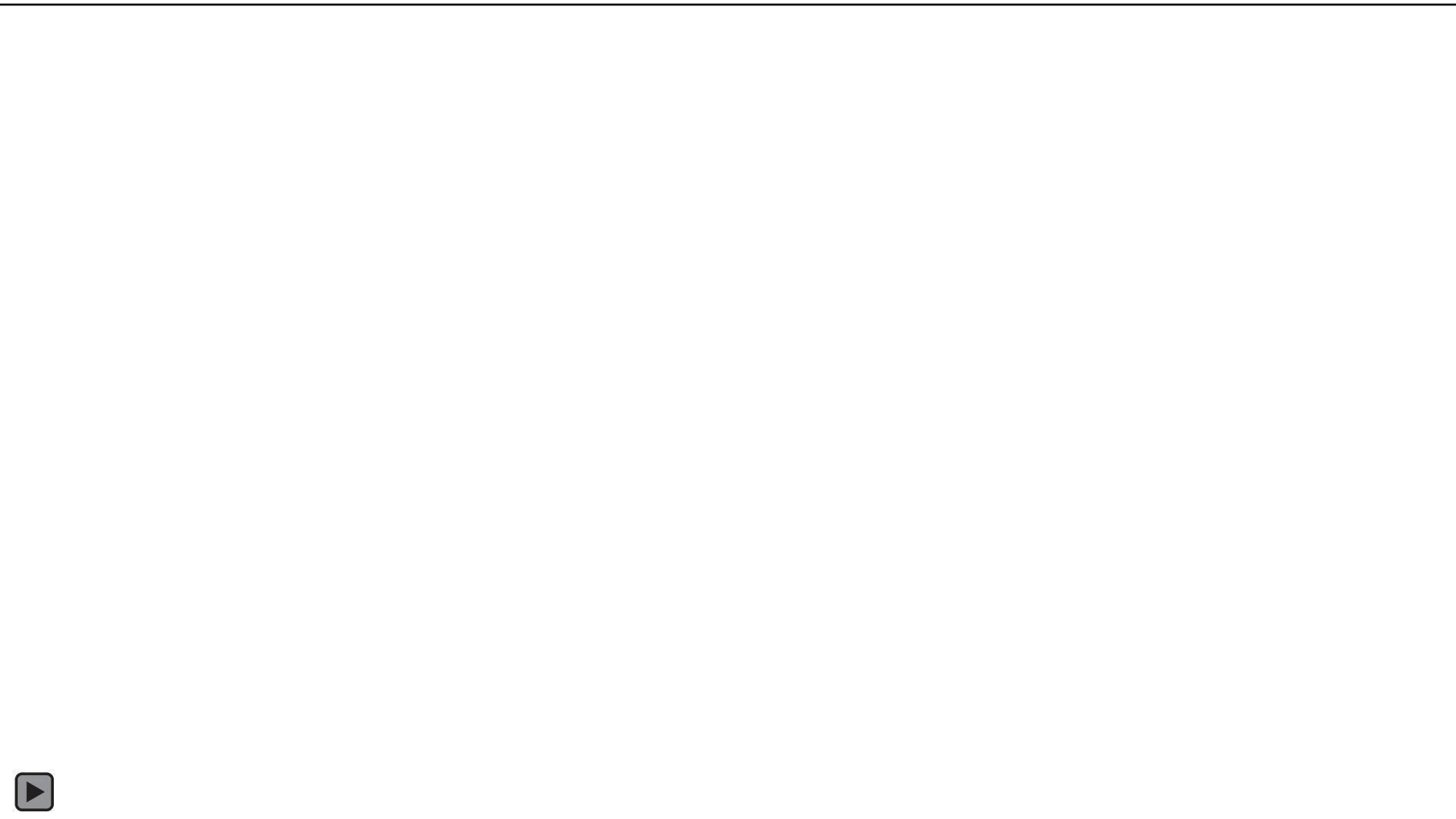


Earthquake Engineering: Post-Disaster Reconnaissance



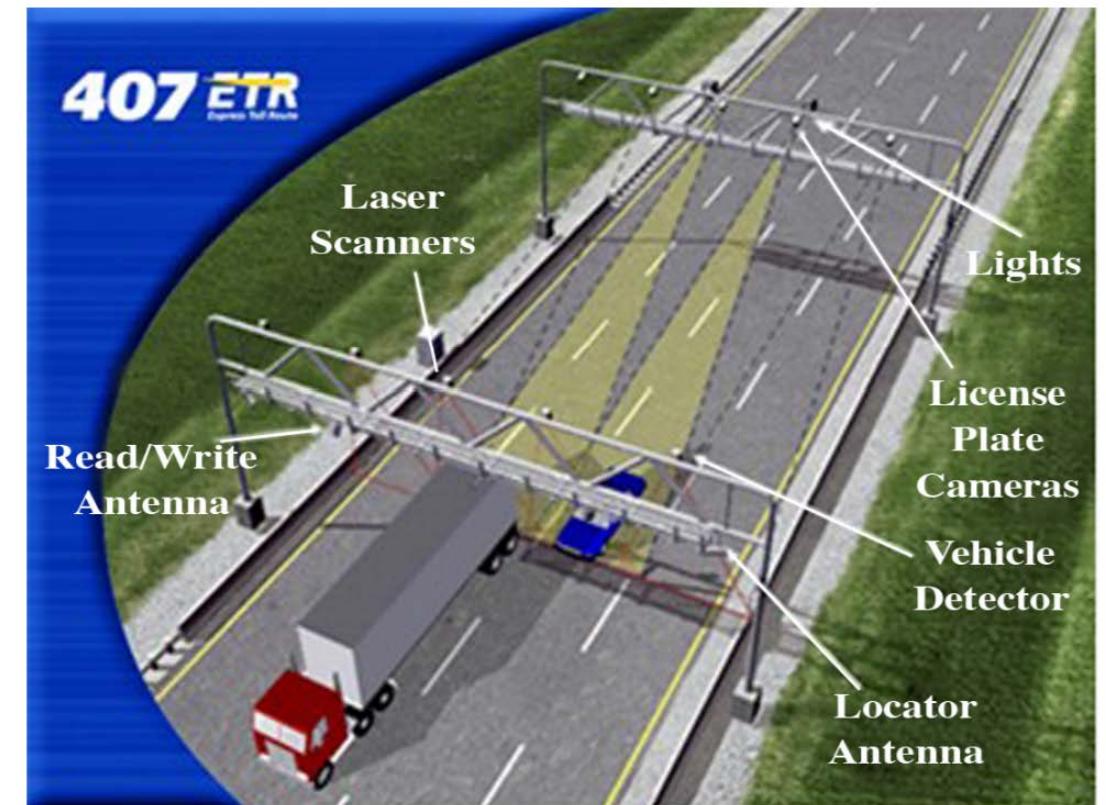
- Yeum, C. M., Dyke, S. J., Benes, B., Hacker, T., Ramirez, J., Lund, A., & Pujol, S. (2018). Postevent Reconnaissance Image Documentation Using Automated Classification. *Journal of Performance of Constructed Facilities*, 33(1), 04018103.
- <https://youtu.be/zNwoogoYQ7o>

