Introduction of Smart Structure Technology

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CIVE 497 – CIVE 700: Smart Structure Technology

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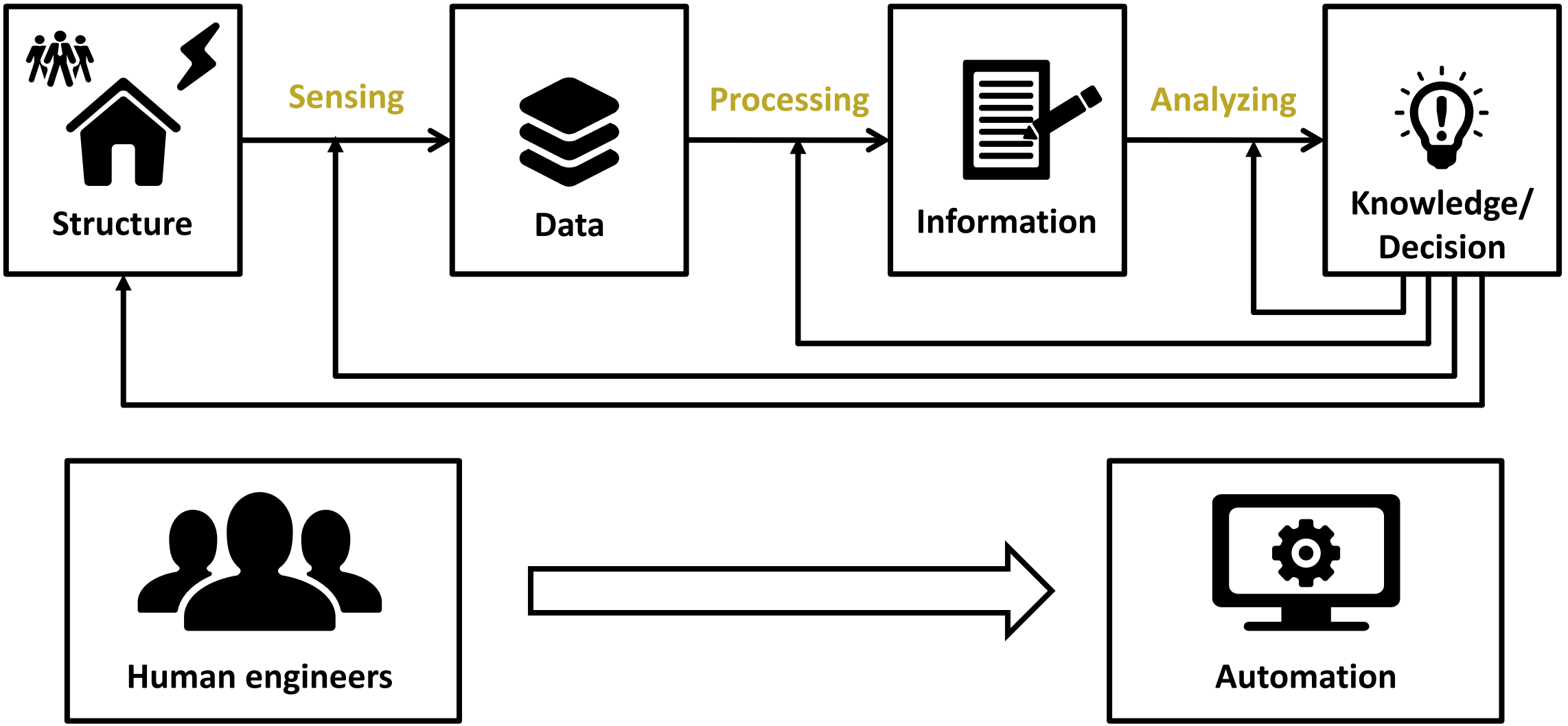
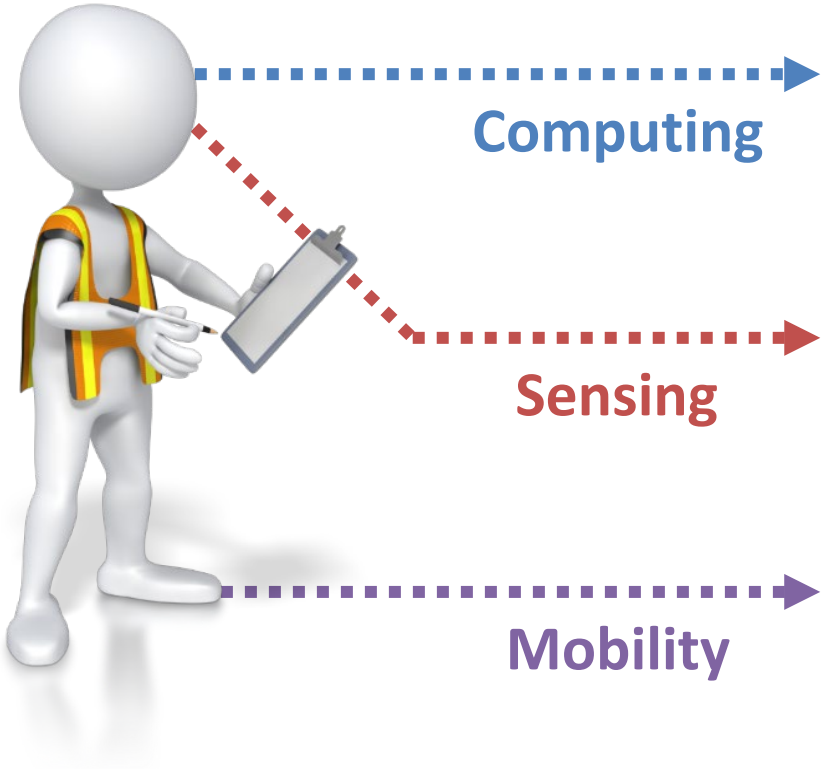
UNIVERSITY OF WATERLOO
FACULTY OF ENGINEERING

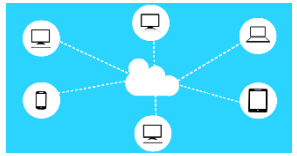
Smart Structures and Systems



Smart Sensing and Data Processing



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.

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)

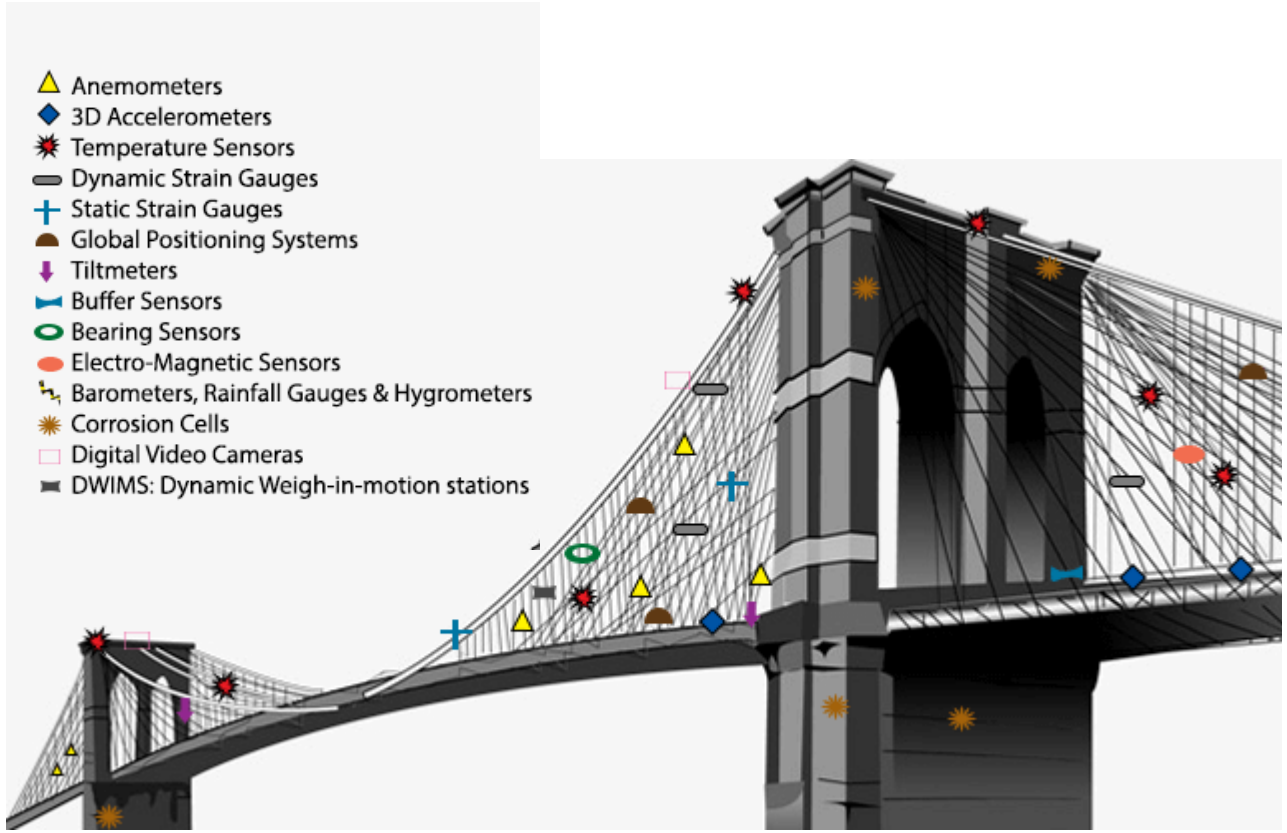
Motivations for Structural Health Monitoring

