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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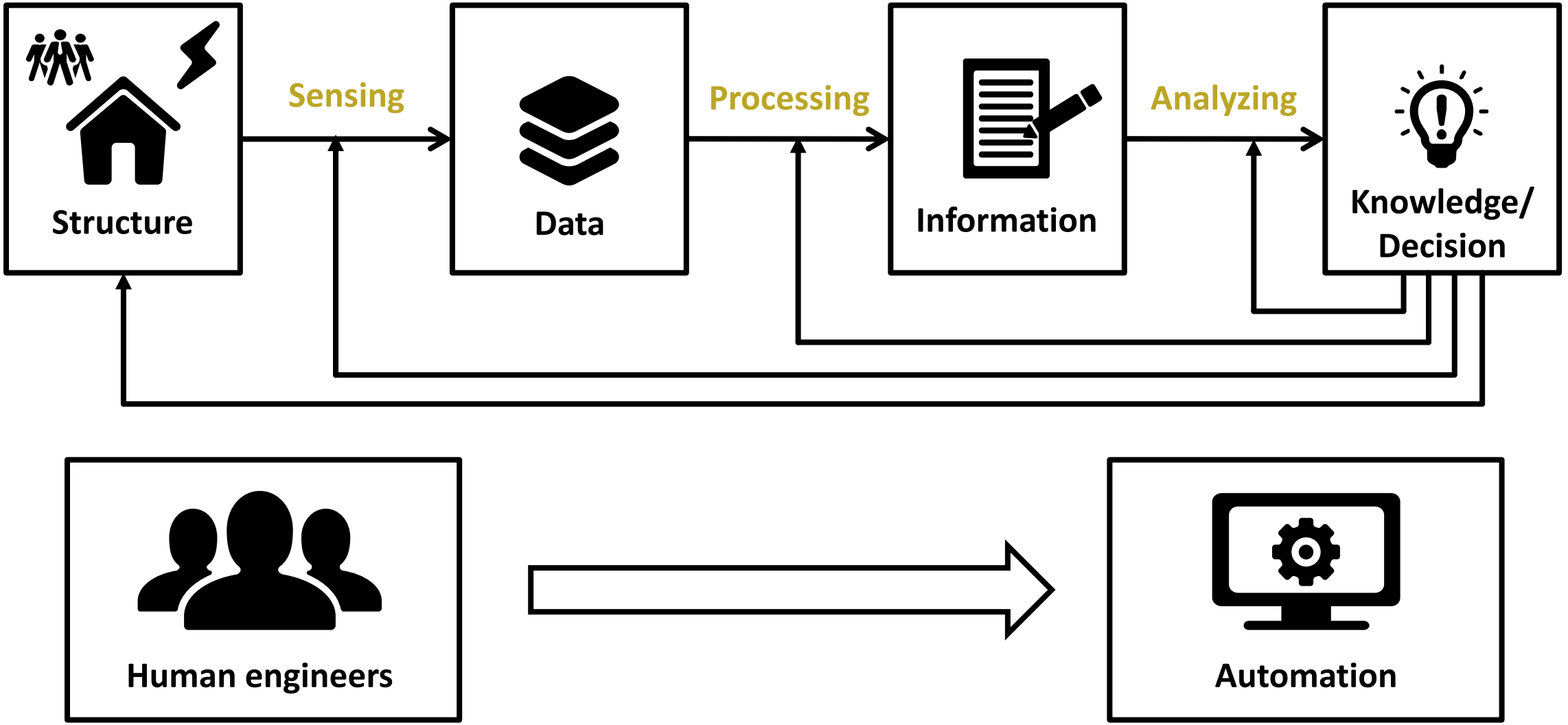
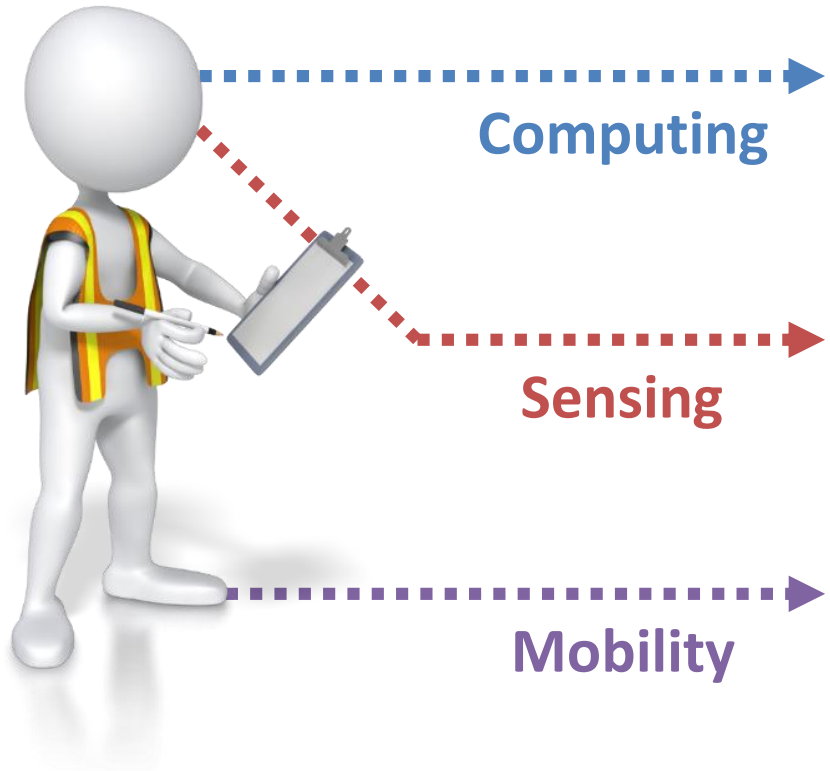
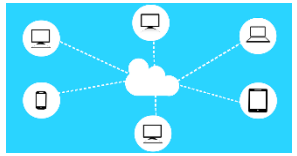
Smart Structures and Systems



Smart Sensing and Data Processing



Computing



Sensing

Mobility

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.

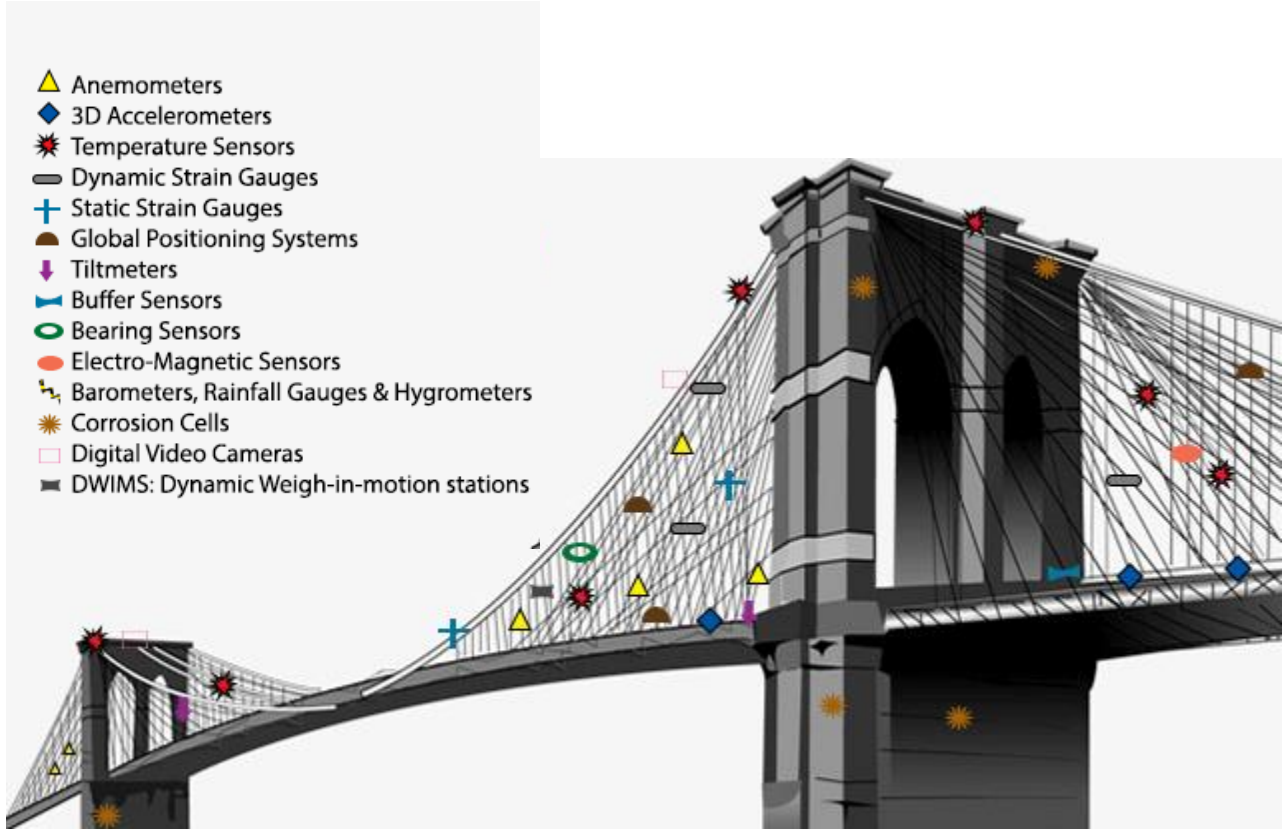
Motivations for Structural Health Monitoring

- 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**



Rytter, A. (1993). Vibrational based inspection of civil engineering structures
https://www.vackergroup.ae/our-products/monitoring-systems/structural-health-monitoring/

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)
  - 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

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 interactive with objects.