Transportation Engineering: Vehicle Tracking / Counting



<https://www.youtube.com/watch?v= i4numqiv7Y&t=8s>

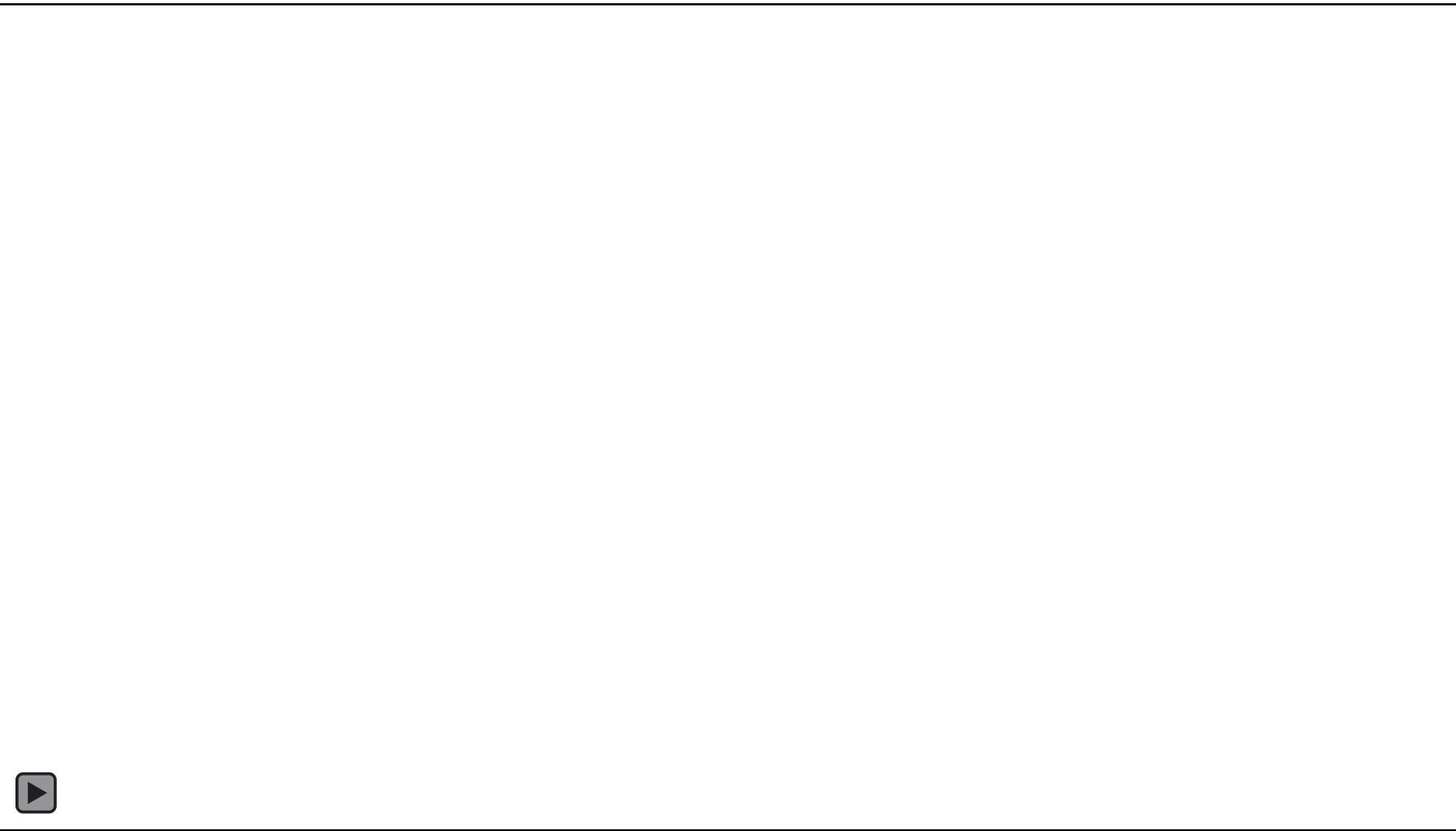
Transportation Engineering: License Plate Estimation