- 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**

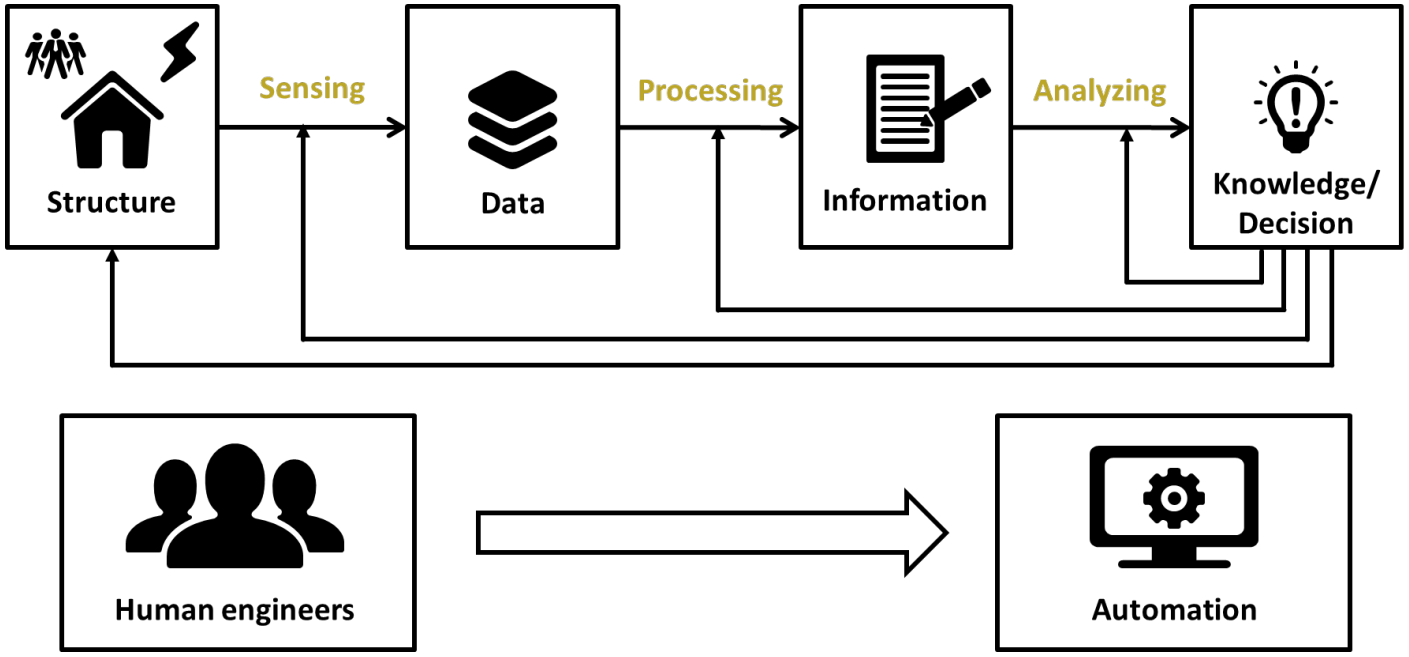


Rytter, A. (1993). Vibrational based inspection of civil engineering structures
https://www.vackergroup.ae/our-products/monitoring-systems/structural-health-monitoring/