GPS

Camera

Accelerometer


Thermometer


Interac


Stethoscope


Smoke detector


IR-camera

Passive sensor


Scanner


Ultrasound


Laser scanner


Camera + flash


X-ray

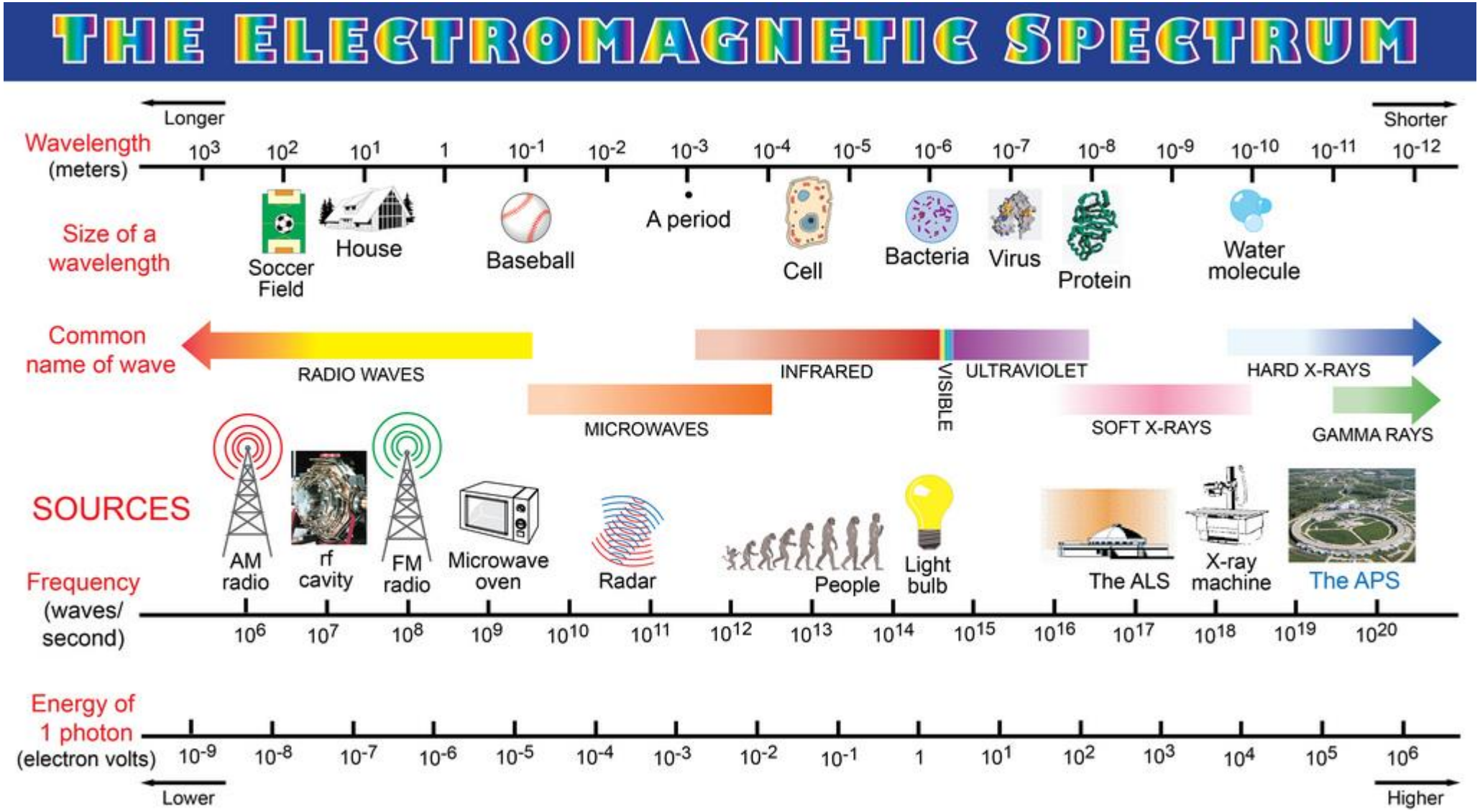
Measuring laser

Kinect


Thermometer

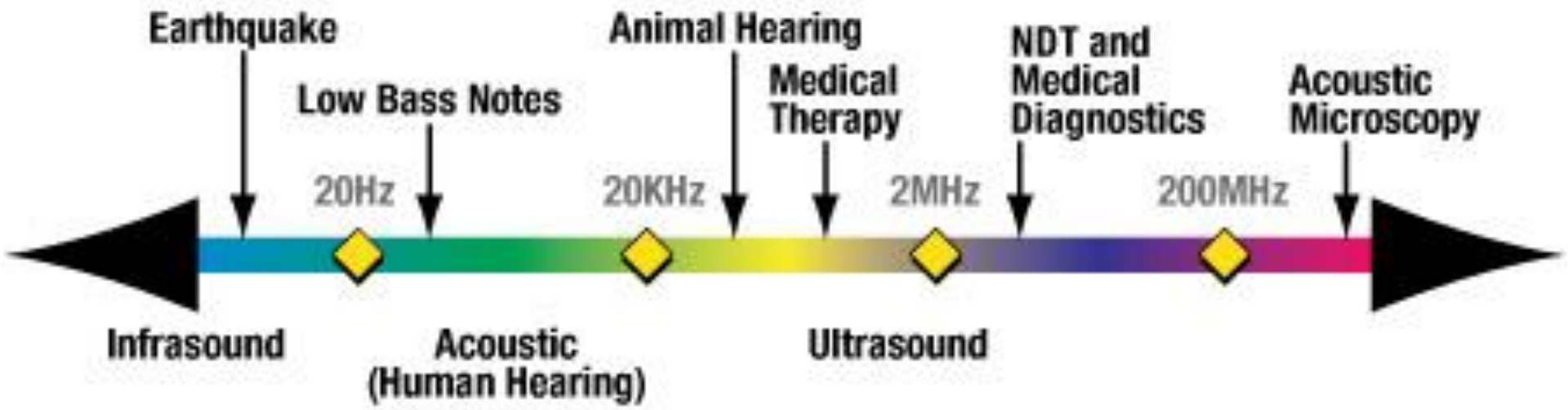
Active sensor

Electromagnetic Spectrum



https://www.flickr.com/photos/advancedphotonsource/5940581568

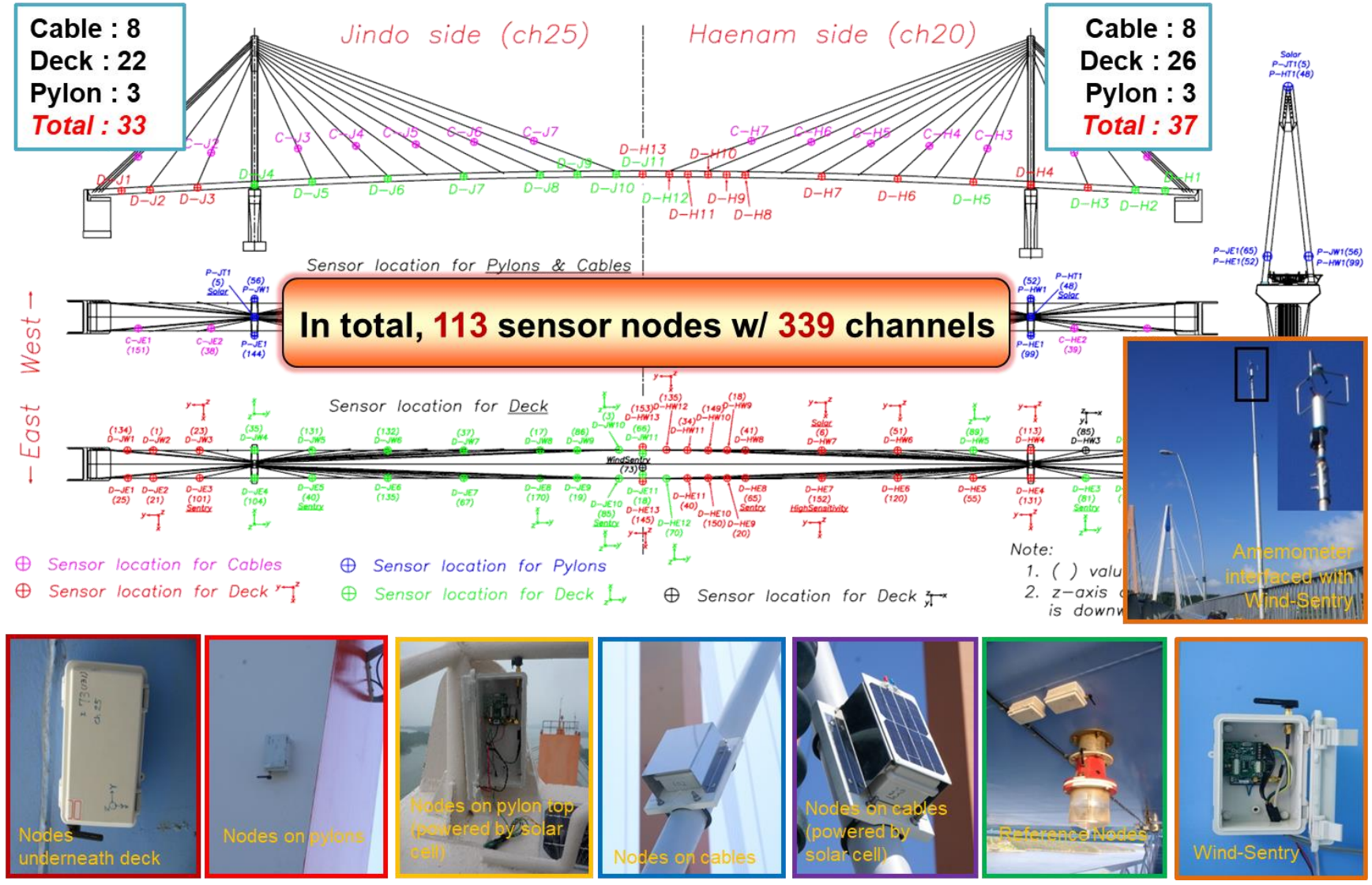
Mechanical Vibration



https://www.olympus-ims.com/en/ndt-tutorials/flaw-detection/ultrasound/

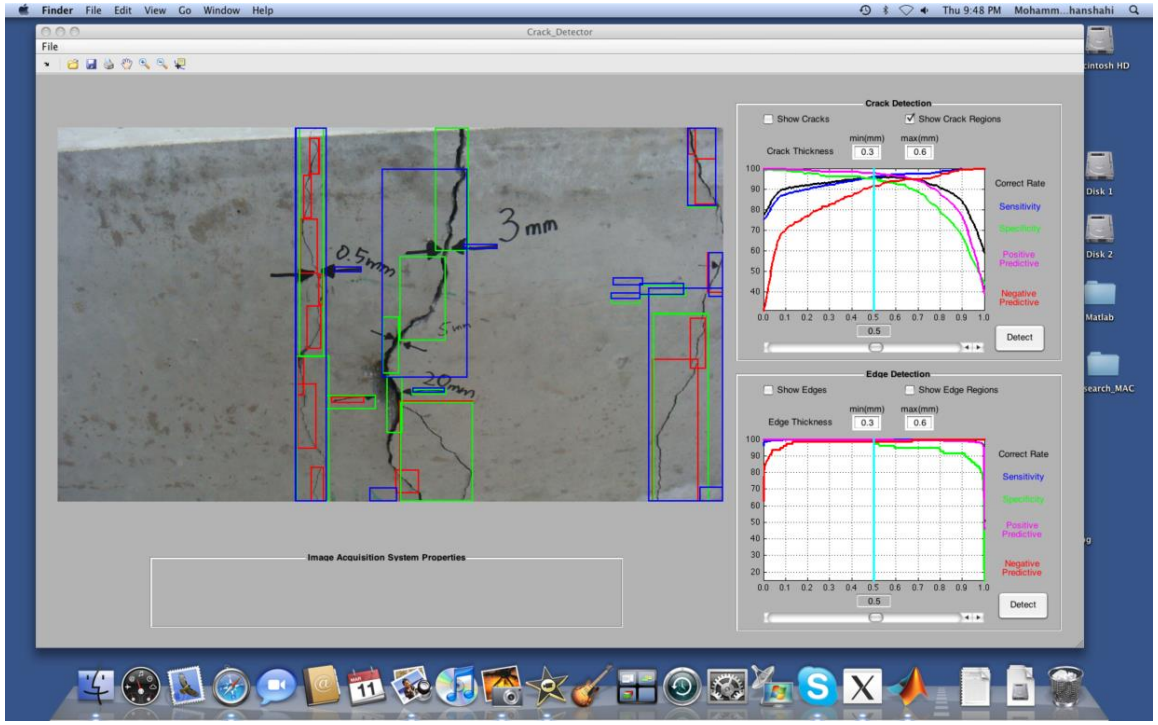
Applications of Smart Structure Technology in Civil Engineering

