INSPECTING AND PRESERVING INFRASTRUCTURE THROUGH ROBOTIC EXPLORATION

Robot-Assisted Bridge Inspection and Maintenance

TRB Webinar on
Robot-Enabled Sensing and Augmented Learning (RESEAL) for Bridge Inspection

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Director of INSPIRE University Transportation Center
Missouri University of Science and Technology

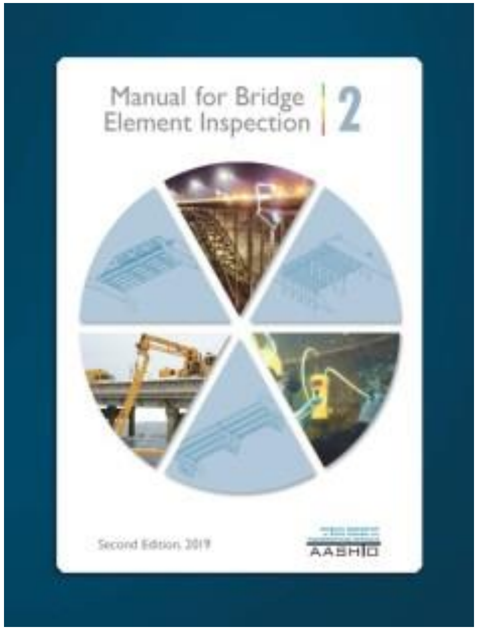
March 29, 2022, 1:00 – 2:30 pm

Outline of This Presentation

- **Bridge Element Inspection in the U.S.**
  - **2019 Manual for Bridge Element Inspection**
- **Data-driven Bridge Management**
  - **INSPIRE University Transportation Center Goal**
  - **Sensing and Nondestructive Evaluation Integration for Bridge Inspection and Maintenance**
  - **Robotic Platforms**
- **Robot-assisted Bridge Maintenance and Inspection**
  - **Fatigue evaluation of steel structures from thermal imaging**
  - **Scour evaluation from smart rocks as magnetic sensors**
- **Pooled-fund Study on 72 Highway Bridges**
- **Concluding Remarks**

Bridge Element Inspection

- **2019 Manual for Bridge Element Inspection**
  - **All elements have 4 conditions of deterioration**
  - **Current visual inspection**
    - ✓ ***Difficult to record all defects***
    - ✓ ***Difficult to accurately estimate quantities***



	Condition States			
	1	**2**	**3**	**4**
Defects	**GOOD**	**FAIR**	**POOR**	**SEVERE**
Delamination/Spall/ Patched Area (1080)	None.	Delaminated. Spall 1 in. or less deep or 6 in. or less in diameter. Patched area that is sound.	Spall greater than 1 in. deep or greater than 6 in. diameter. Patched area that is unsound or showing distress. Does not warrant structural review.	The condition warrants a structural review to determine the effect on strength or serviceability of the element of a bridge.
Exposed Rebar (1090)	None.	Present without measurable section loss.	Present with measurable section loss but does not warrant structural review.	

Data-driven Bridge Management

- **5-Year Goal at the INSPIRE University Transportation Center**
  - **To transform the current labor-intensive, inconsistent, and expensive inspection and maintenance process
into an efficient, safe, reliable, and cost-effective management system for bridges**
    - ✓ ***Make a paradigm shift from ad hoc local processes to a data-driven decision-making protocol***
    - ✓ ***Involve basic, advanced, and applied research in sensing, nondestructive evaluation (NDE), data analytics, robotics, and workforce development***

Data-driven Bridge Management

- **Contact/Remote Sensing and NDE Integration for Bridge Inspection and Maintenance**

Girder Bridge Inventory

Sensor Monitoring of Representative Bridges and their Critical Elements for Quantitative Assessment

Remote Sensing of all Bridges and In-depth NDE Inspection of Targeted Bridges on Robotic Platform for Qualitative Assessment

Confirmation Visual Inspection on Bridges with Abnormal Behavior for Load Rating

INSPECTION

MAINTENANCE

Maintenance Prioritization

Local Maintenance Work with a Mobile Manipulating UAV

Robotic Platforms

- **Unnamed Aerial Vehicle (UAV)**
  - **Close-distance inspection**

H. Zhang, Z. Li, G. Chen, A. Reven, B. Scharfenberg & J. Ou. UAV-based smart rock localization for bridge scour monitoring, *Journal of Civil Structural Health Monitoring*, https://doi.org/10.1007/s13349-020-00453-w.

Robotic Platforms

- **Structural Crawler in Collaboration with Dr. Hung La from the University of Nevada, Reno**
  - **Near-surface inspection and testing**