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

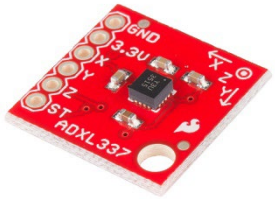


Passive and Active Sensors

- **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

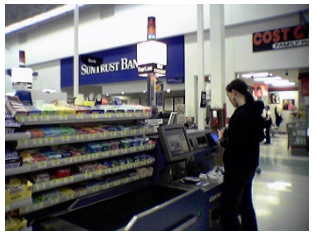

Interac


Stethoscope


Smoke detector


IR-camera

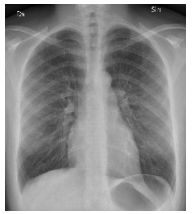
Passive sensor


Scanner


Ultrasound


Laser scanner


Camera + flash


X-ray

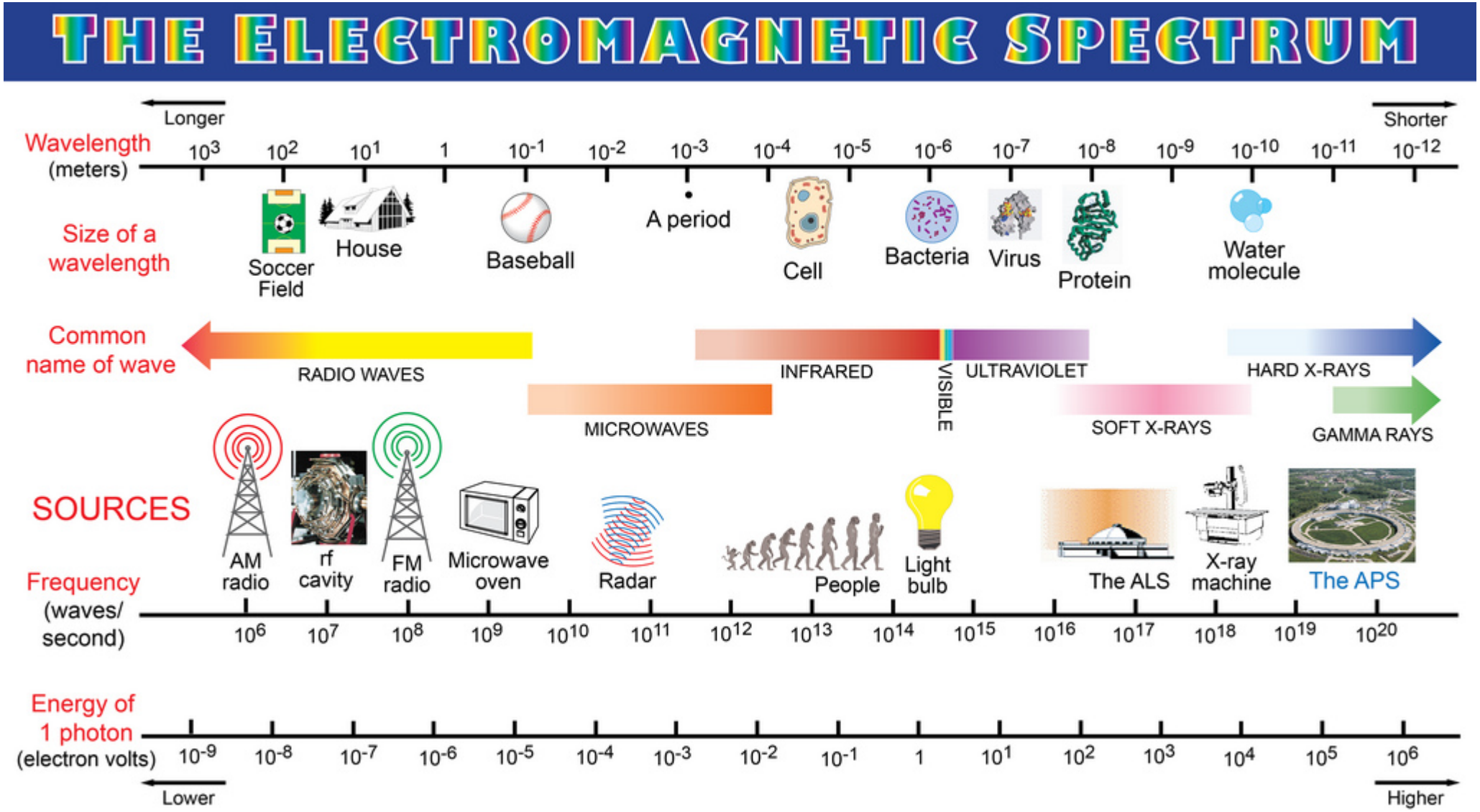
Measuring laser

Kinect


Thermometer

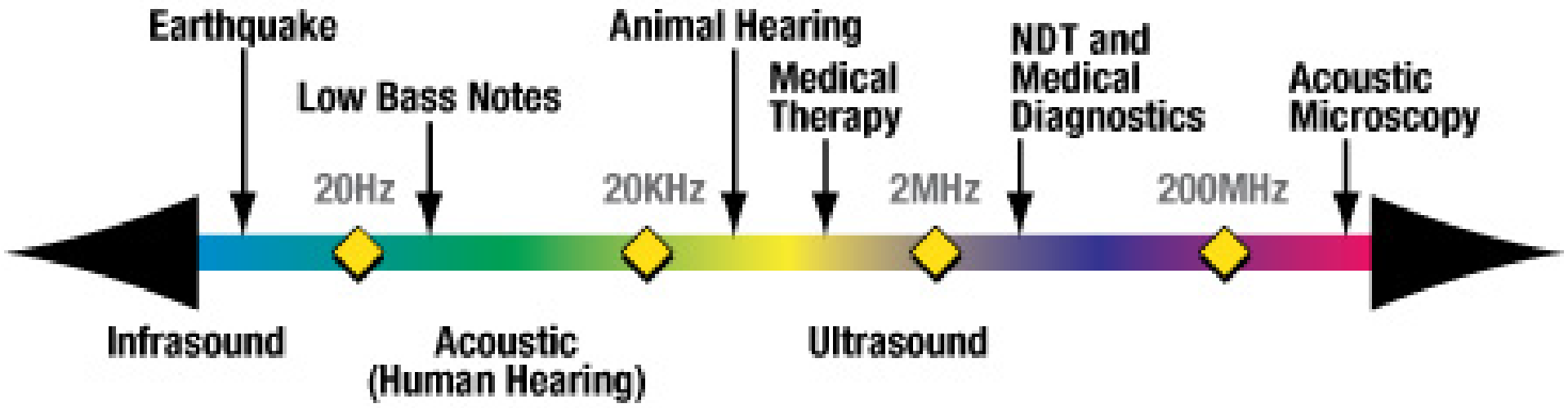
Active sensor

Electromagnetic Spectrum



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

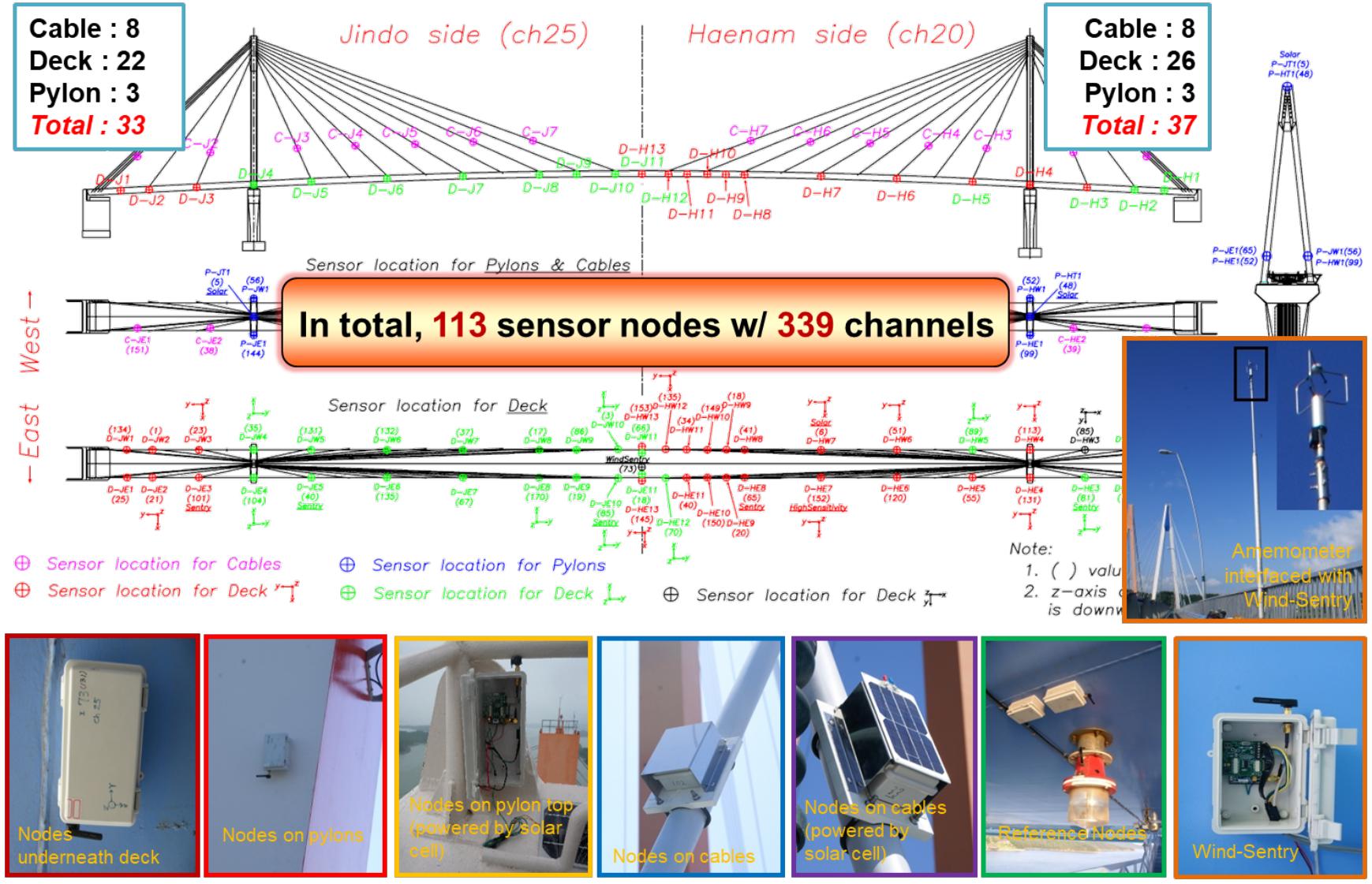
Mechanical Vibration



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

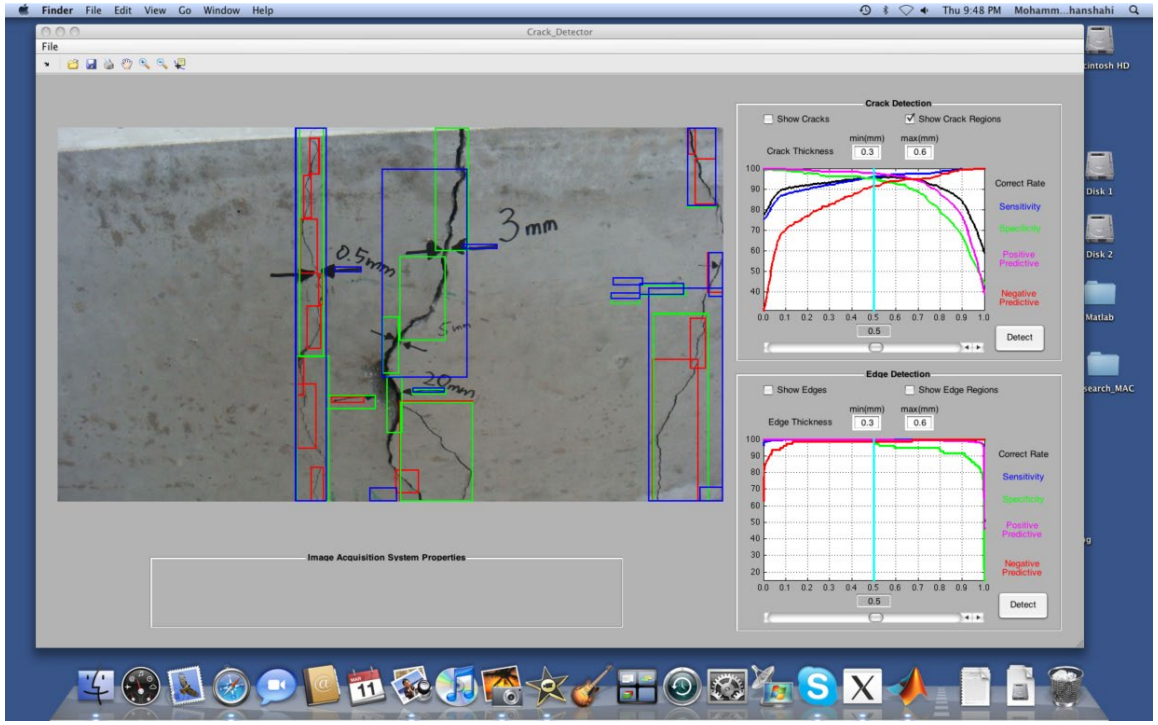
Applications of Smart Structure Technology in Civil Engineering

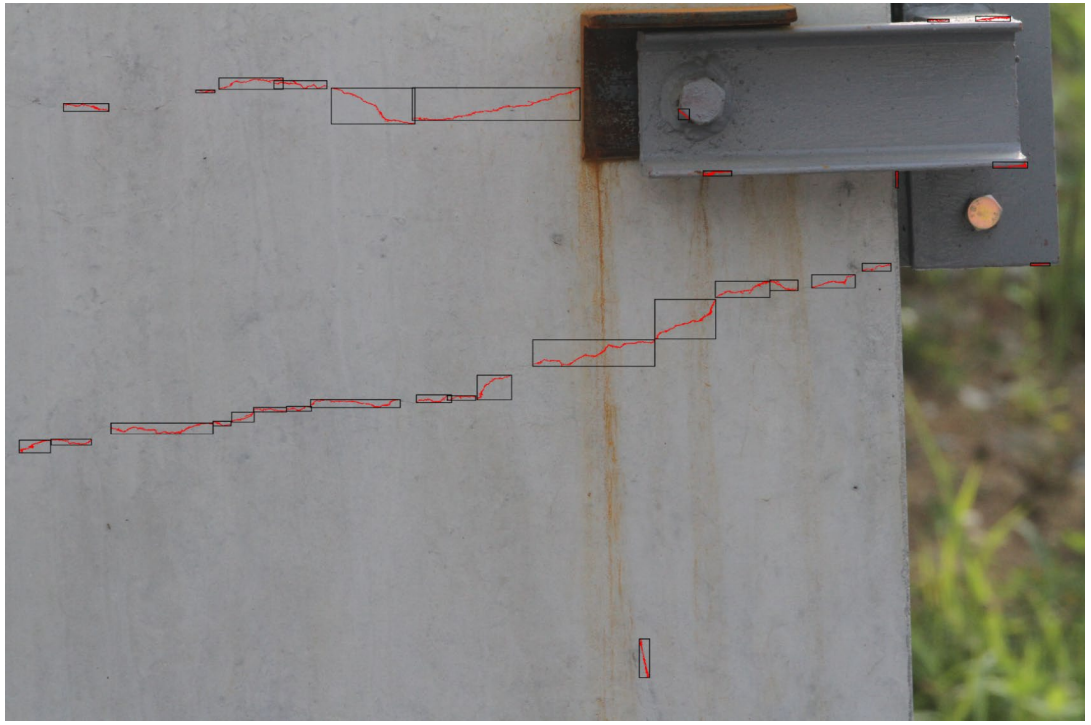
Structural Engineering: Wireless Monitoring of a Cable-Stayed Bridge



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

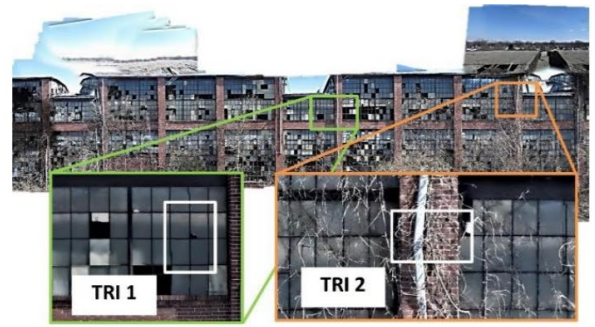


Figure 7. Selection of two sample TRIs (TRI 1 and TRI 2) on the orthophoto.

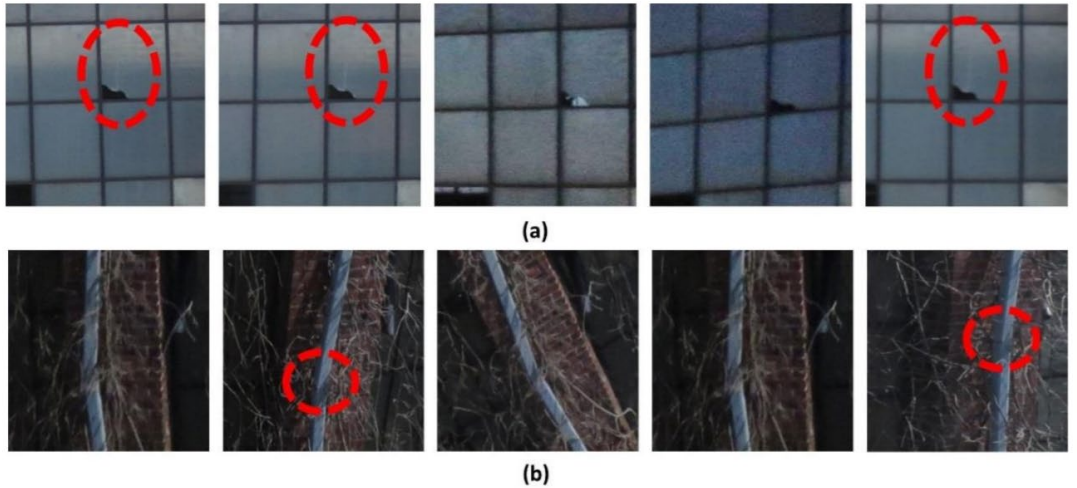
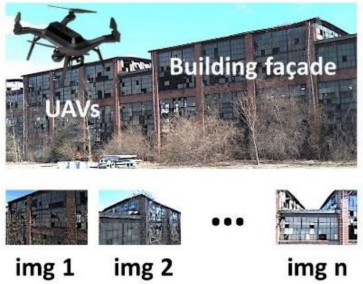
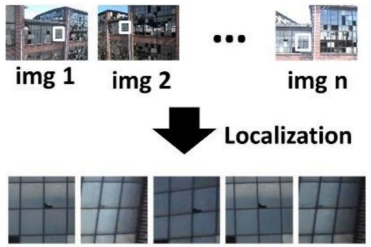


Figure 8. Localized ROIs corresponding to TRI 1 in (**a**) and TRI 2 in (**b**): The hairline vertical crack on a window pane in TRI 1 and damage on a drainage pipe in TRI 2 are only visible in specific ROIs and those damage locations are marked with a red dotted line.