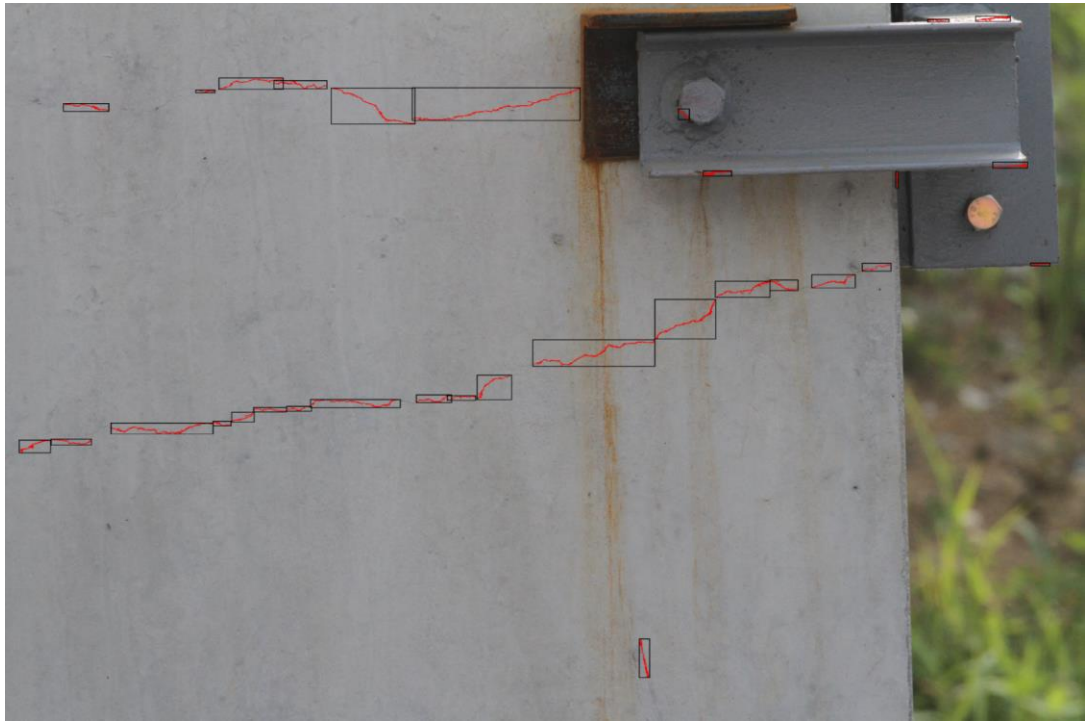
Structural Engineering: Wireless Monitoring of a Cable-Stayed Bridge



Cho, S., Jo, H., Jang, S., Park, J., Jung, H. J., Yun, C. B., ... & Seo, J. W. (2010). Structural health monitoring of a cable-stayed bridge using wireless smart sensor technology: data analyses. Smart Structures and Systems, 6(5-6), 461-480.

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

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

Structural Engineering: Visual Inspection – Façade Inspection using UAVs

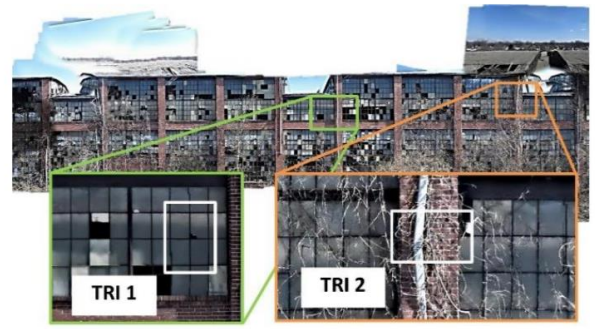


Figure 7. Selection of two sample TRIs (TRI 1 and TRI 2) on the orthophoto.

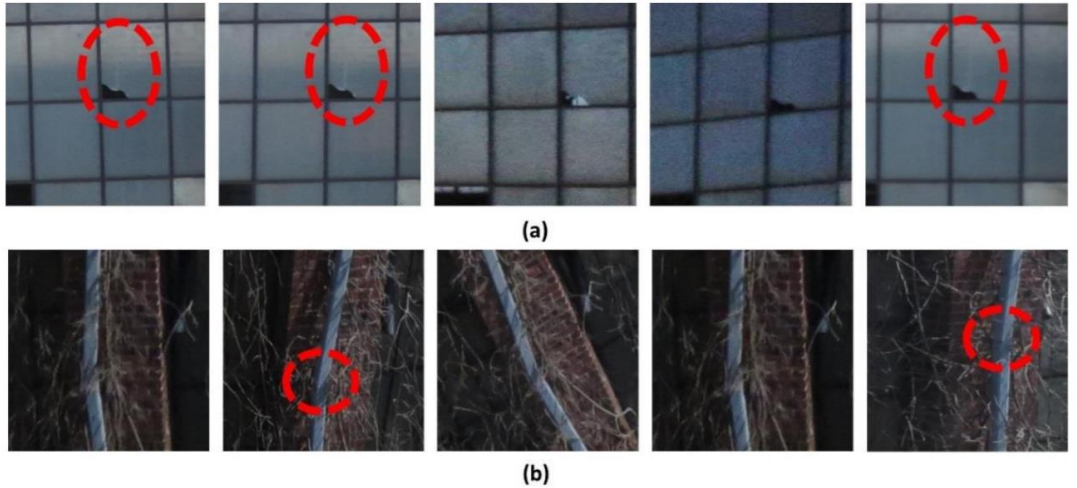
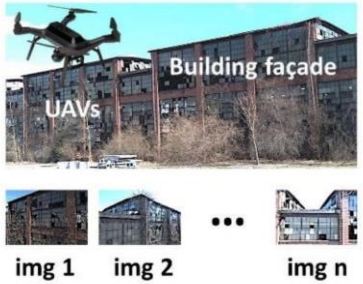
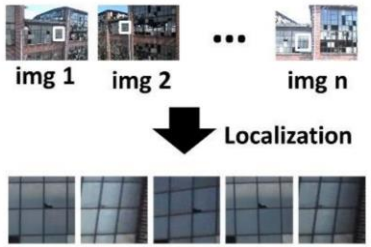


Figure 8. Localized ROIs corresponding to TRI 1 in (**a**) and TRI 2 in (**b**): The hairline vertical crack on a window pane in TRI 1 and damage on a drainage pipe in TRI 2 are only visible in specific ROIs and those damage locations are marked with a red dotted line.



Step 1. Image collection

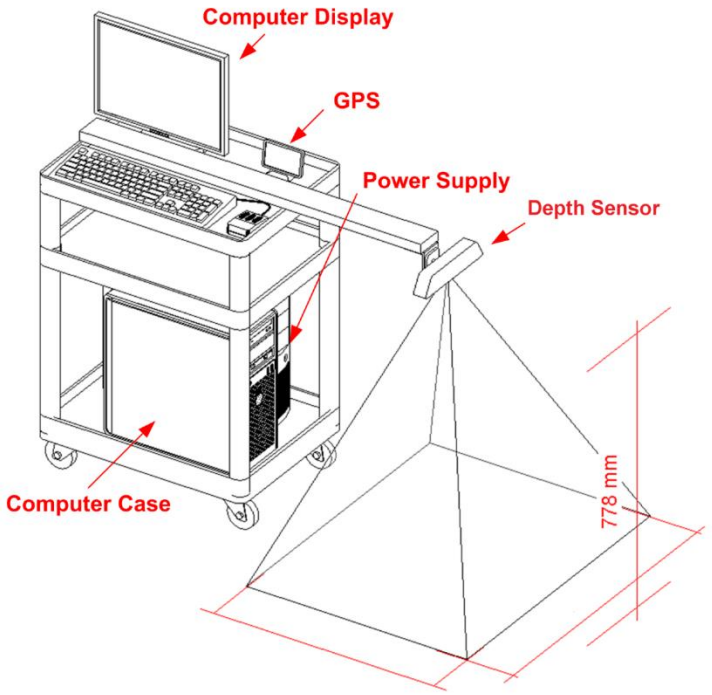
Step 2. Orthophoto generation



Step 3. ROI localization

Choi, J., Yeum, C., Dyke, S., & Jahanshahi, M. (2018). Computer-aided approach for rapid post-event visual evaluation of a building façade. Sensors, 18(9), 3017.

Structural Engineering: Visual Inspection – 3D Pavement Inspection



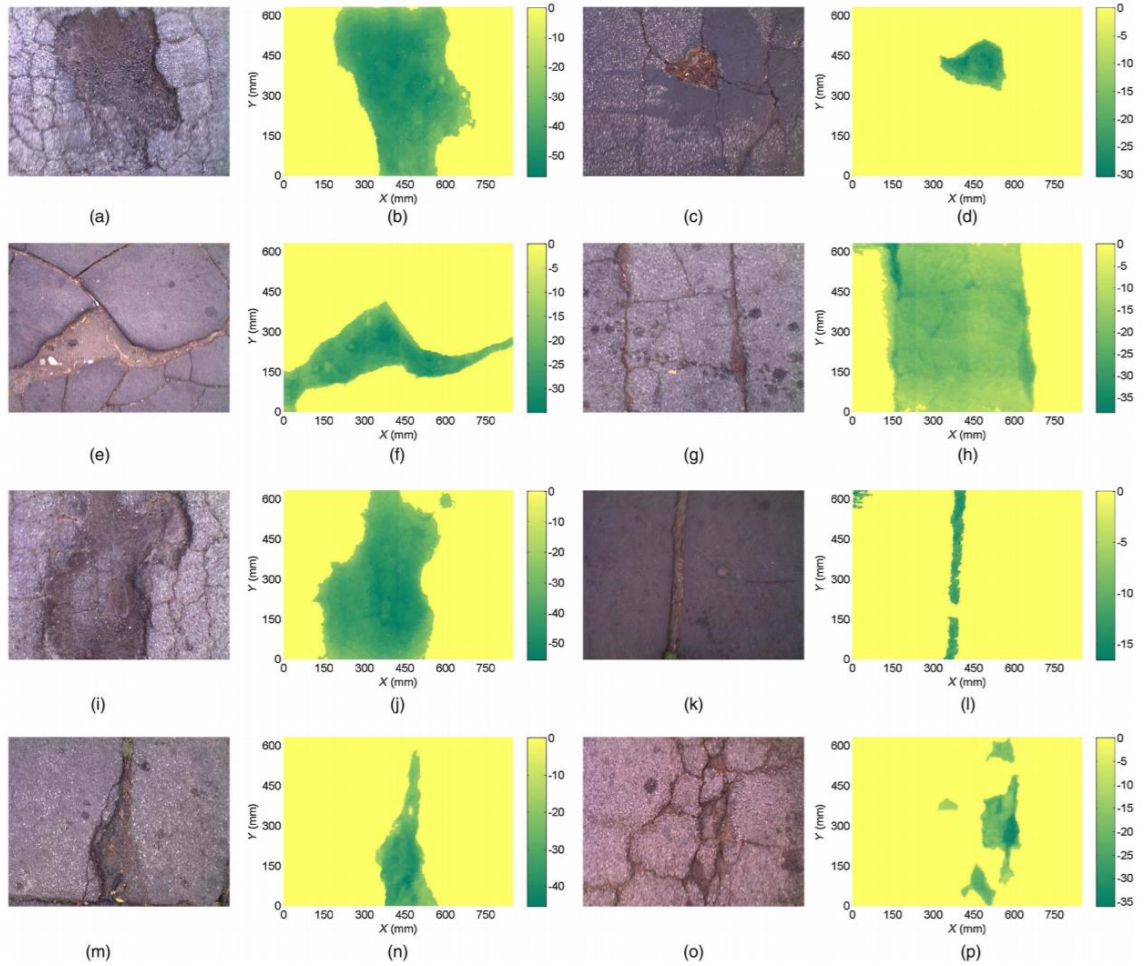
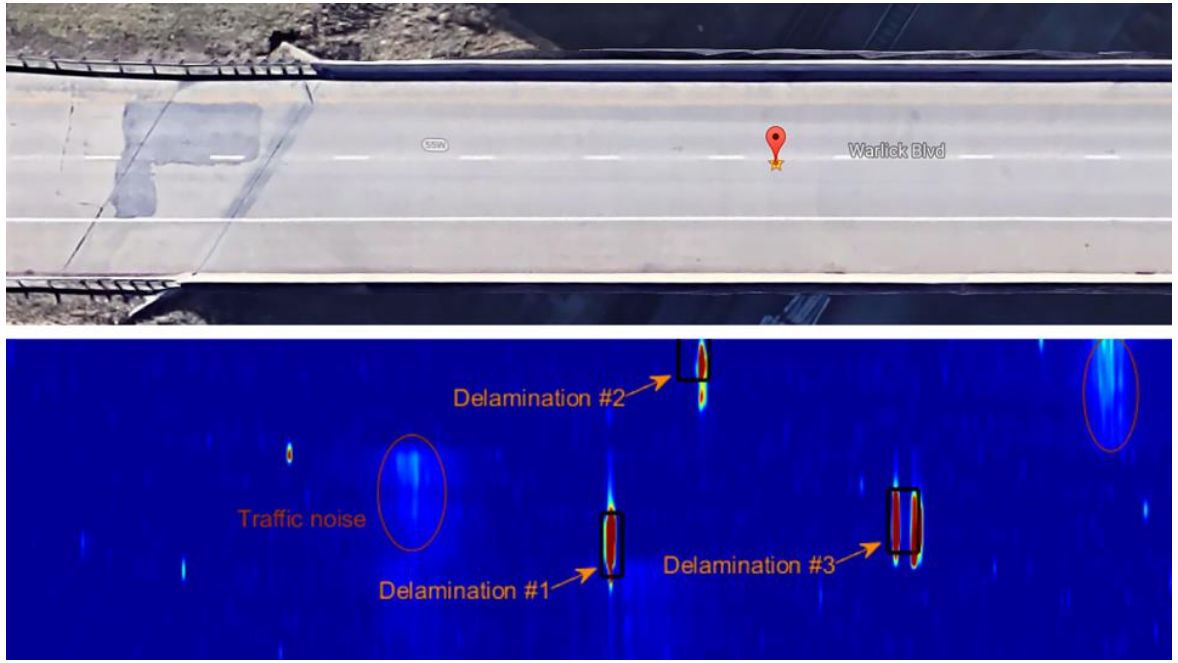