Transportation Engineering: Driver Distraction Monitoring

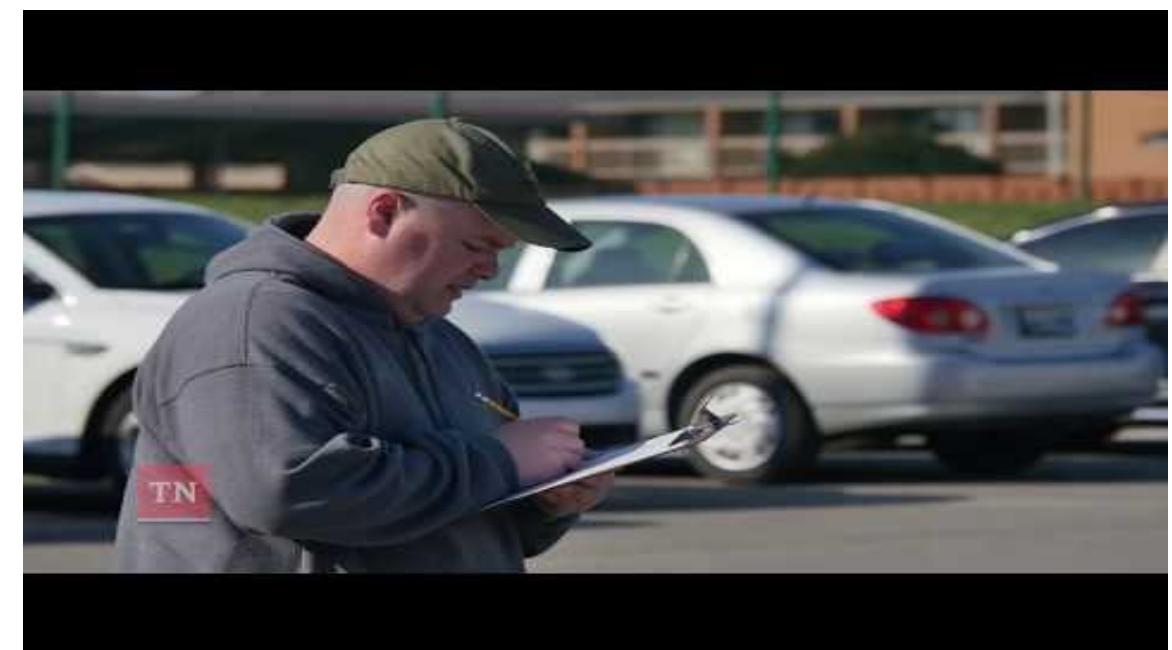
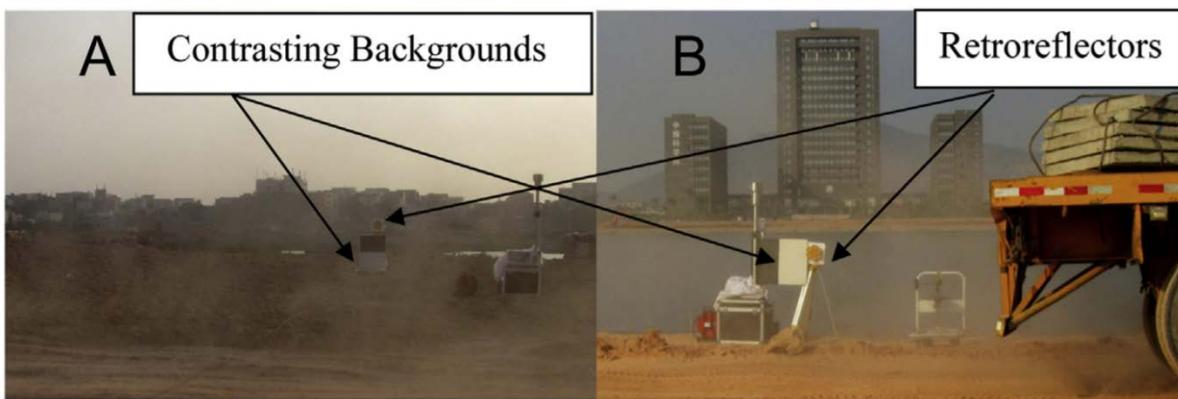
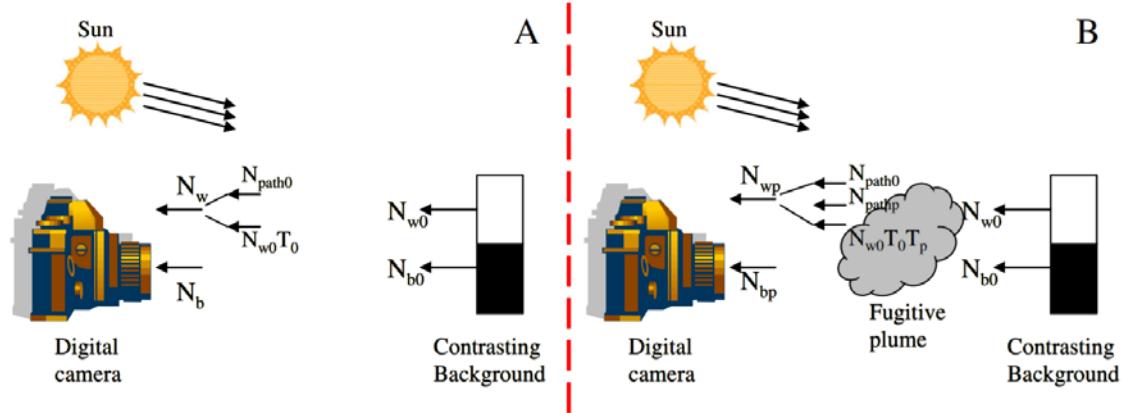


Environmental Engineering: Air Quality Monitoring (Breathe Cam)



- <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



Surveying: GeoSLAM ZEB-REVO



Smart Structures and Systems