Step 1. Image collection

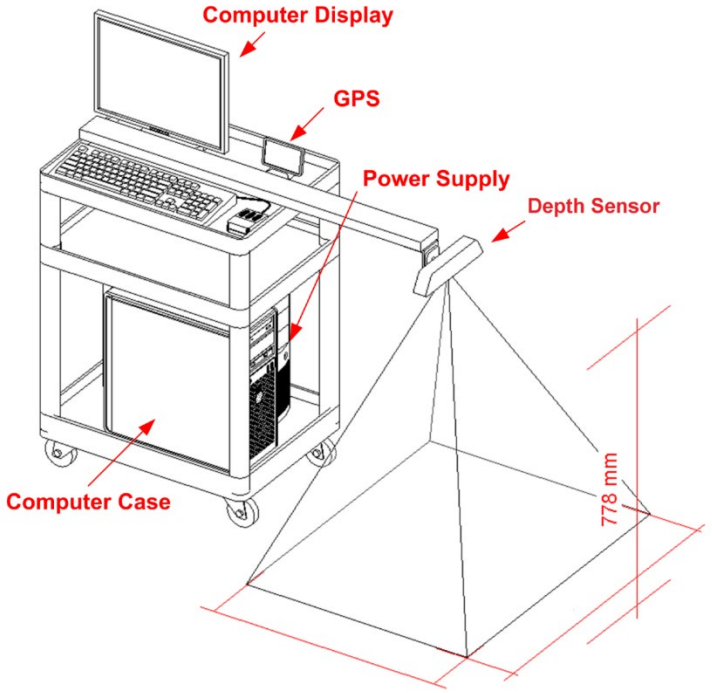
Step 2. Orthophoto generation



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



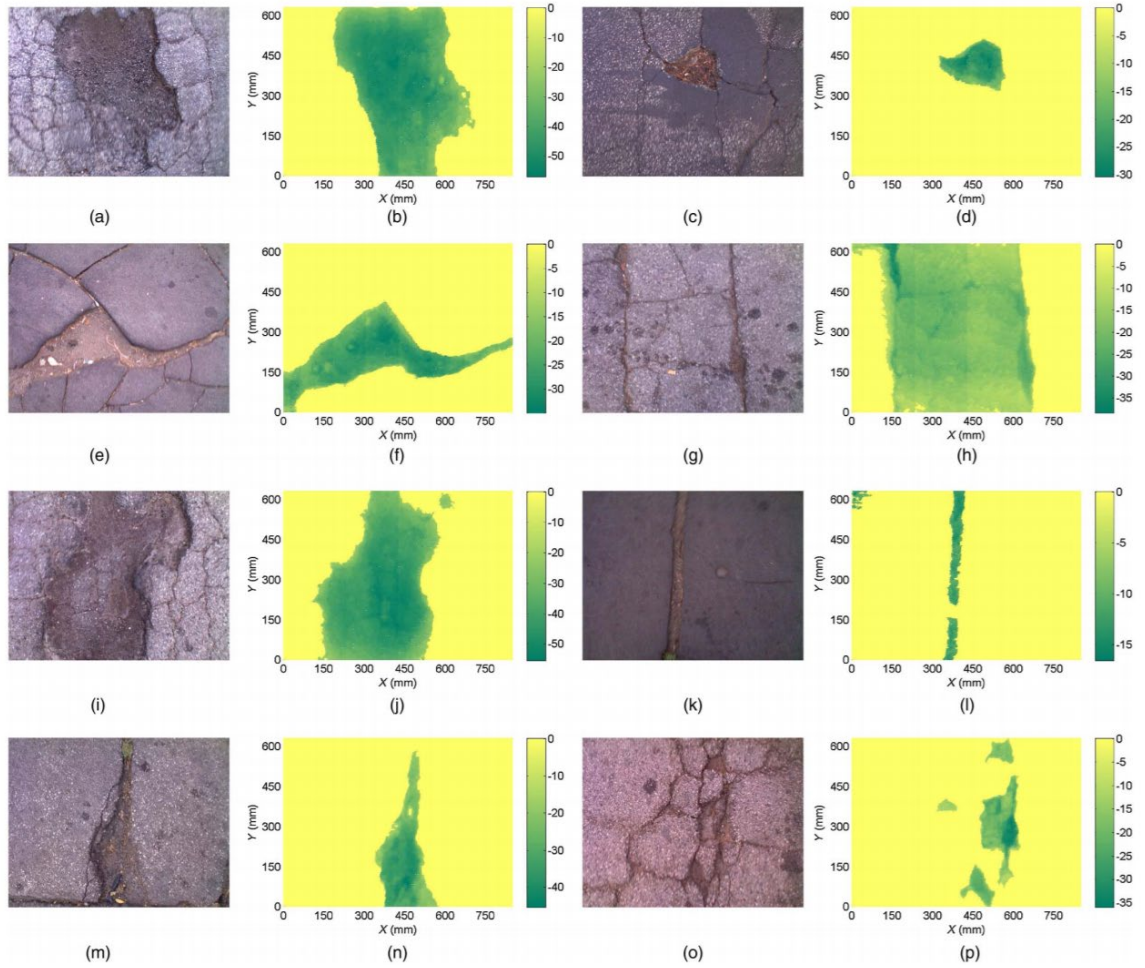
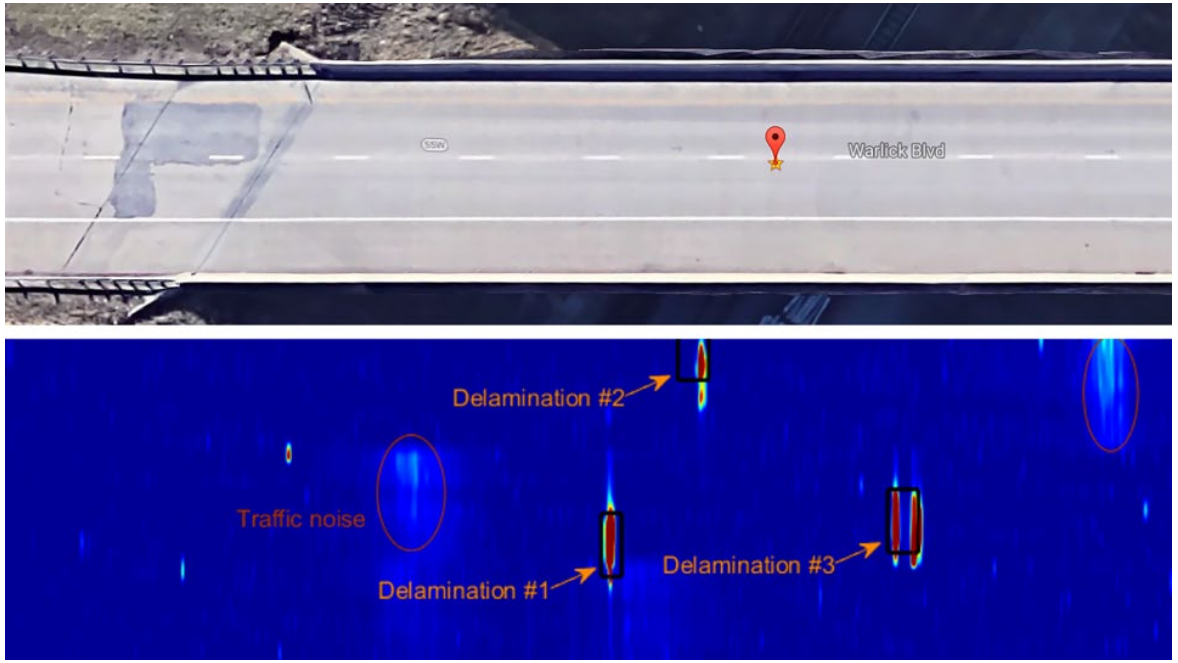


Fig. 6. Defect detection and depth quantification: (a), (c), (e), (g), (i), (k), (m), and (o) are the images of the defects, and (b), (d), (f), (h), (j), (l), (n) and (p) are the corresponding depth maps, respectively

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

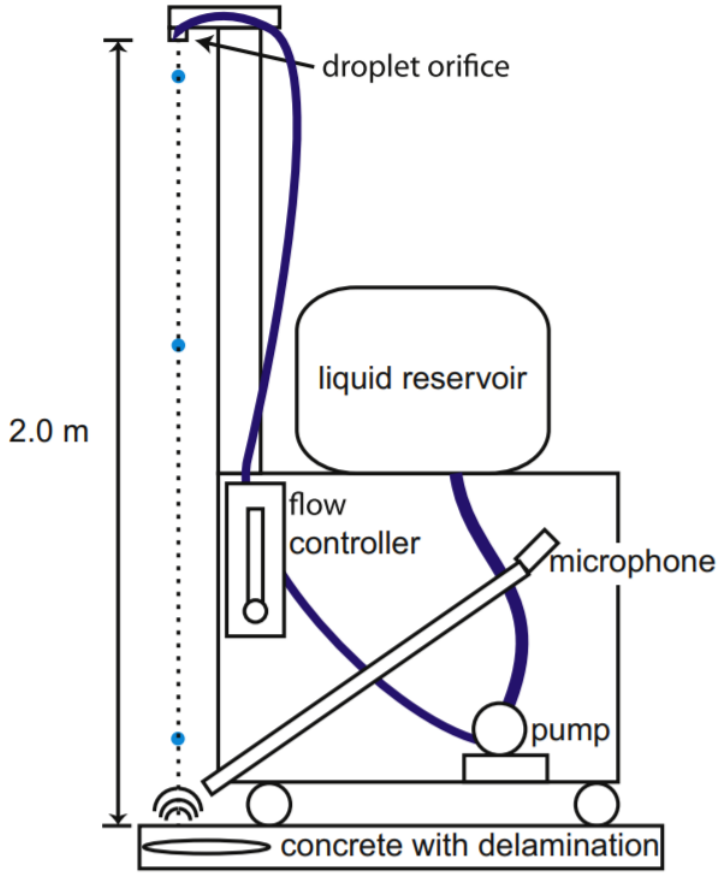


https://go.unl.edu/ic7w

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

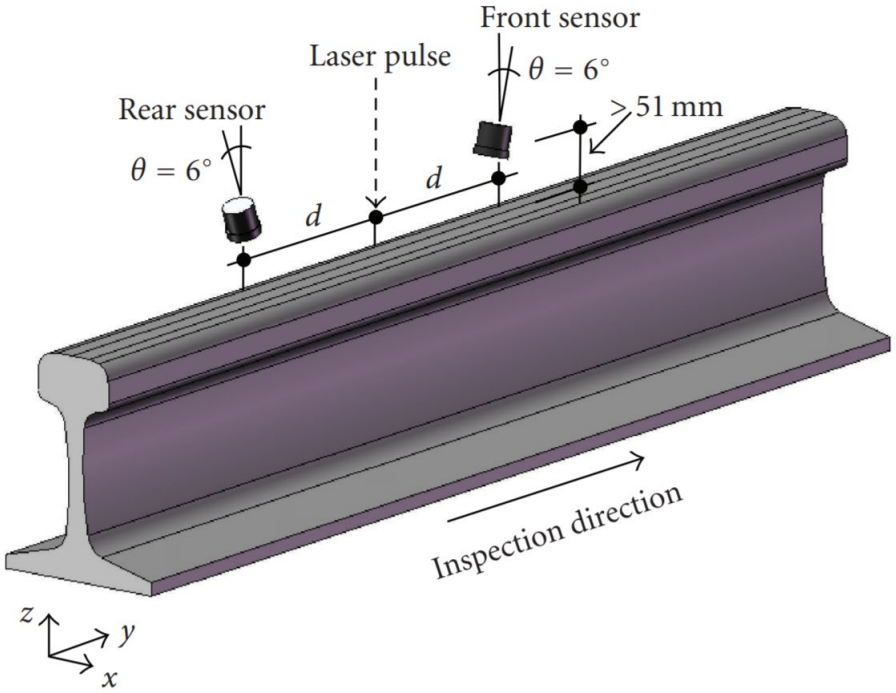
Structural Engineering: Robotic for Structural Assessment