Fig. 6. Defect detection and depth quantification: (a), (c), (e), (g), (i), (k), (m), and (o) are the images of the defects, and (b), (d), (f), (h), (j), (l), (n) and (p) are the corresponding depth maps, respectively

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

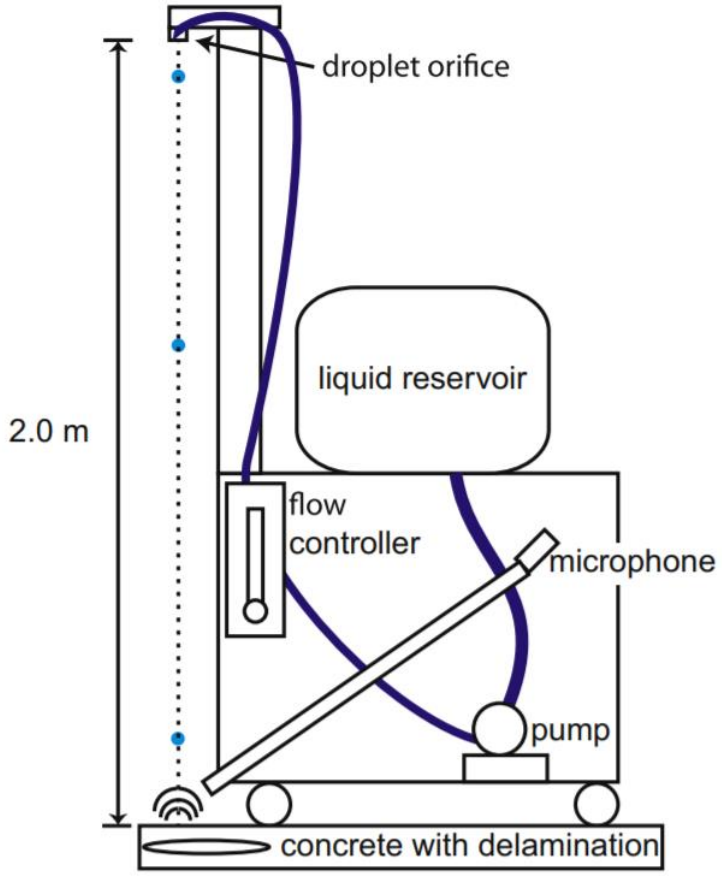


https://go.unl.edu/ic7w

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

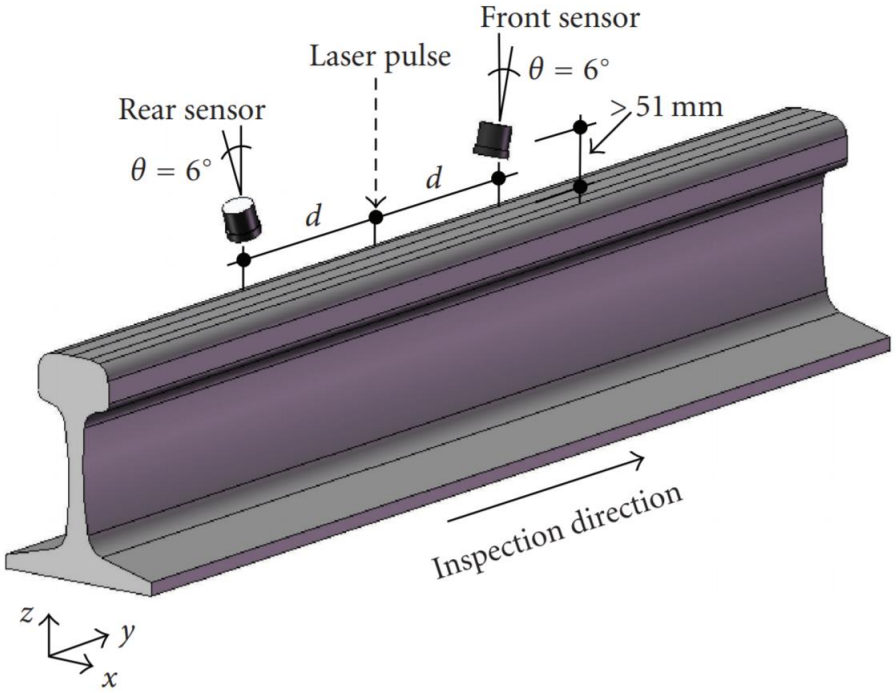
Structural Engineering: Robotic for Structural Assessment

https://youtu.be/YCihWIBIGZ8

Structural Engineering: Video Surveillance of Vehicle Clearance

https://www.youtube.com/yovo68

Structural Engineering: Rail Inspection using Non-contact Ultrasonic Transducers



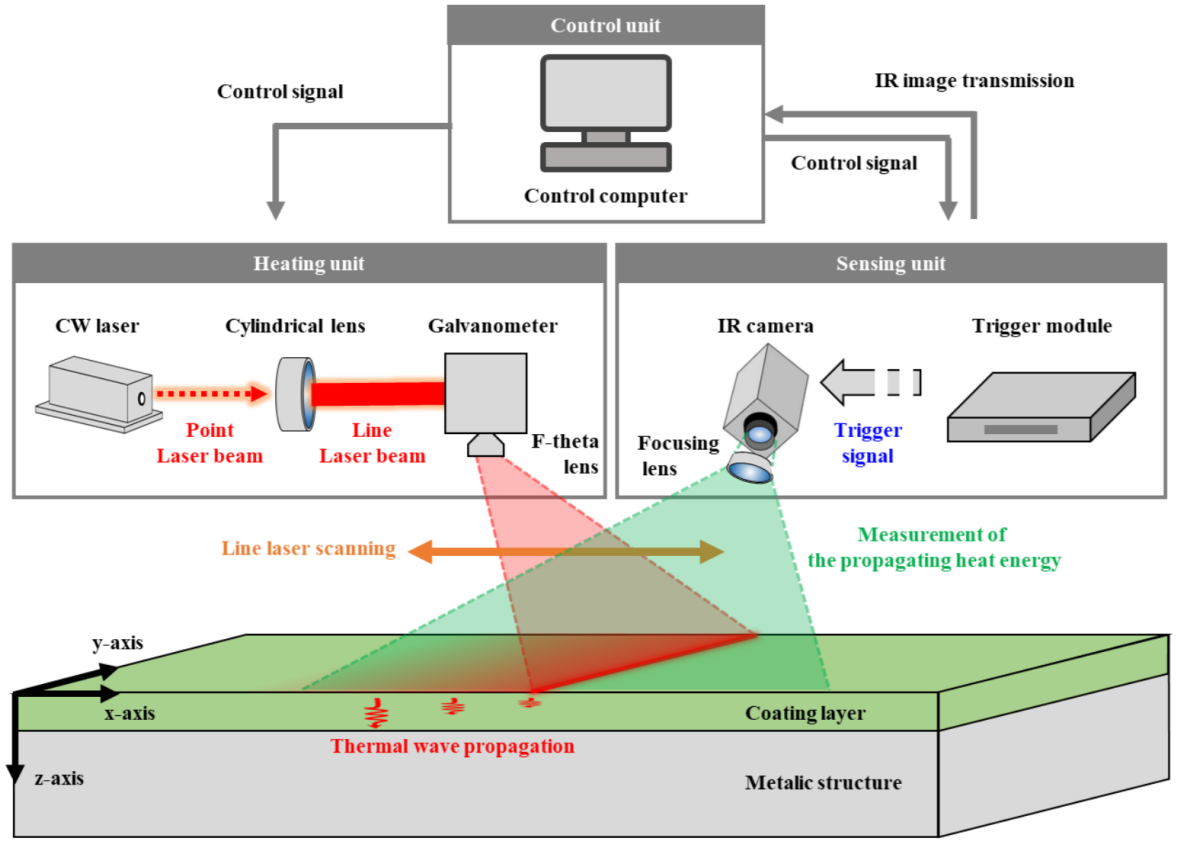
(a) (b)