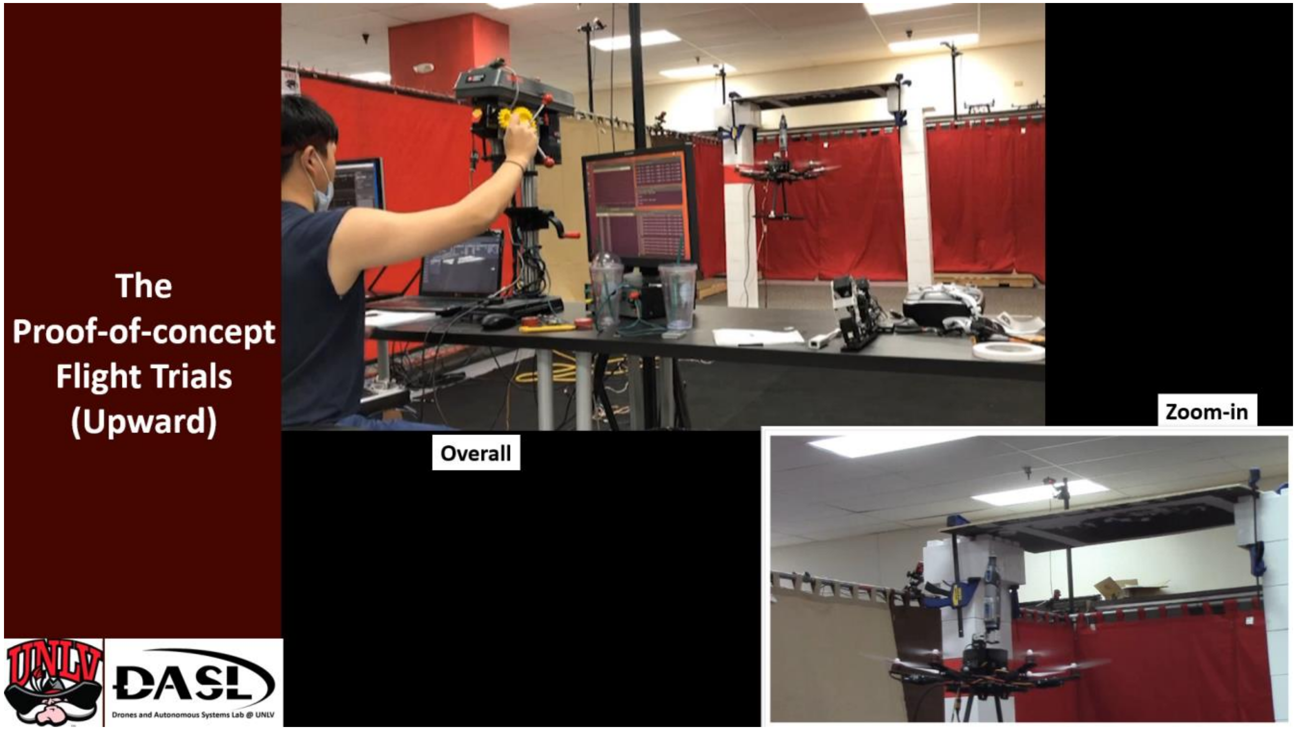
Robotic Platforms

- **Hybrid Unmanned Vehicle (BIRDS, proof of concept)**
  - ➢ **Increased operation time**
  - ➢ **Stable measurement platform**
  - ➢ **Ease in navigation**
  - ➢ **Accurate positioning**

A. Reven, C. Fritsche & G. Chen (2019). Unmanned aerial and traversing robot as mobile platform for bridge inspections, *Proceedings of the International Conference on Structural Health Monitoring of Intelligent Infrastructure*, St. Louis.

Robot-assisted Bridge Maintenance

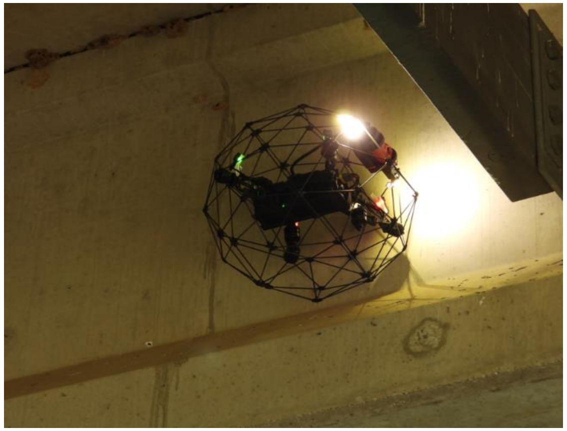
- **UAV with Aerial Manipulator (proof of concept)**
- **Dr. Paul Oh's Laboratory at the University of Nevada, Las Vegas**

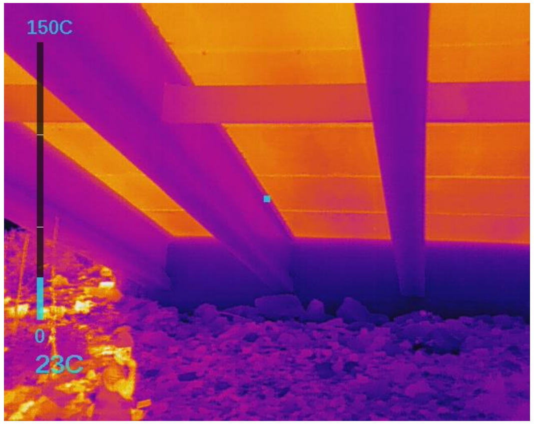


Robot-assisted Bridge Inspection

- **Bridge No. 3128 – Steel and PC Girders, MO**

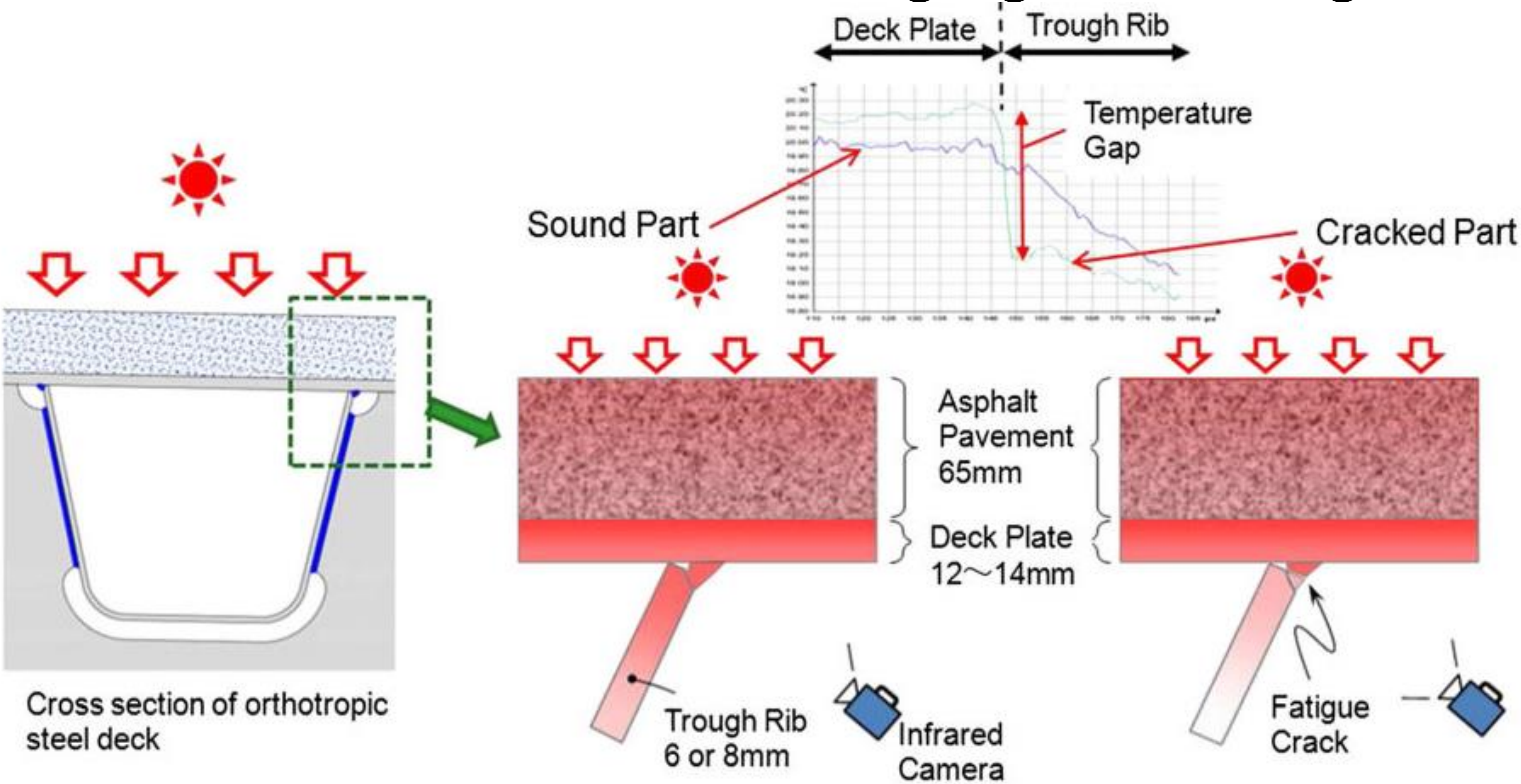
- **Elios 2 Drone and Passive Thermal Image**