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



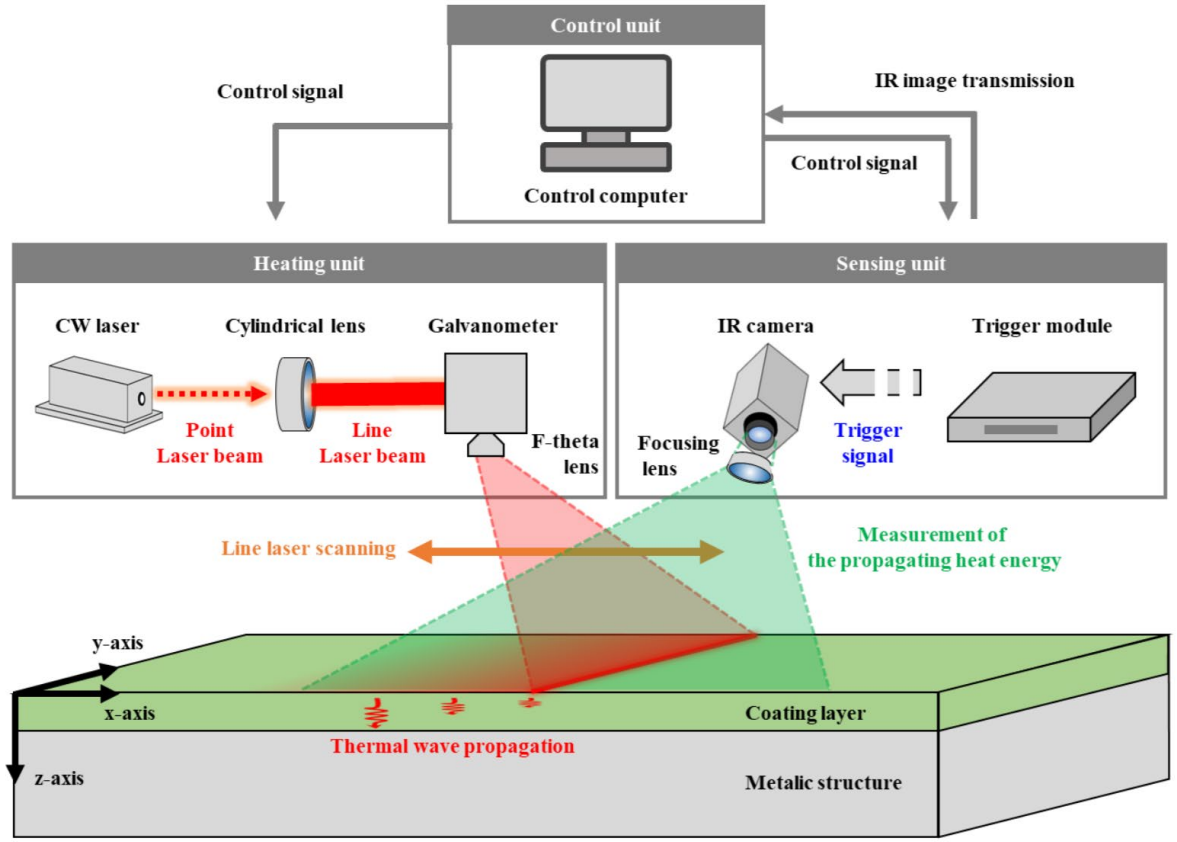
(a) (b)

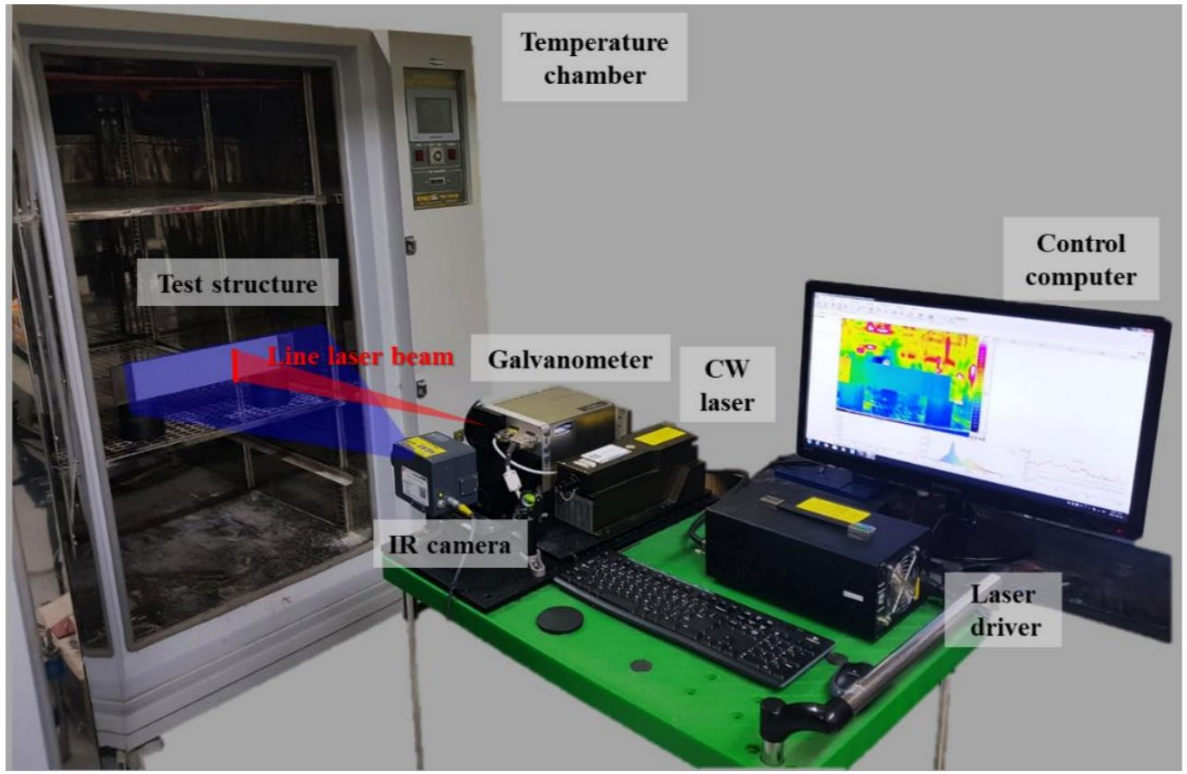
IGURE 10: (a) Test site near Gettysburg, Pennsylvania. (b) Photo of the latest inspection prototype tested in the field.

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*.

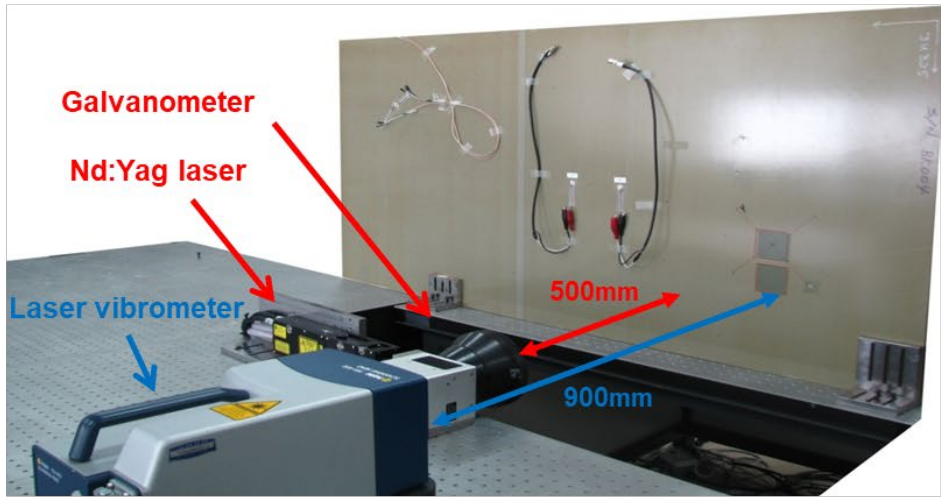
Structural Engineering: Coating Thickness Quantification using Laser Thermography



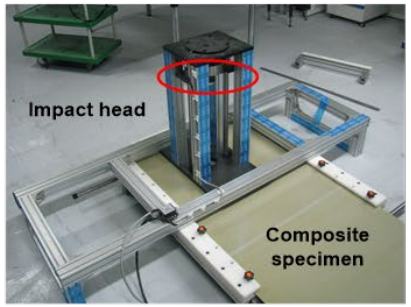


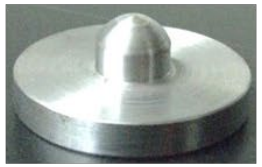
Hwang, S., Park, J., Jin, Z., & Sohn, H. Reference-free Coating Thickness Quantification using Laser Thermography under Various Exterior Temperature Conditions.