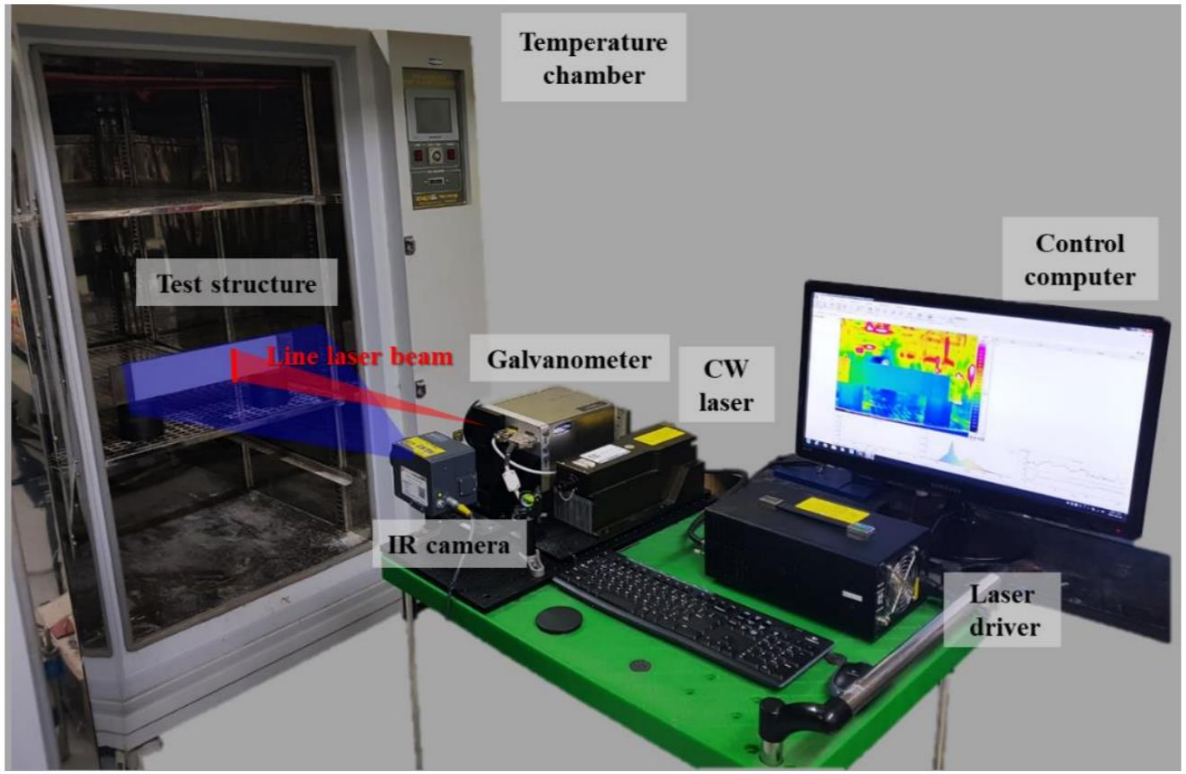
IGURE 10: (a) Test site near Gettysburg, Pennsylvania. (b) Photo of the latest inspection prototype tested in the field.

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

Rizzo, P., Cammarata, M., Bartoli, I., di Scalea, F. L., Salamone, S., Coccia, S., & Phillips, R. (2010). Ultrasonic guided waves-based monitoring of rail head: laboratory and field tests. *Advances in Civil Engineering*, *2010*.

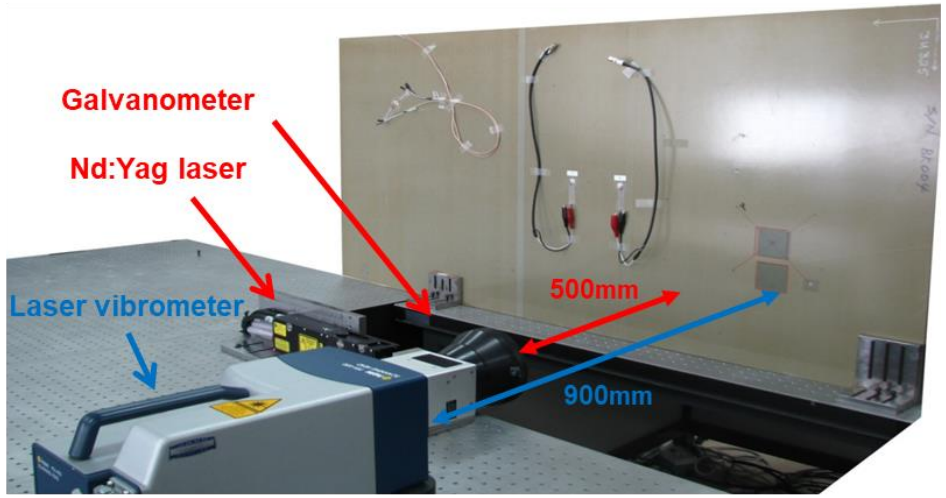
Structural Engineering: Coating Thickness Quantification using Laser Thermography



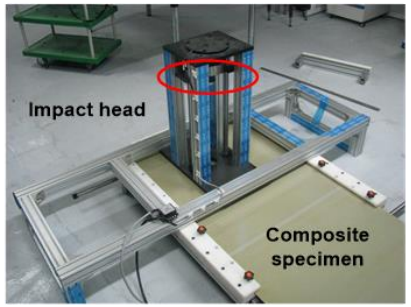


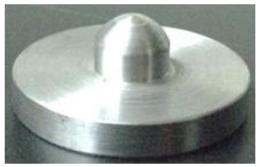
Hwang, S., Park, J., Jin, Z., & Sohn, H. Reference-free Coating Thickness Quantification using Laser Thermography under Various Exterior Temperature Conditions.

Structural Engineering: Delamination Detection using Piezoelectric Sensors

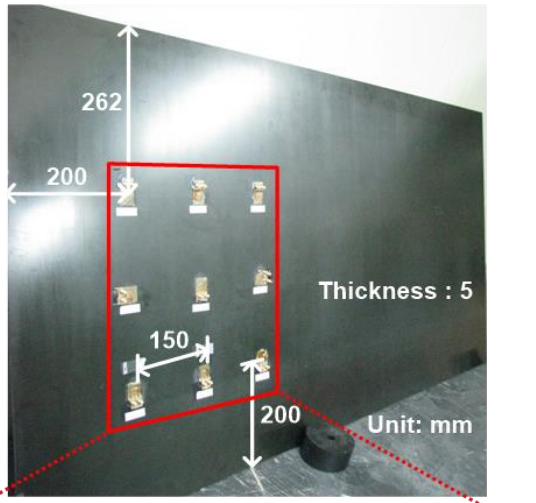


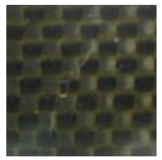
Low velocity impact test



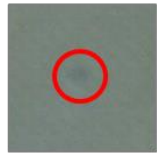


A low velocity impact with a 1cm radius steel cone-shape tip is used to produce delamination.

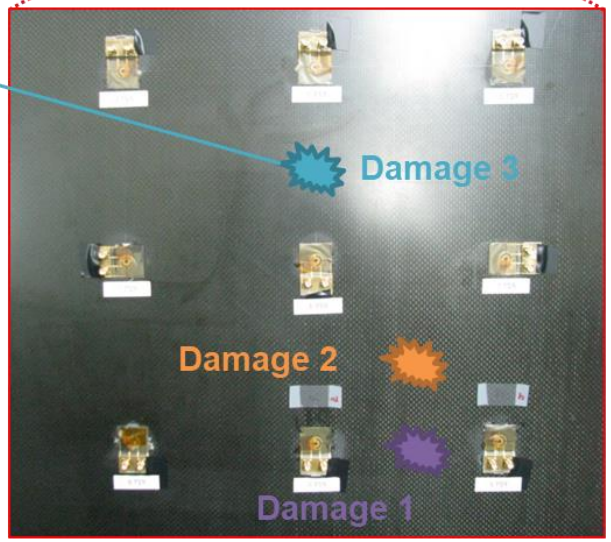




Back side

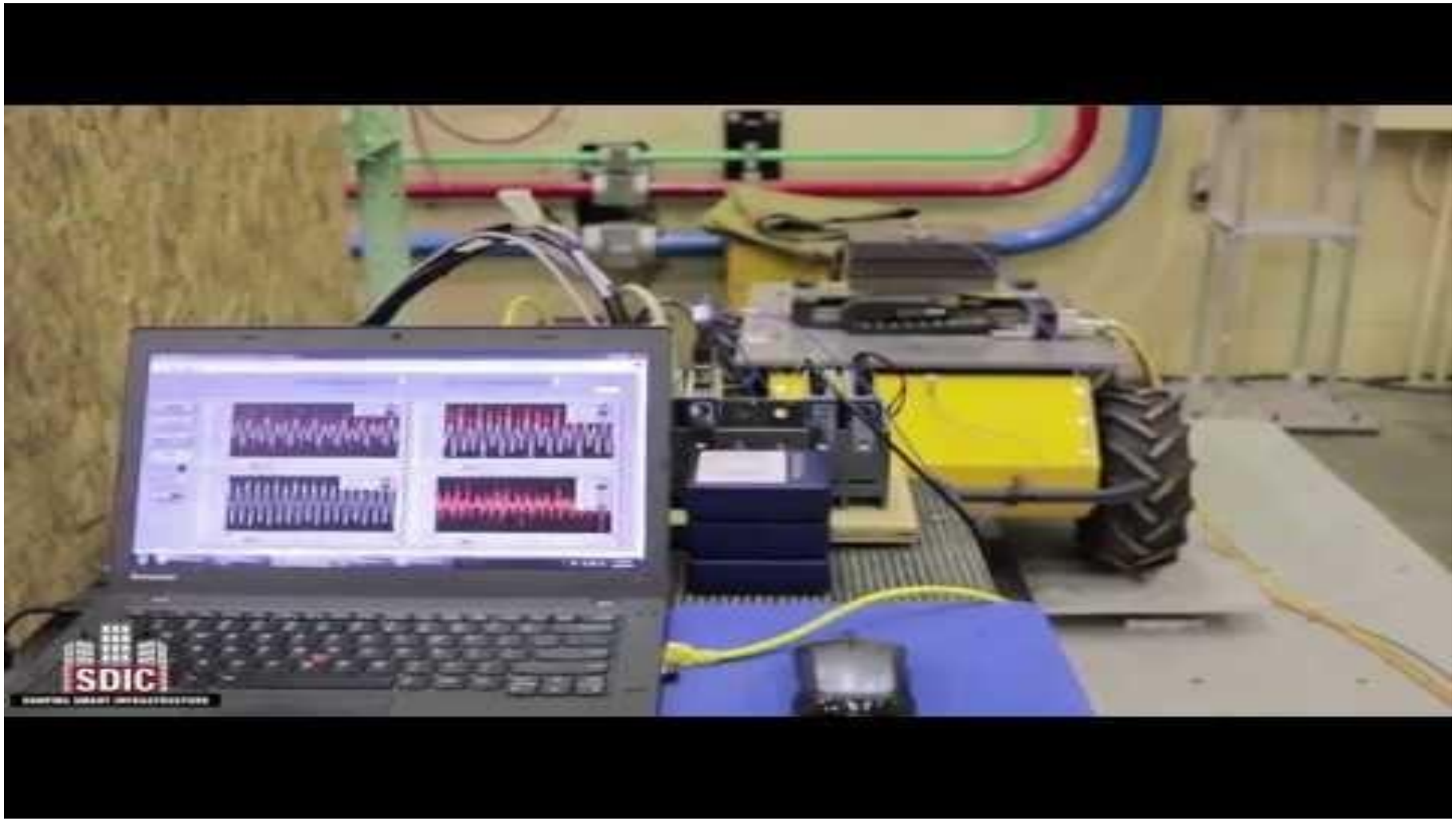


Scanned side (Impact side)