Robot-assisted Bridge Inspection

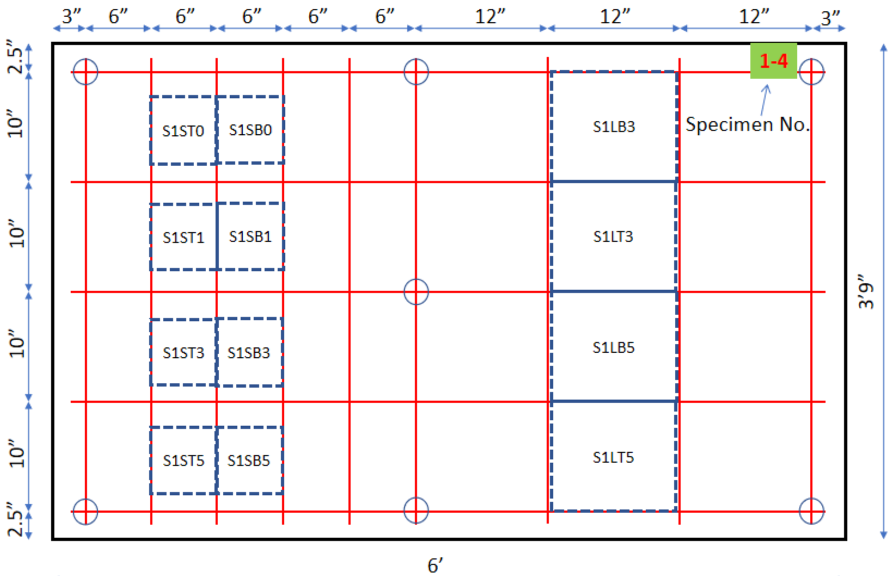
- **Through-weld Fatigue Crack Detection from Passive Thermal Imaging in a Bridge**



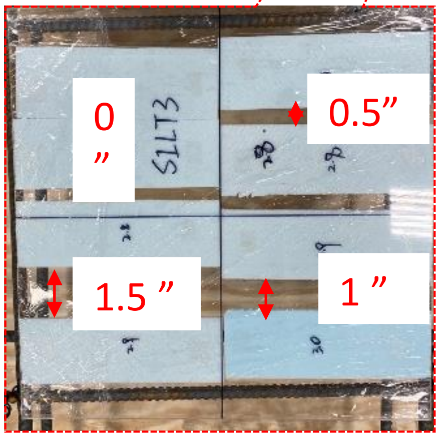
Sakagami, T. (2015) Remote nondestructive evaluation technique using infrared thermography for fatigue cracks in steel bridges. Fatigue & Fracture of Engineering Materials & Structures. doi: 10.1111/ffe.12302 (an invited review article).

Robot-assisted Bridge Inspection

- **Concrete Delamination Detection from Active Thermal Imaging**



Not in final positions

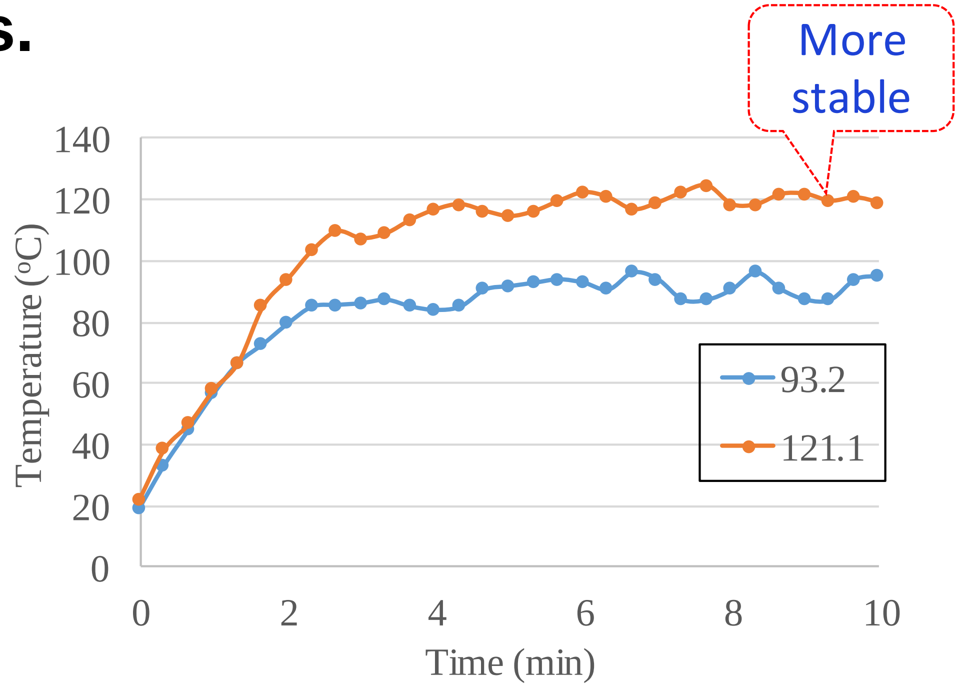


Material	Conductivity (W/mK)	Specific heat (MJ/m³K)
Extruded Polystyrene (XPS)	0.0243	0.025
Acrylic board (Plastic holder)	0.213	1.274
Concrete	2.006	1.807
Steel reinforcement	45	3.5
Air	0.025	1.000

- 4 Slabs S1-S4
- 2 types of delamination: small and large
- 2 thicknesses: 3 and 5 mm in large foams
- 4 thicknesses: 0, 1, 3, and 5 mm in small foams
- Plastic holder: 2 mm