Structural Engineering: Delamination Detection using Piezoelectric Sensors

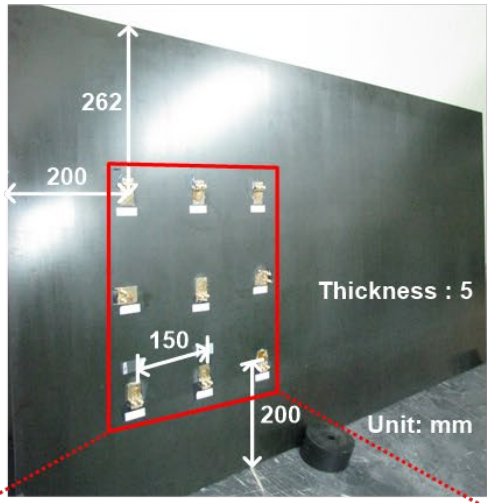


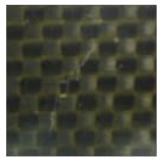
Low velocity impact test





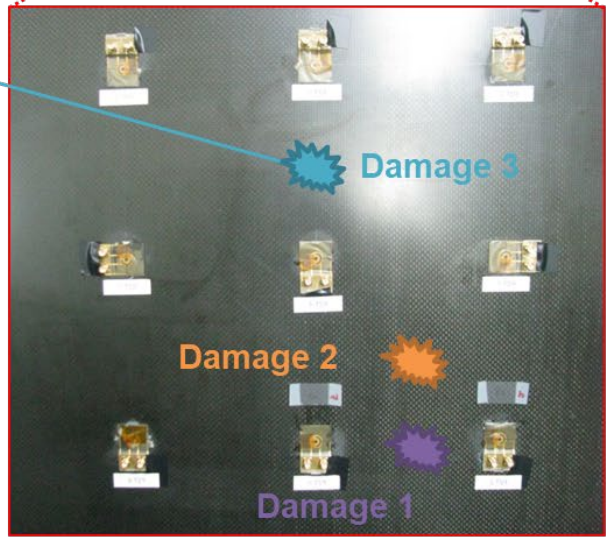
A low velocity impact with a 1cm radius steel cone-shape tip is used to produce delamination.





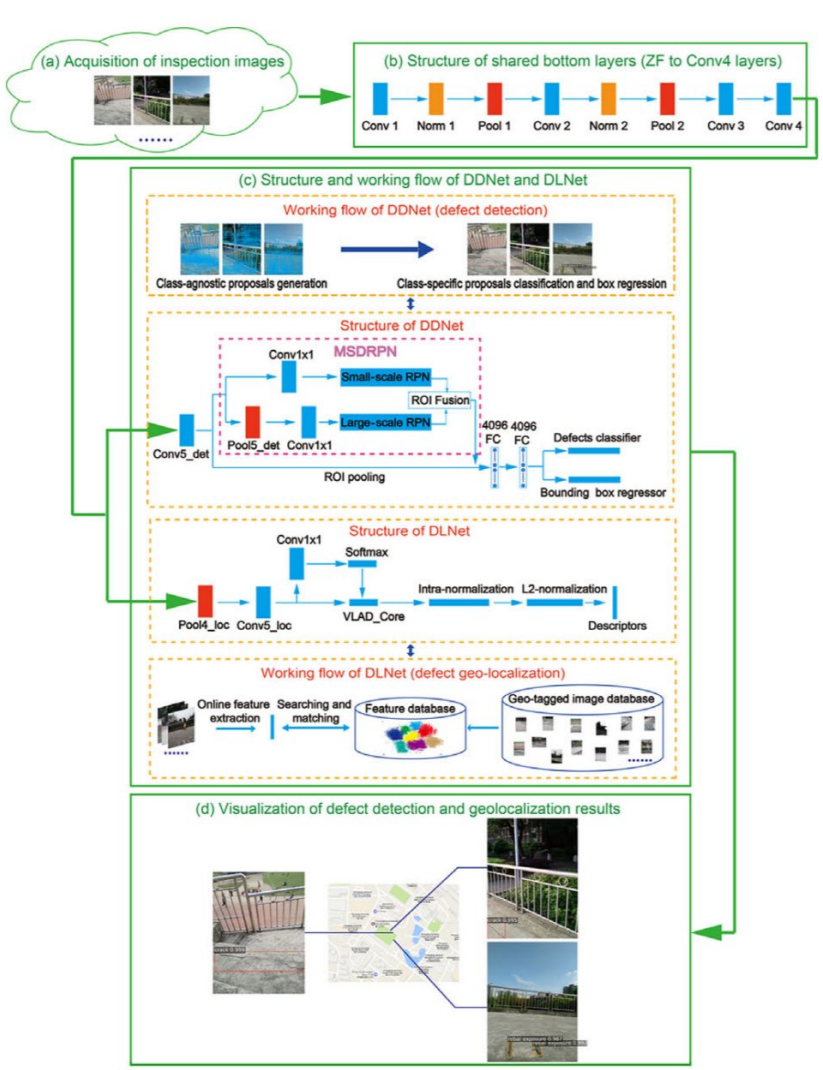
Back side

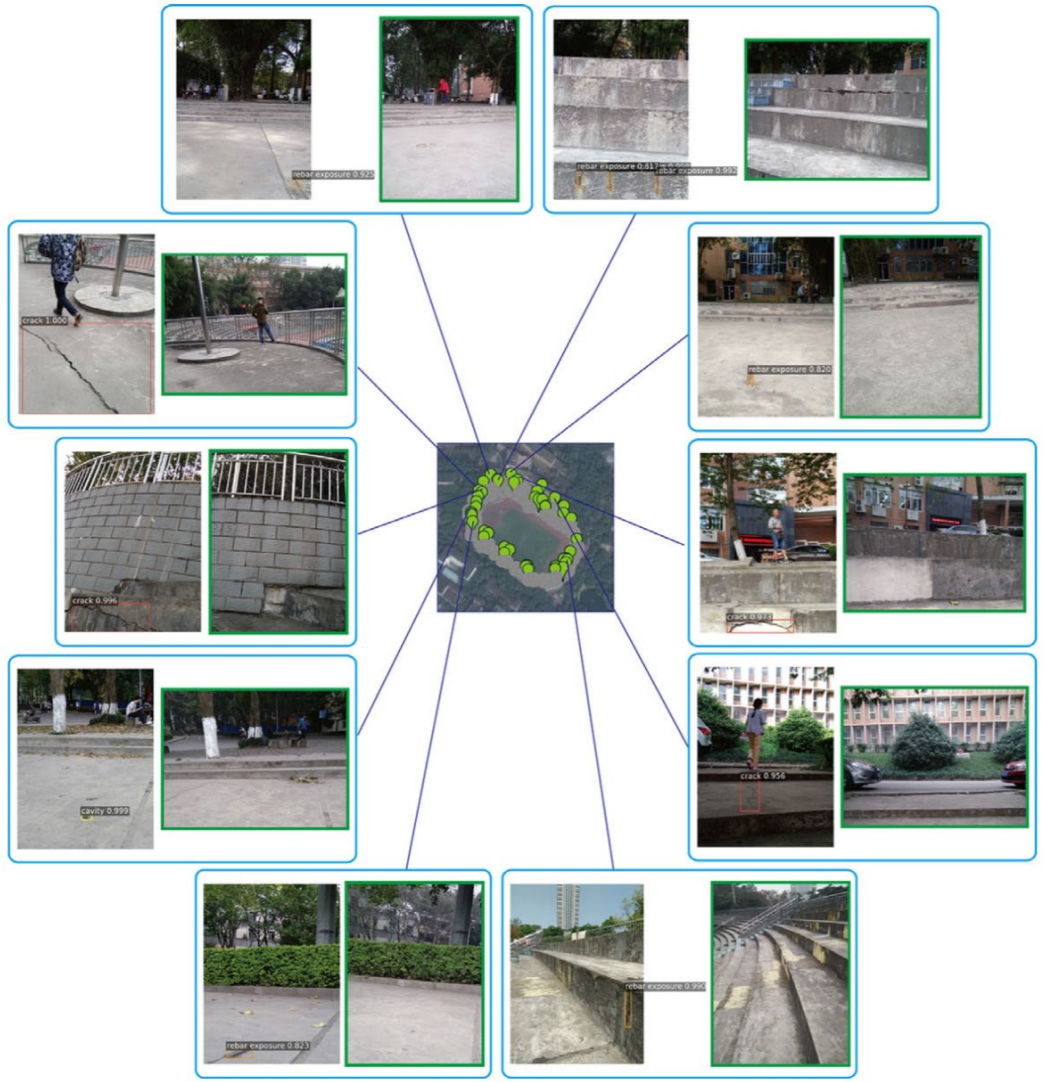
Scanned side (Impact side)



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: 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

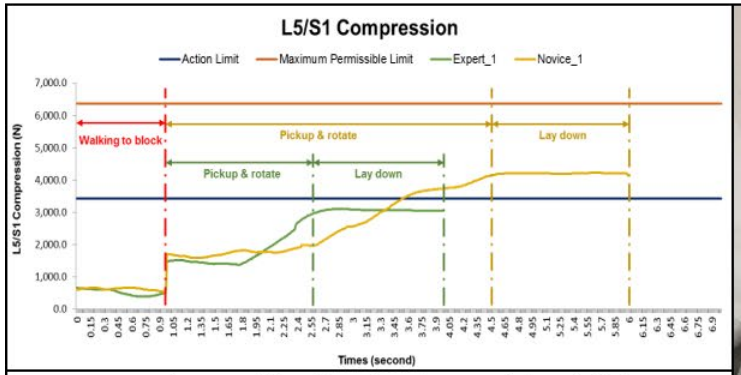
Smart Material: Self-Healing Pavement

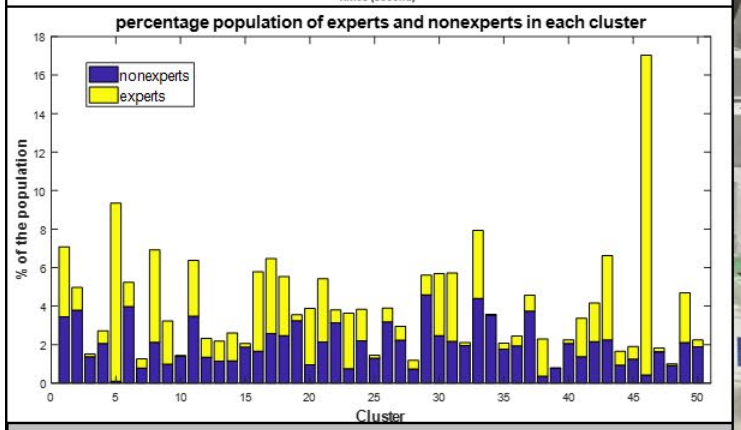
https://www.youtube.com/watch?v=XpKlvMB_c7o&feature=emb_logo&ab_channel=uwaterloo

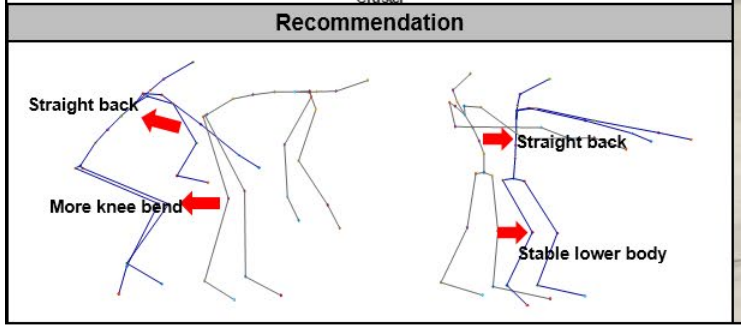
Construction Engineering: Crane Camera Solution (Pix4D)