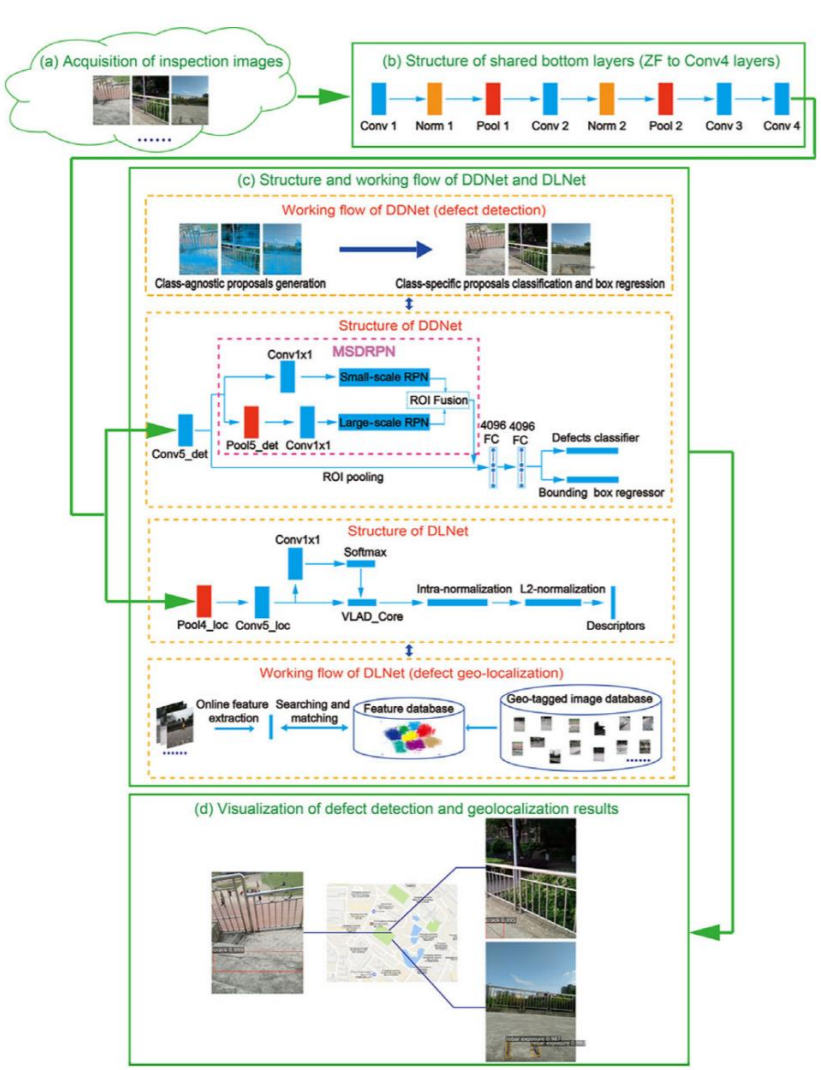
Yeum, C. M., Sohn, H., & Ihn, J. B. (2011, March). Delamination detection in a composite plate using a dual piezoelectric transducer network. In Health Monitoring of Structural and Biological Systems 2011 (Vol. 7984, p. 798406).

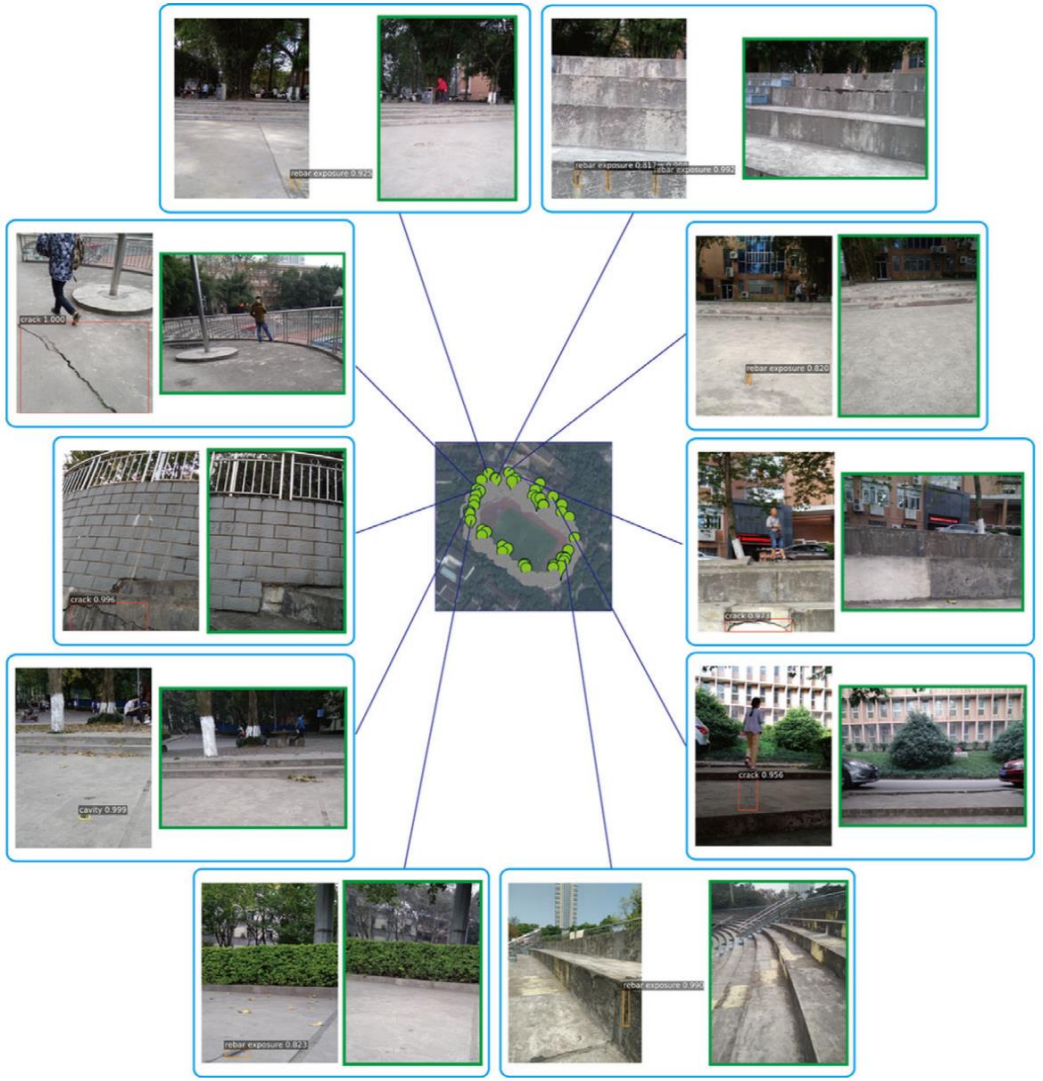
Structural Engineering: Autonomous Vehicle for Structural Control and Assessment



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

Structural Engineering: Image Registration





Li, R., Yuan, Y., Zhang, W., & Yuan, Y. (2018). Unified Vision-Based Methodology for Simultaneous Concrete Defect Detection and Geolocalization. Computer-Aided Civil and Infrastructure Engineering.

Structural Engineering: Crowdsourcing to Enable Lifecycle Infrastructure

https://www.youtube.com/watch?v=xaHyl8qYd64

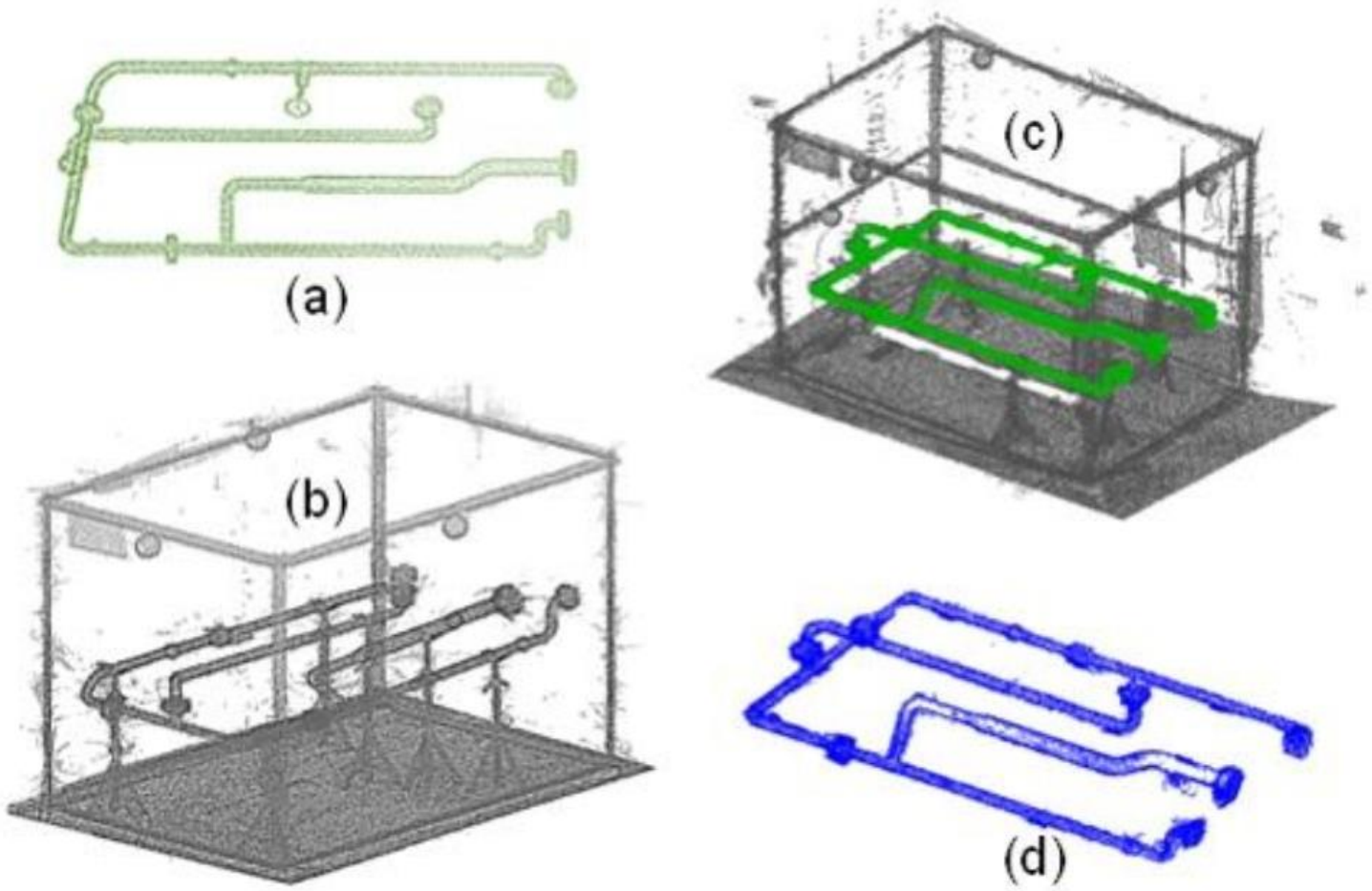
Material Engineering: Self-Healing Concrete