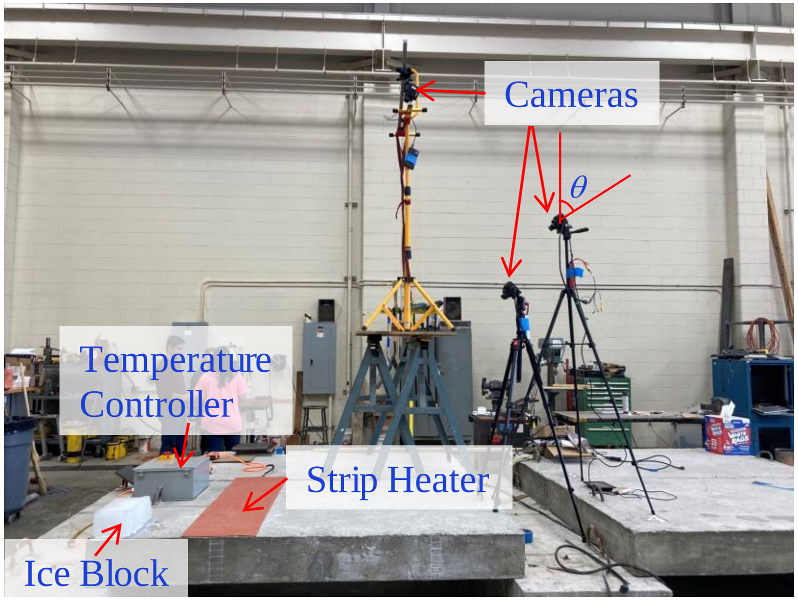
Robot-assisted Bridge Inspection

- **Test Procedure**
  - ➢ **Heat each slab using a strip heater for 10 minutes to achieve the highest temperature of 121.1 ℃.**
  - ➢ **Remove the strip heater and then take thermal images every 1 minute during the cooling process.**



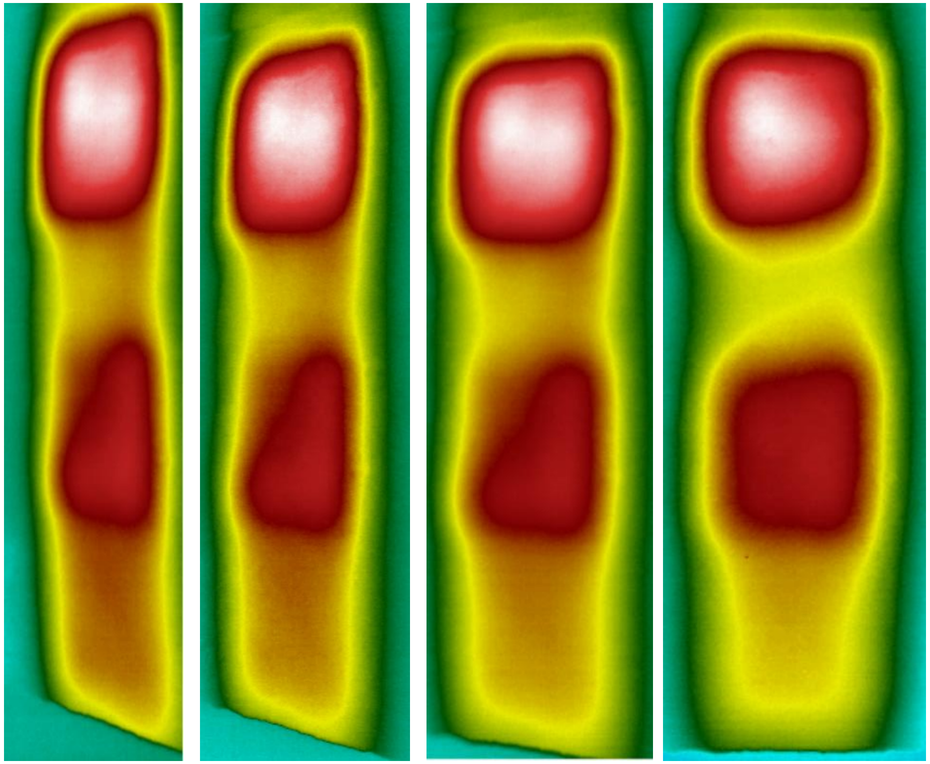
Robot-assisted Bridge Inspection

- **Effect of the Angle of Camera View**



Delamination Area $= Heat\ Area / \cos\theta$

$\theta =$ 45° 30° 15° 0°



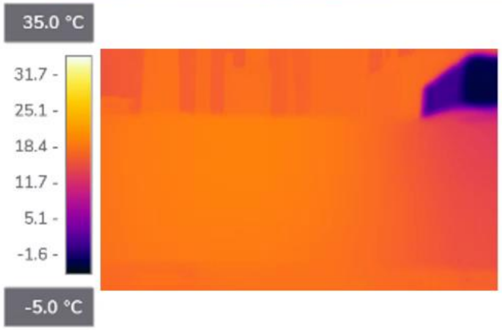
Angle of view θ (°)	Delamination Area (mm²)	Error
0	63826	3.0%
15	66485	6.8%
30	67013	8.2%
45	67880	9.6%

Robot-assisted Bridge Inspection

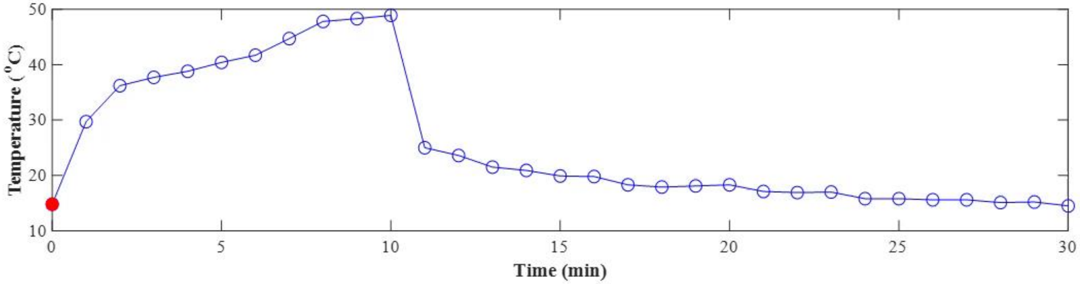
- **Temperature on Top and Side Surfaces of the Heater**

Top view:

Side view:

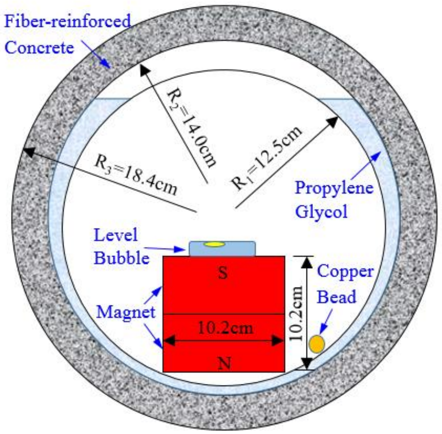


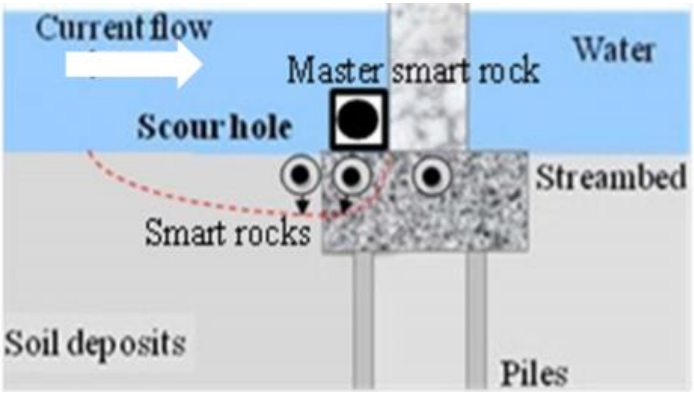
Temperature vs. time:



Robot-assisted Bridge Inspection

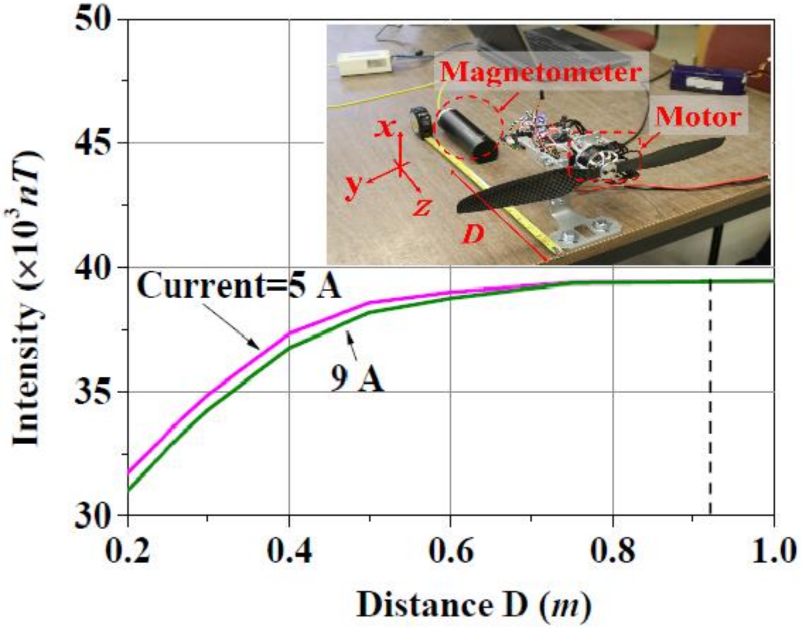
- **Scour Evaluation from Smart Rocks**
  - **A smart rock in ball shape**
    - ✓ ***Easy to roll to the bottom of a scour hole when formed at an unknown location and depth as deposits around the hole are washed away.***
    - ✓ ***Designed based on water flow velocity and soil shear resistance.***

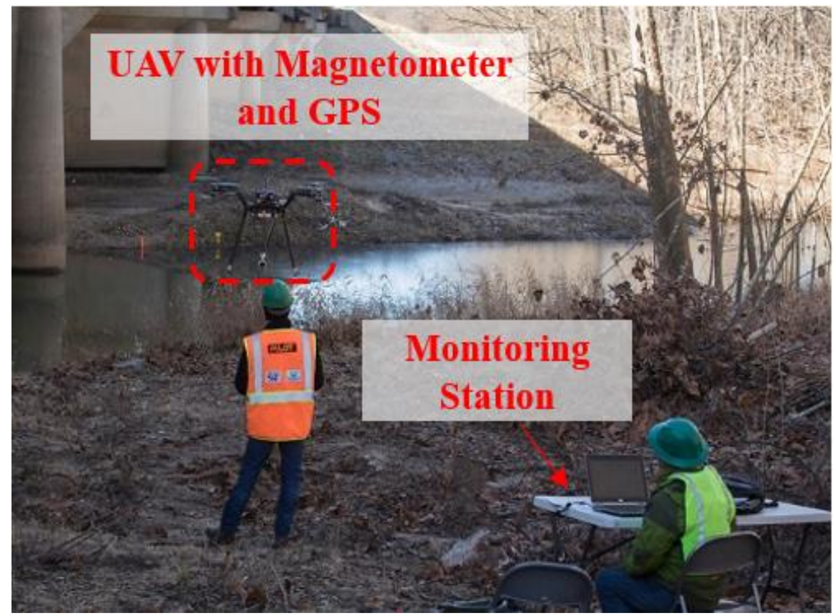




Robot-assisted Bridge Inspection

- **A Magnetometer**
  - ➢ **Set 0.92 m away from the motors to eliminate magnetic interference**
  - ➢ **Wired and plugged into the WIFI router with wireless communication with the nearby ground station**





Haibin Zhang, Zhaochao Li, Genda Chen, Alec Reven, Buddy Scharfenberg and Jinping Ou. "UAV-based Smart Rock Localization for Bridge Scour Monitoring," Journal of Civil Structural Health Monitoring, January 19, 2021. https://doi.org/10.1007/s13349-