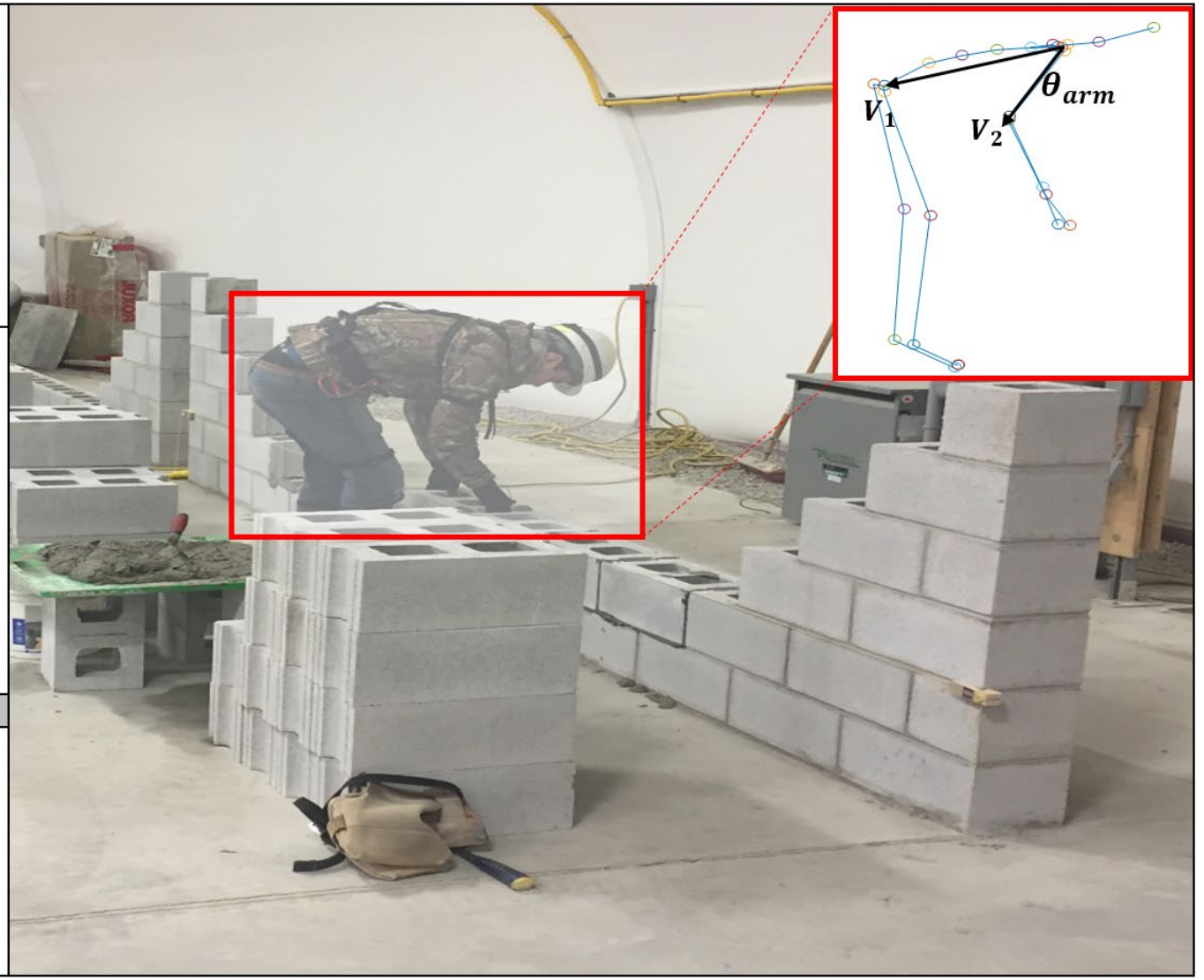
https://www.youtube.com/watch?v=lQtbrv4hxJ4&ab_channel=Pix4D

Construction Engineering: Craft Worker Health and Productivity Improvement







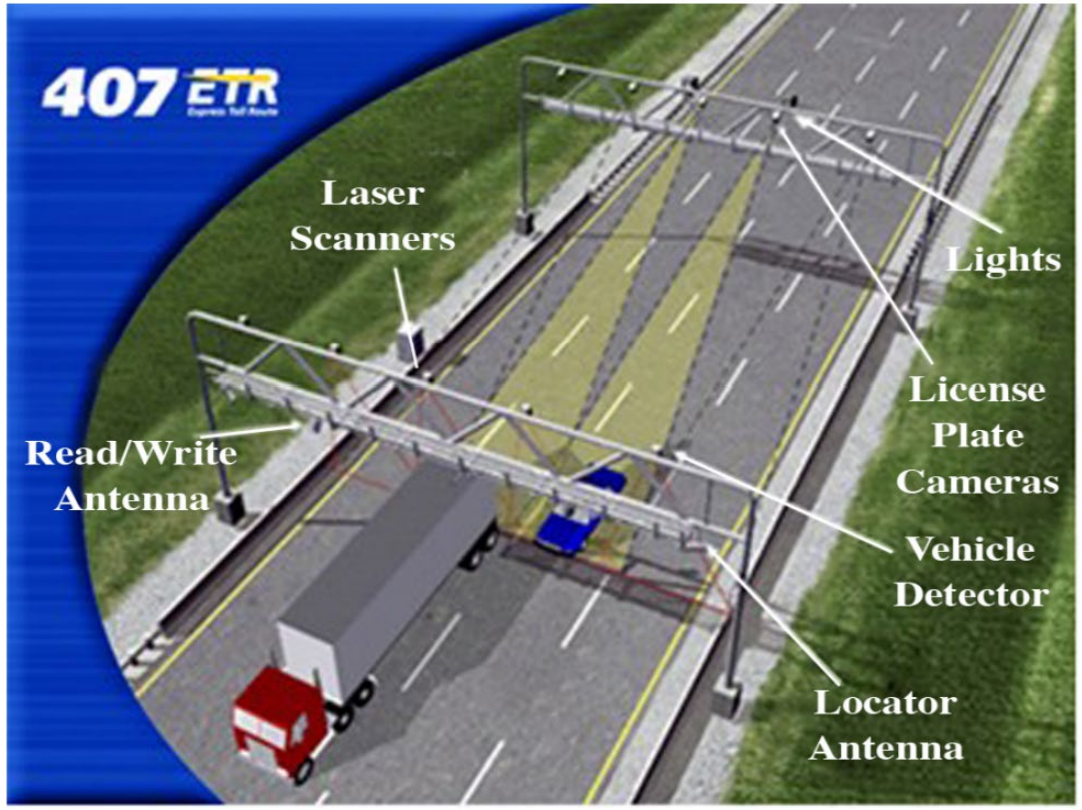


https://uwaterloo.ca/scholar/chaas/research

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: License Plate Estimation



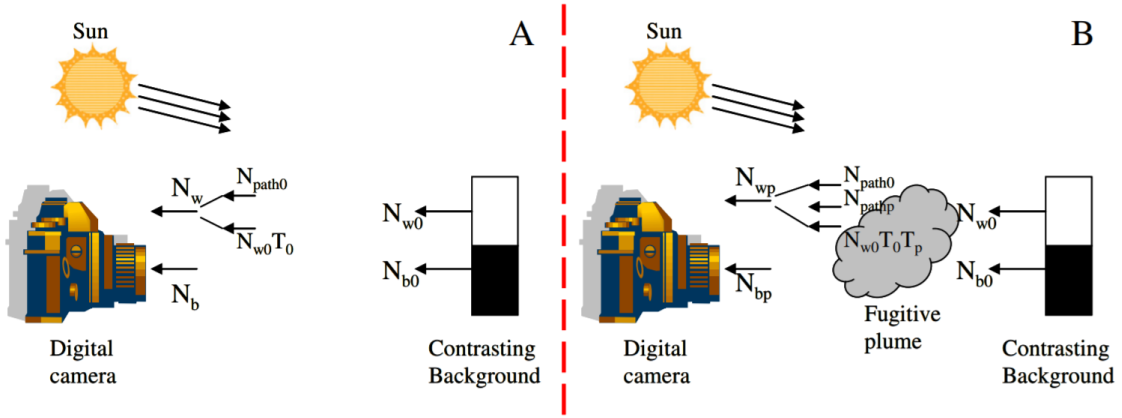
Transportation Engineering: Driver Distraction Monitoring

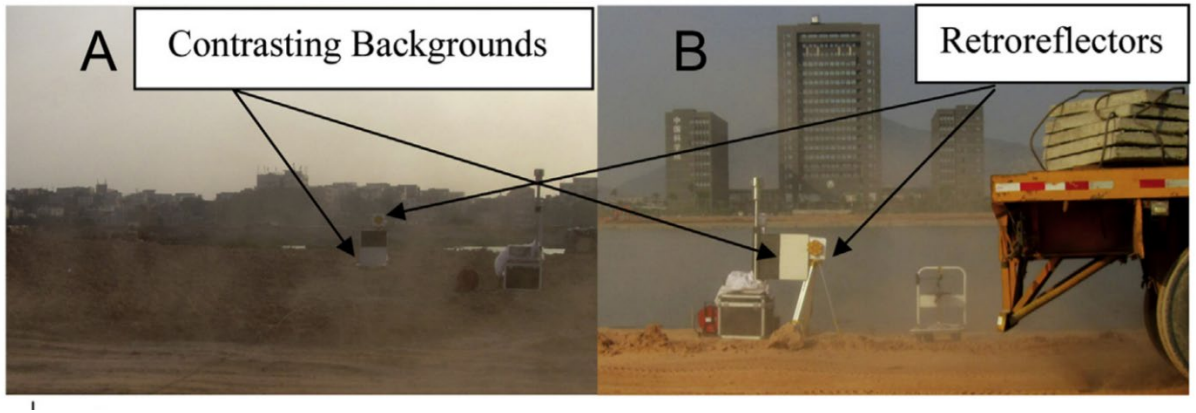
https://www.youtube.com/watch?v=ImAlBVLXiBA