https://www.youtube.com/watch?v=eN-vJB7yeJI

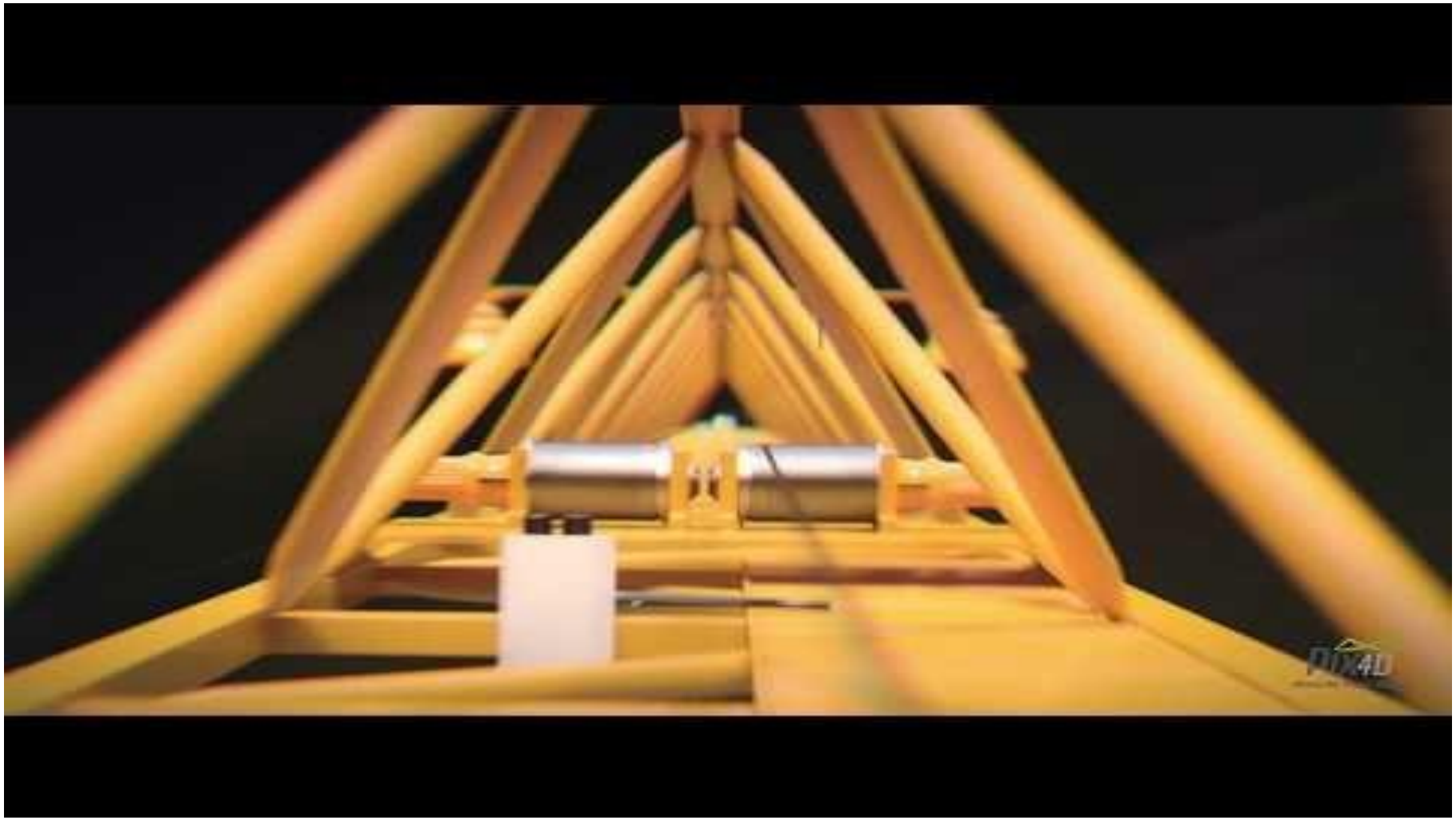
Material Engineering: Shape Alloy

https://youtu.be/-K57cbOhA5g

Construction Engineering: Automated Construction State Estimation



Construction Engineering: Crane Camera Solution (Pix4D)

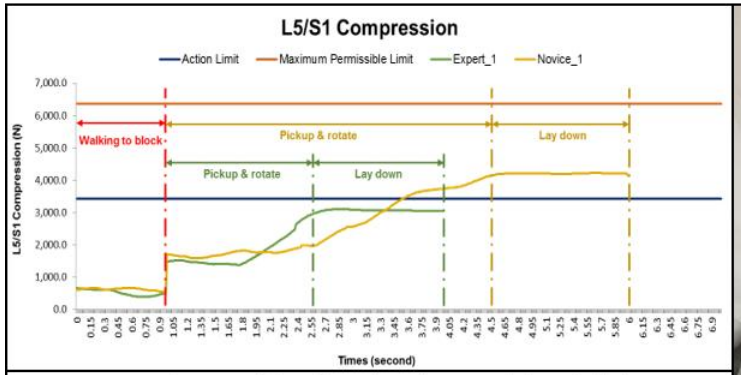


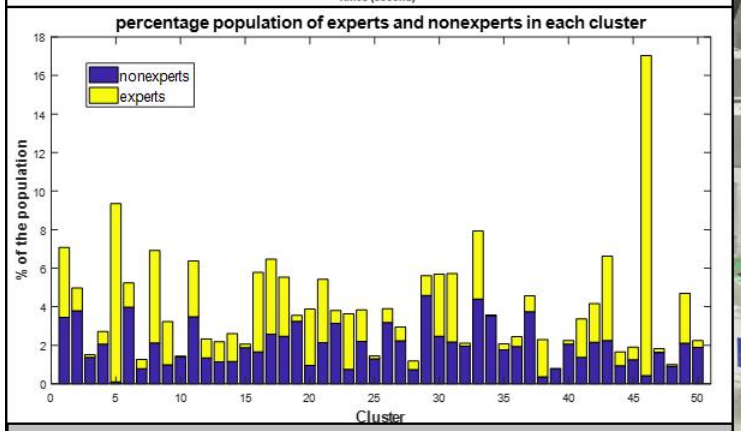
https://youtu.be/wZazAliljKw

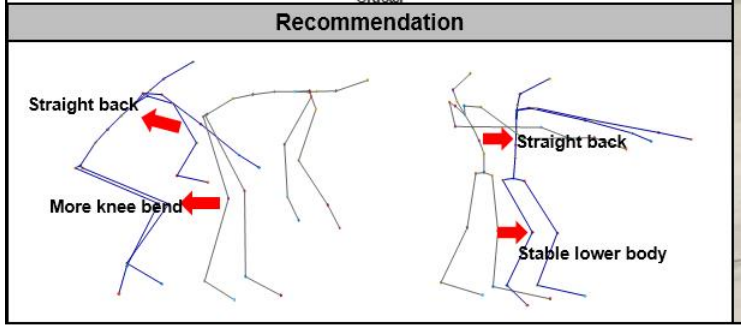
Construction Engineering: Action Recognition in Construction Sites

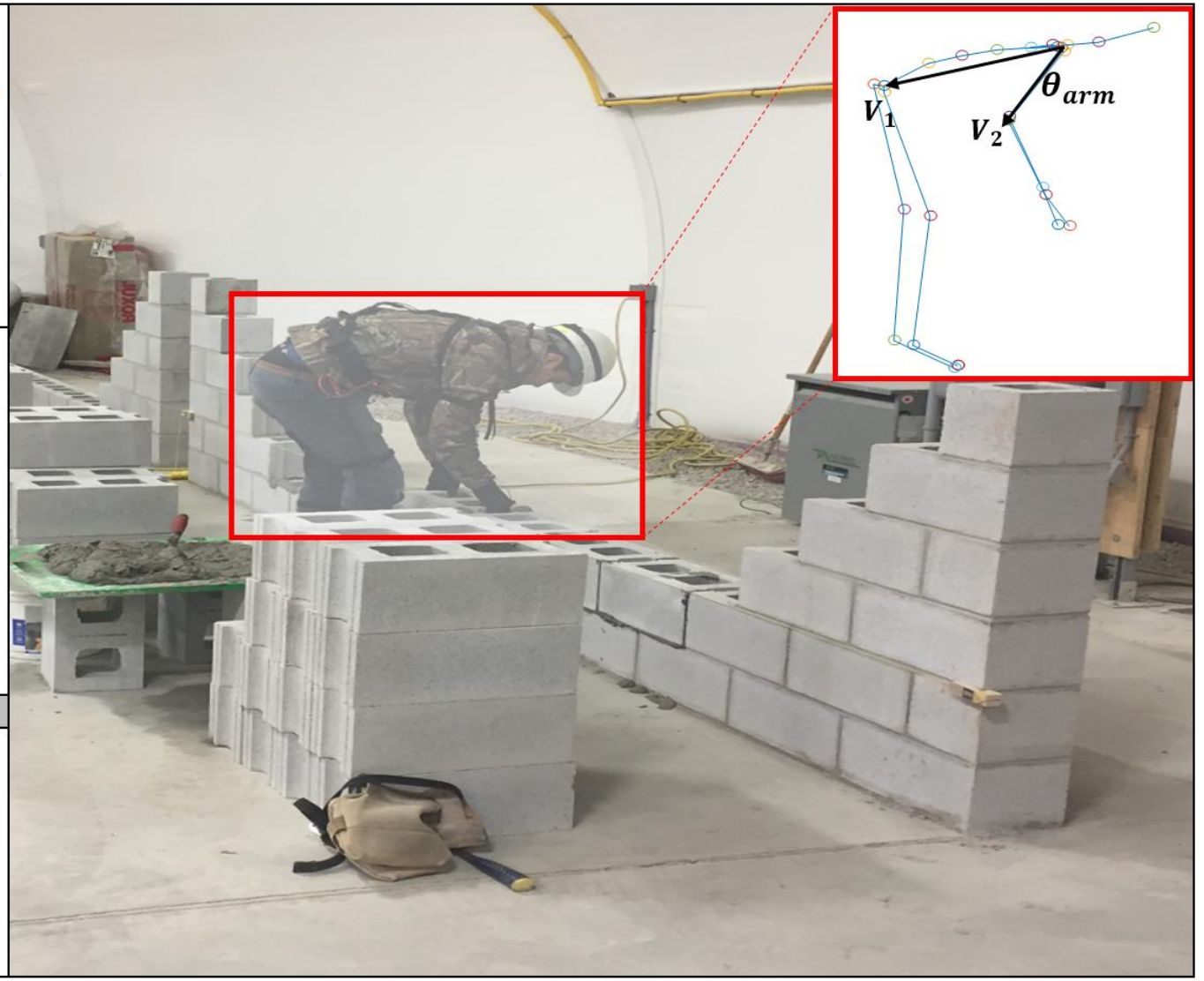
Golparvar-Fard, M., Heydarian, A., & Niebles, J. C. (2013). Vision-based action recognition of earthmoving equipment using spatio-temporal features and support vector machine classifiers. *Advanced Engineering Informatics*, *27*(4), 652–663.