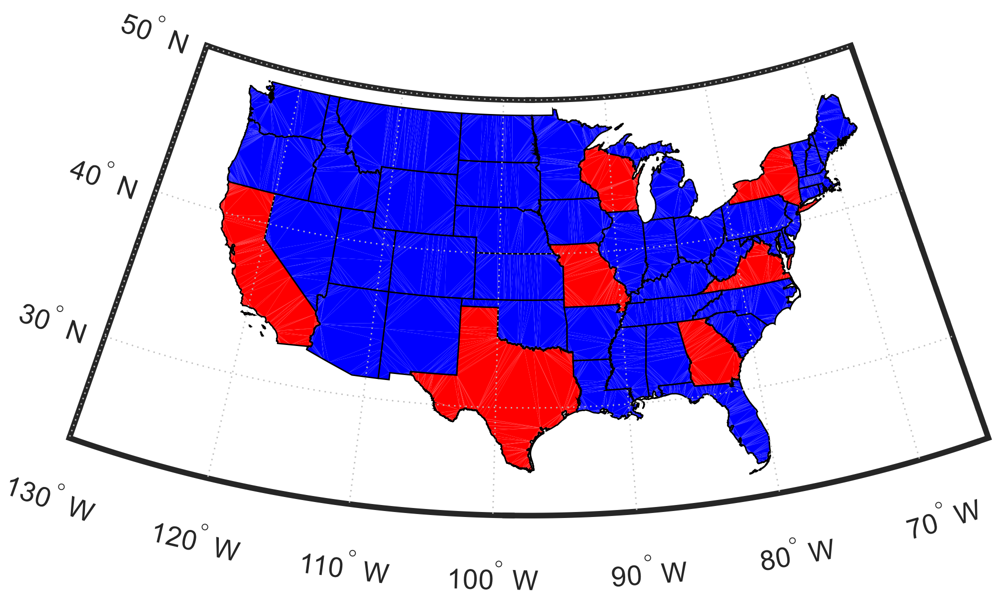
Robot-assisted Bridge Inspection

- **Drone- vs. Crane-based Measurements**

Monitoring method	Date	Predicted coordinate			Measured coordinate			Error (m)
		X	Y	Z	X	Y	Z	
CRANE (1st)	11/06/2015	0.06	23.49	-3.03	0.09	23.24	-3.04	0.26
CRANE (2nd)	04/14/2016	0.55	24.38	-3.21	0.37	24.60	-3.38	0.33
CRANE (3rd)	10/20/2016	0.00	22.73	-2.59	0.00	22.63	-2.87	0.30
UAV (4th)	01/24/2018	0.02	23.50	-2.89	0.25	23.77	-2.93	0.36
UAV (5th)	05/10/2018	0.49	25.00	-2.81	0.45	24.78	-3.01	0.30
UAV (6th)	10/08/2018	0.43	25.07	-2.76	0.41	24.84	-2.98	0.32
UAV (7th)	02/25/2019	0.37	25.60	-3.16	0.35	25.50	-3.41	0.28
UAV (8th)	05/17/2019	0.43	24.00	-3.02	0.26	23.80	-3.17	0.30
UAV (9th)	08/27/2019	0.41	23.32	-3.12	0.23	23.53	-3.22	0.29

Pooled-fund Study TPF-5(395)

- **Goals**
  - ➢ **To engage closely with 7 state Departments of Transportation (DOTs).**
  - ➢ **To leverage the center resources to develop case studies, protocols, and guidelines that can be adopted by state DOTs for bridge inspection without adversely impacting traffic flow.**

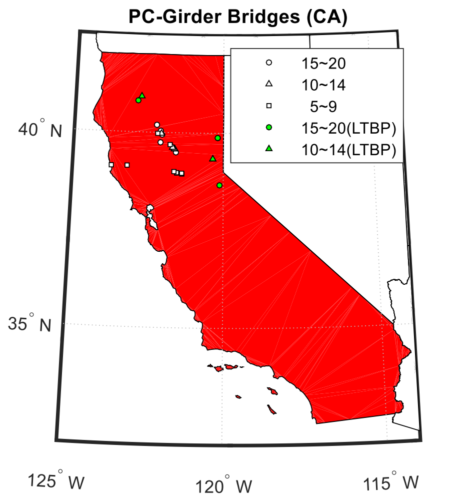


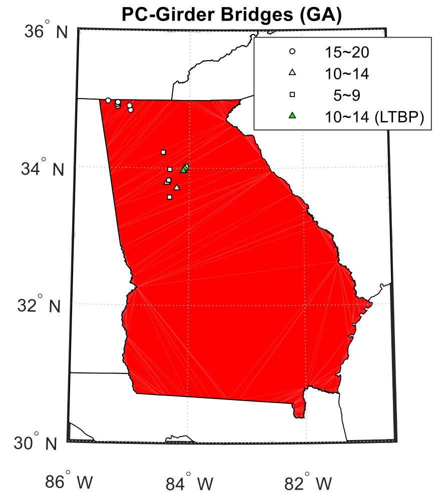
Pooled-fund Study TPF-5(395)

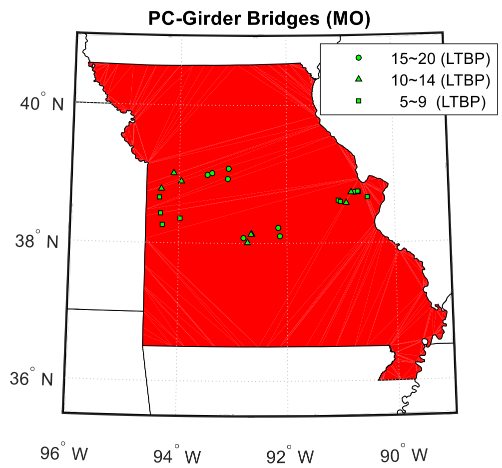
- **Bridge Selection**
  - **National Bridge Inventory**
  - **Long Term Bridge Performance Program**
- **Bridge Selection Criteria**
  - **State owned**
  - **Not over a railroad**
  - **Max span length between 10 and 50 m**
  - **Maximum of four lanes on bridge**
  - **Average daily traffic (ADT) less than 50,000**
  - **Built after 1970**
  - **Three Age Groups**
    - ✓ ***15-20 Years***
    - ✓ ***25-30 Years***
    - ✓ ***35-40 Years***

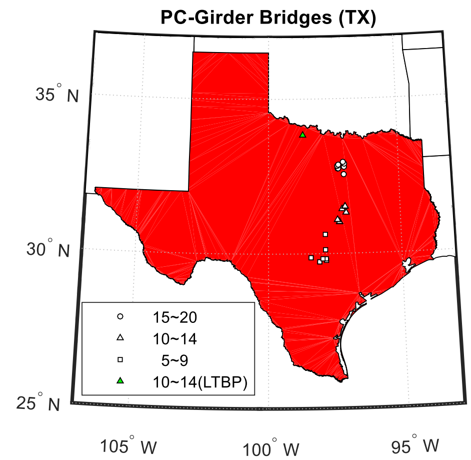
Pooled-fund Study TPF-5(395)