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





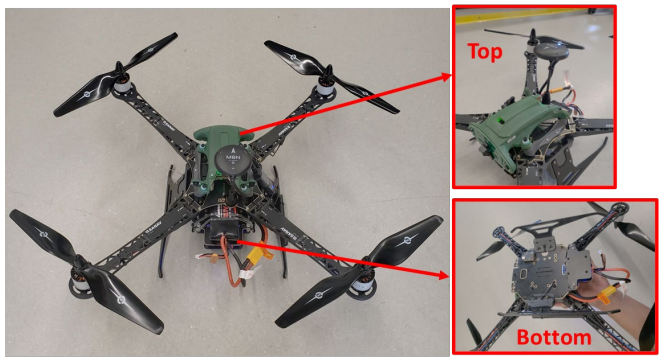
https://youtu.be/tNse9hYYEBc

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

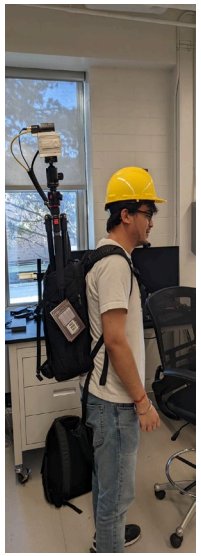
Surveying: Mobile Mapping Solution

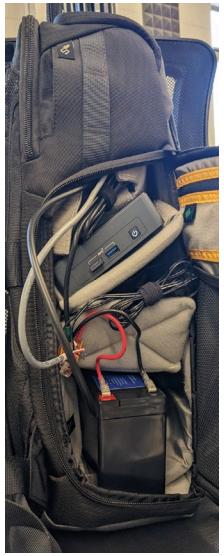
https://youtu.be/52x1N7U0EAk

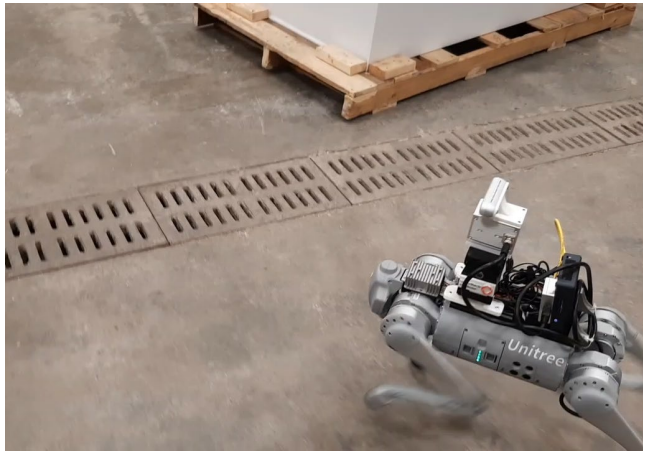
Digital Twinning Physical Structures and Assets (at CVISSLab)



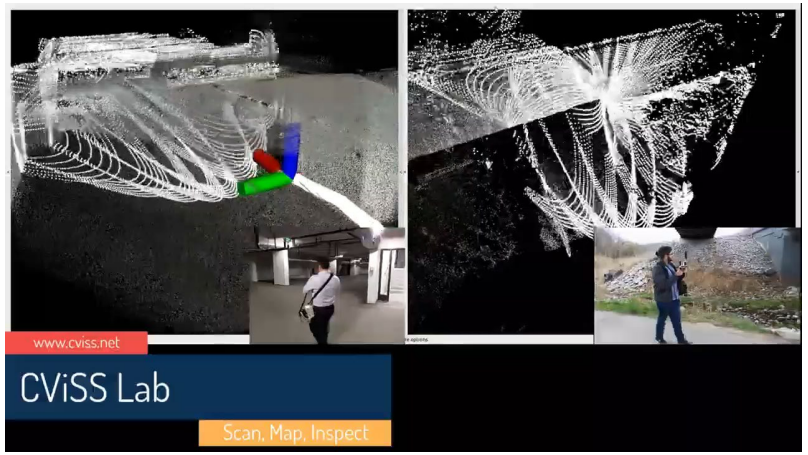
Open-source drone with 5G



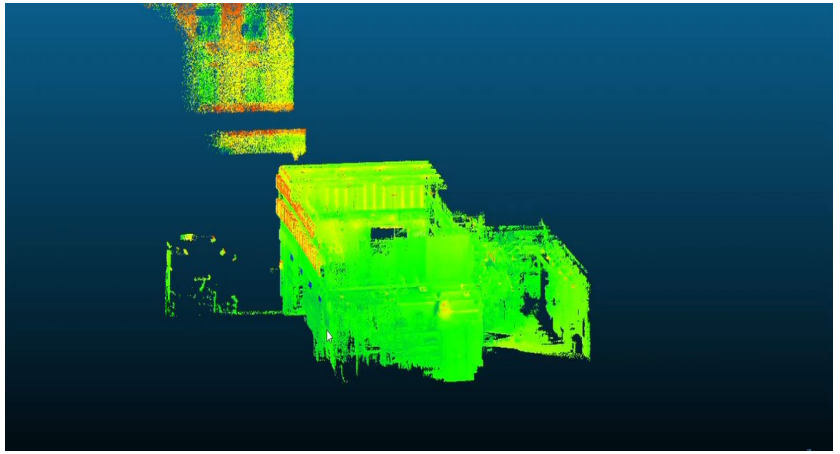




Robot integration



Mobile scanner



Thermal scanner

Large Scale High-resolution Data Collection (at CVISSLab)

- Collection of high-quality street-view building imagery database

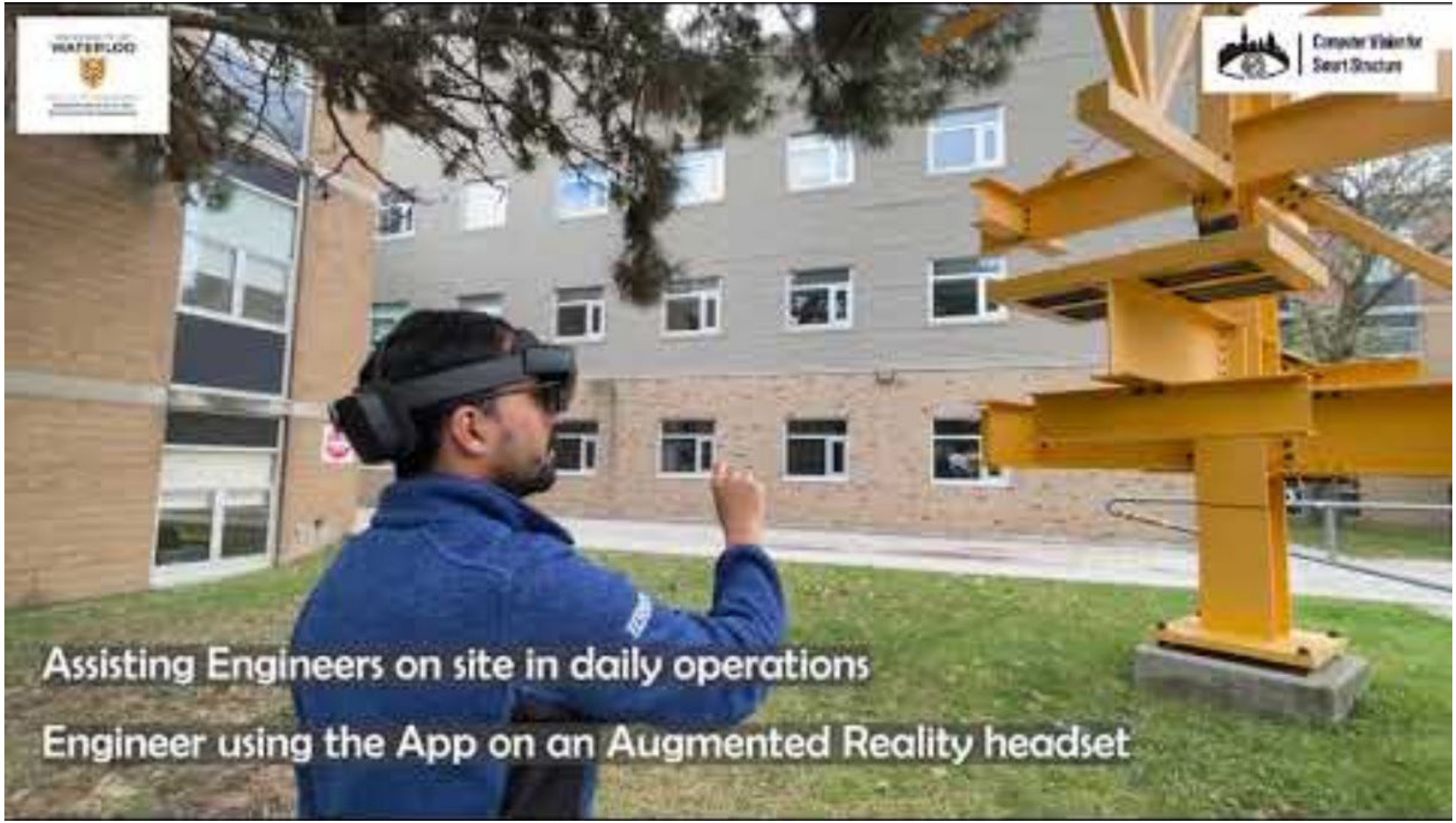
- Development of automated tools and procedures for property characterization from street-level images

Mobile scanning cargo

Mobile scanning backpack

Demonstration of AR-based Interactive Segmentation (at CVISSLab)

Integrating Augmented Reality and GPT 4.0 for Real-Time Immersive Assistance (at CVISSLab)

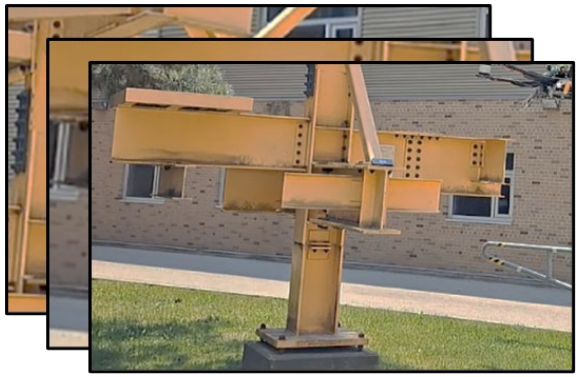


3D Photorealistic Rendering for Remote Inspection (at CVISSLab)

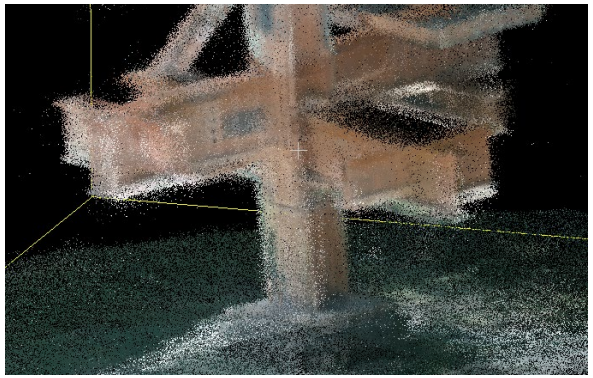
Onsite

Remote experts w/ VR

How to provide realistic site scenes to the remote users for inspection?



A set of images



Colorized point cloud

Rendering with a Nerf

Neural radiance fields (**NeRFs**) are a technique that generates 3D representations of an object or scene from 2D images by using advanced machine learning.

Smart Structures and Systems