Construction Engineering: Craft Worker Health and Productivity Improvement









https://uwaterloo.ca/scholar/chaas/research

Earthquake Engineering: Social Media Data Analysis

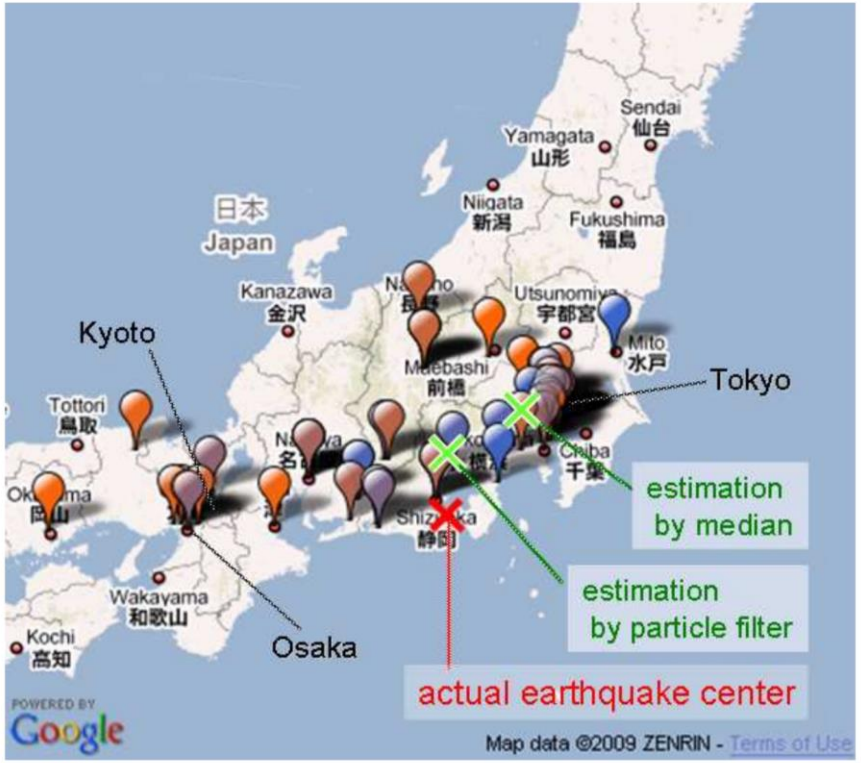
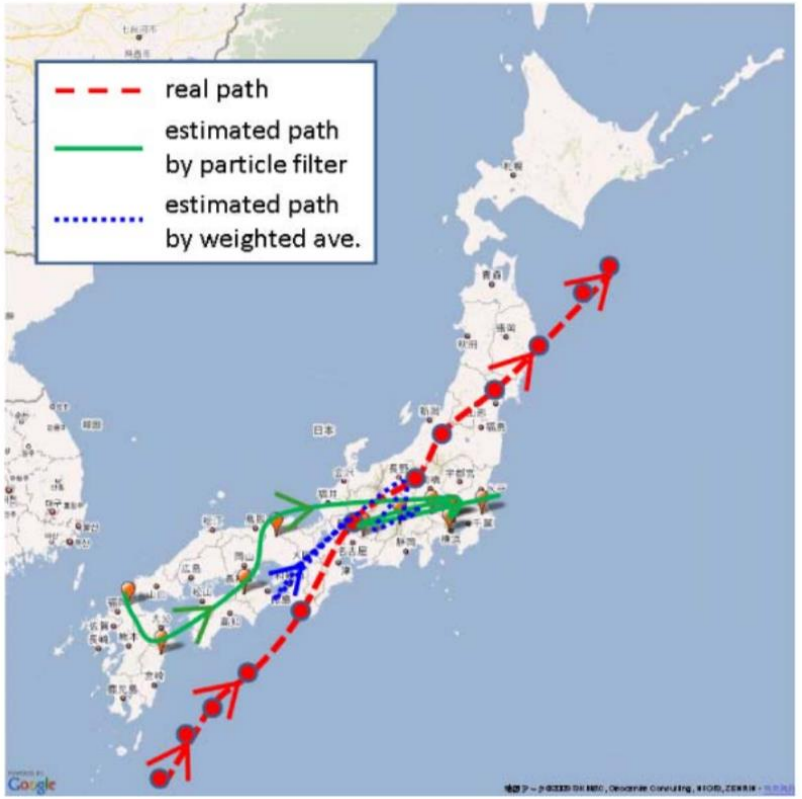


Figure 9: Earthquake location estimation based on tweets. Balloons show the tweets on the earthquake. The cross shows the earthquake center. Red represents early tweets; blue shows later tweets.

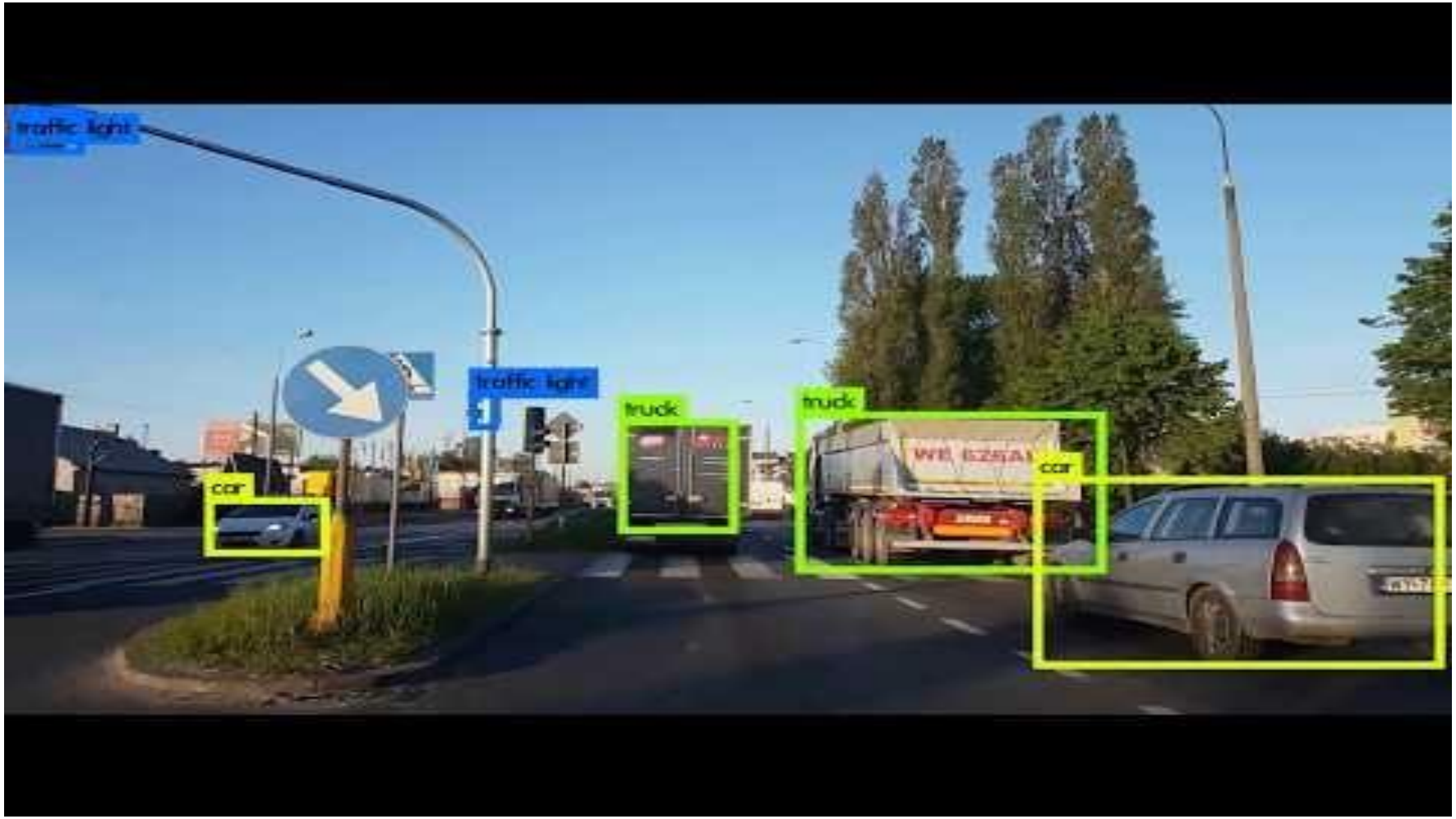


Sakaki, T., Okazaki, M., & Matsuo, Y. (2013). Tweet Analysis for Real-Time Event Detection and Earthquake Reporting System Development. IEEE Transactions on Knowledge and Data Engineering, 25(4), 919–931.

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/aKIj7sRVBv8

Transportation Engineering: Vehicle Tracking / Counting



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

Transportation Engineering: Autonomous Vehicle

https://youtu.be/xsQvq4WlUYU

Transportation Engineering: License Plate Estimation

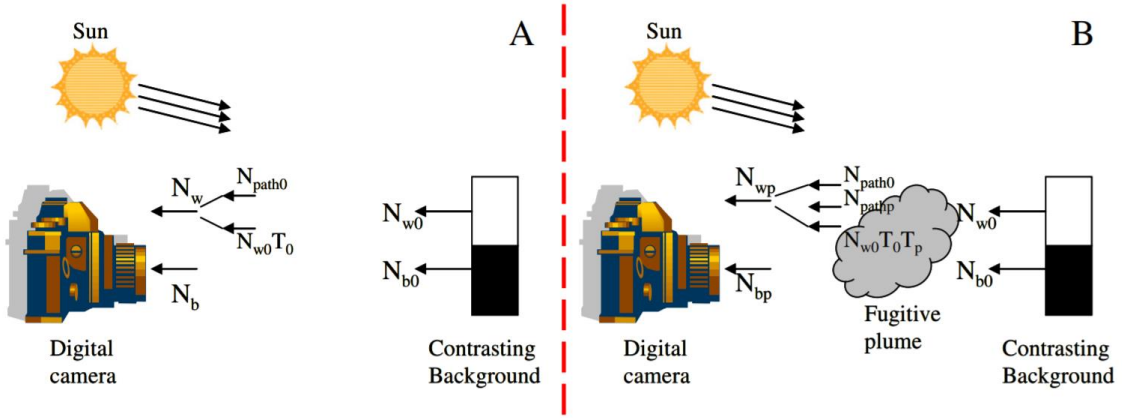
Transportation Engineering: Driver Distraction Monitoring

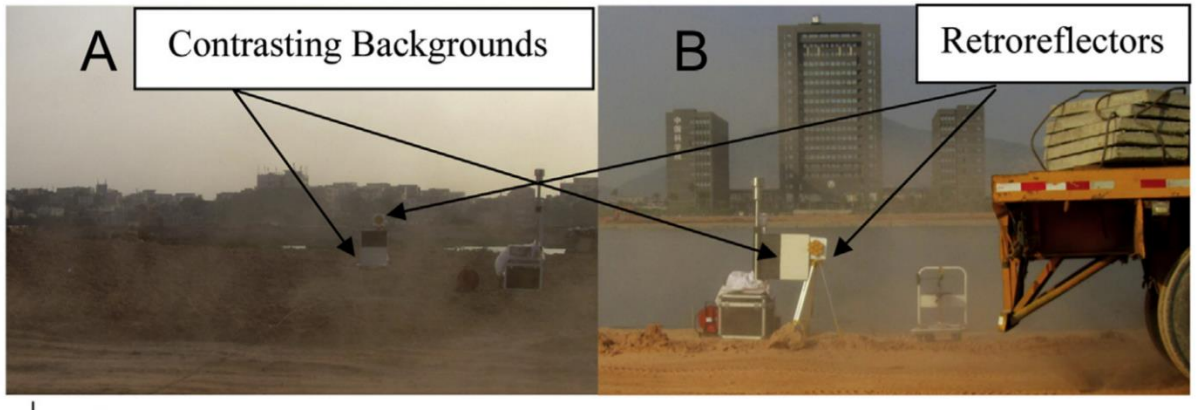
https://www.youtube.com/watch?v=ImAlBVLXiBA

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

Du, Ke, et al. "Digital Optical Method to quantify the visual opacity of fugitive plumes." *Atmospheric environment* 77 (2013): 983-989.

Environmental Engineering: Assessment of Water Distribution Networks

https://youtu.be/uVMzonvlIVU

Surveying: Photogrammetry

https://youtu.be/uZ5KIgQmJ9w

Surveying: Mobile Mapping Solution

https://youtu.be/52x1N7U0EAk

Surveying: GeoSLAM ZEB-REVO

GeoSLAM: All-in-one Mobile Scanning Device: https://youtu.be/czqVuoubADo

Smart Structures and Systems