- **36 Prestressed Concrete Girder Bridges**



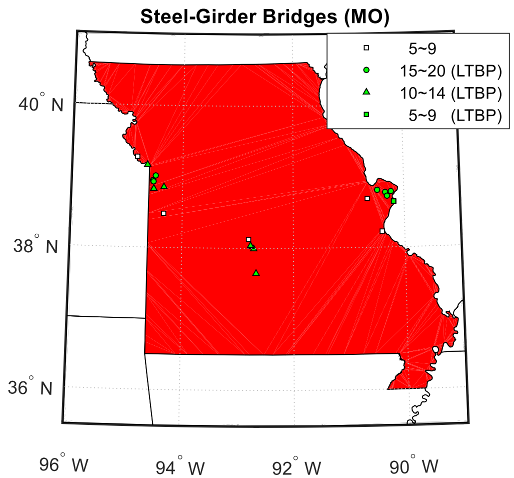


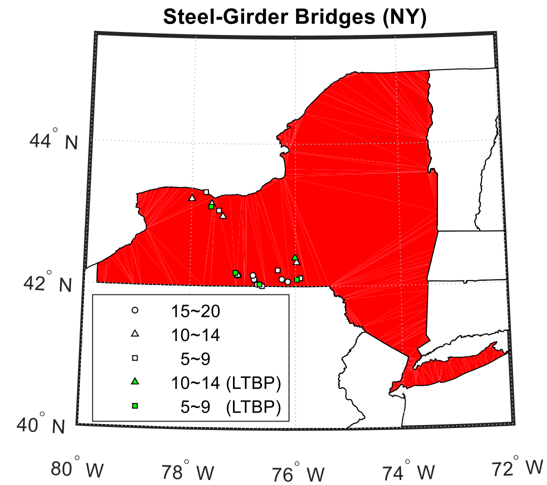


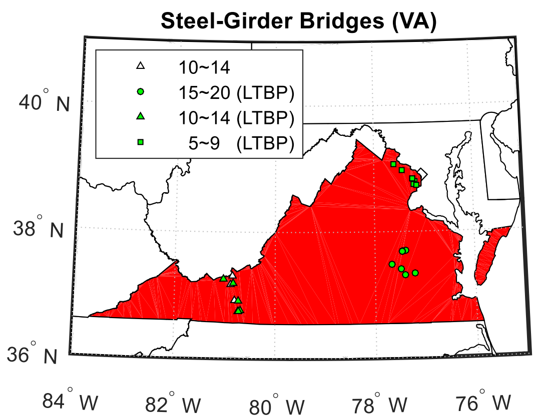


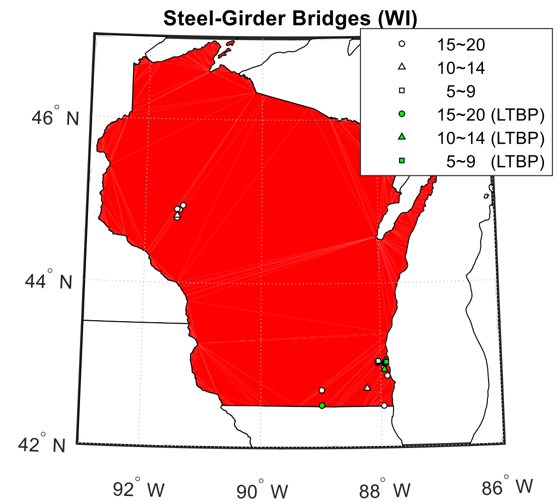
Pooled-fund Study TPF-5(395)

- **36 Steel Girder Bridges**



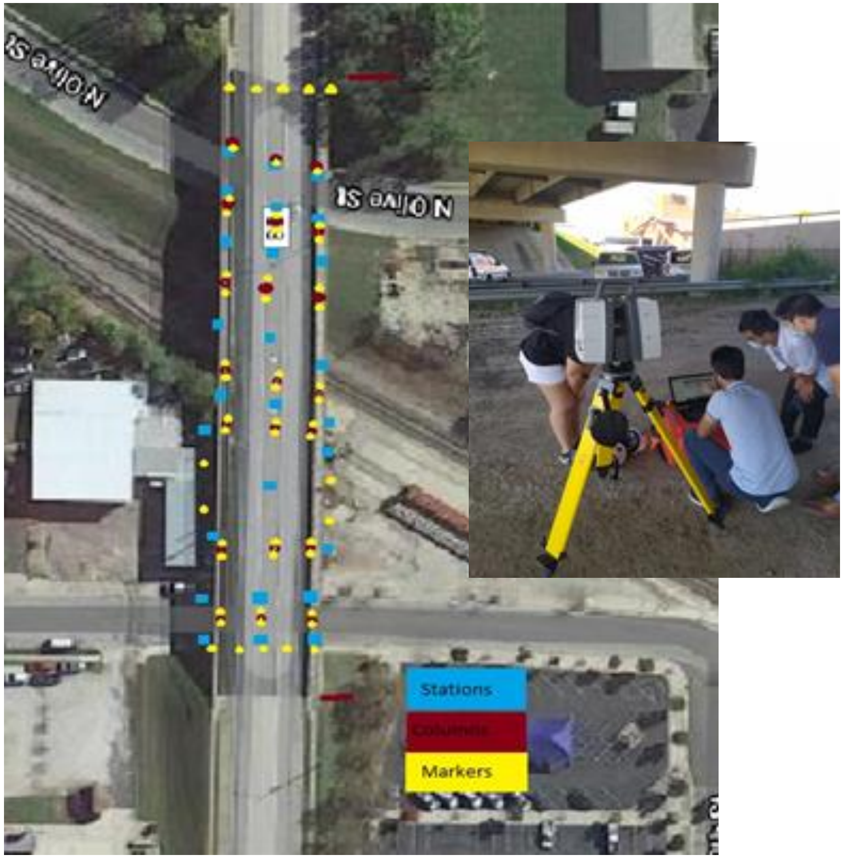






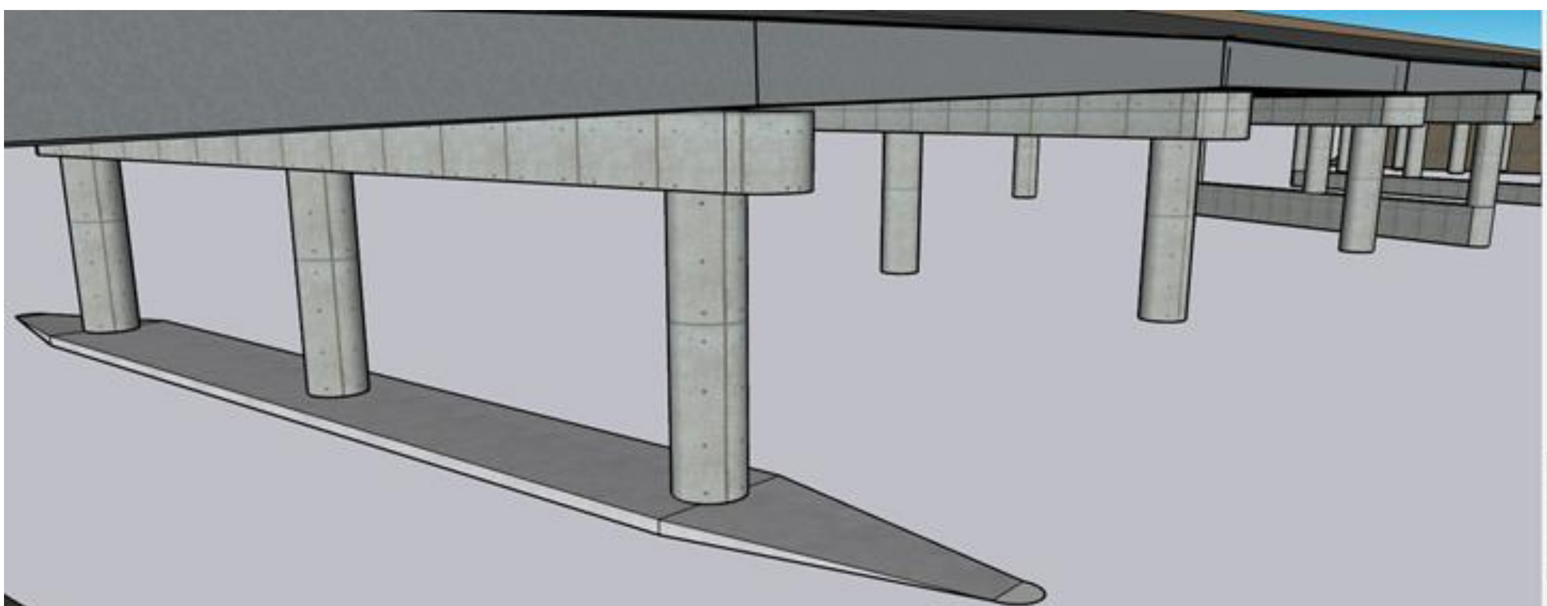
Pooled-fund Study TPF-5(395)

- **Steel-girder Bridge No. 3080, Rolla, MO**
- **Bridge Scanning Using P40 Laser Scanner**



Pooled-fund Study TPF-5(395)

- **3D Reconstruction of Bridge No. 3080**



Concluding Remarks

- **An automated inspection platform can help inspect and maintain bridges faster, safer, cheaper, and more consistent.**
- **Advanced technologies to support the automated inspection platform are being developed in the INSPIRE UTC.**
- **The pooled-fund initiative can help develop case studies, protocols, and guidelines that can potentially be adopted by state DOTs for bridge inspection and maintenance.**

Acknowledgement

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- The advanced technologies presented were originally developed with financial support from the U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology (USDOT/OST-R) under Grant No. 69A3551747126 through INSPIRE University Transportation Center (http://inspire-utc.mst.edu) at Missouri University of Science and Technology.
- The views, opinions, findings and conclusions reflected in this publication are solely those of the authors and do not represent the official policy or position of the USDOT/OST-R, or any State or other entity.

INSPECTING AND PRESERVING INFRASTRUCTURE THROUGH ROBOTIC EXPLORATION

Climbing Robots for Steel Bridge Inspections

TRB Webinar on
Robot-Enabled Sensing and Augmented Learning (RESEAL) for Bridge Inspection

Hung (Jim) La, Ph.D., M.ASCE, F.IEEE
Associate Director of INSPIRE University Transportation Center
University of Nevada, Reno

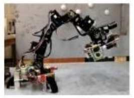
March 29, 2022, 1:00 – 2:30 pm



Talk Outline

- Overview of recent development of steel climbing robots
- Robotic developments for steel bridge inspection from the Advanced Robotic and Automation (ARA) Lab, University of Nevada, Reno
- Defect (crack, rust) detection with the climbing robot

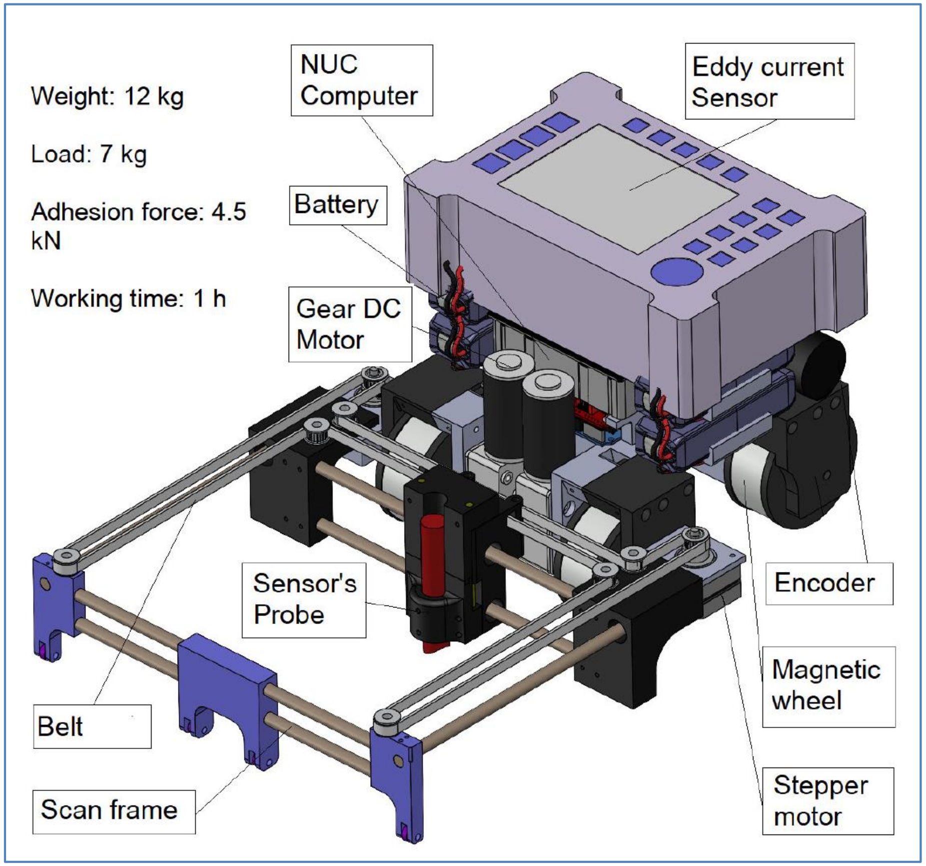
Overview of steel climbing robot developments

Robot	Type of Locomotion	Detail	Climbing Ability	Adhesion Method
Mecanum-wheel Robot [Kamdar2015] 	4-mecanum wheels	681 × 559 × 323 mm 34 kg 0.64 m/min	Flat x Concave Convex x Cylinder	Permanent Magnet (untouched)
Tank-like Robot [Versatrax100-Inuktun] 	2 roller chains	376 x 220 x 115 mm 4.5 kg 0.15 m/s	Flat x Concave x Convex Cylinder	Permanent Magnet (untouched)
4-Wheels robot [Wang_ICA2014] 	4 magnetic wheels (flexible frame)	352 × 215 × 155 mm 3 kg 0.32 m/s	Flat x Concave x Convex x Cylinder	Permanent Magnet
2-Wheels robot [Eich_MED2015] 	2 magnetic wheels	380 x 280 x 150 mm 0,67 kg 0.5 m/s	Flat x Concave x Convex x Cylinder	Permanent Magnet
Inch-worm robot [Ward2016] 	7-DOF-Inch worm	220 x 240 x 150 mm 18 kg 0.2 m/s	Flat x Concave Convex Cylinder	Permanent Magnet
Spider robot [Genki Sato2017] 	6 limbs-spider	600 x 600 x 250 mm 12 kg 0.2 m/min	Flat x Concave Convex Cylinder	Electromagnet

- Most existing designs are developed for particular applications with limited functions.
- Most robots provide visual inspection only. Some robots use untouched magnets making them too heavy.
- Most existing designs have a fixed distance between the magnet and surface, and may not work on different types of surface contours. They might be difficult to apply on complicated structures of real bridges that require adaptable, light, and effectively data-collecting robots.
- Drones still get limited with energy issues and can only perform visual/shallow inspections.

Prototype 1: Wheeled Mobile Climbing Robot

- **Specifications:**
  - ✓ ***Length 465.5 mm***
  - ✓ ***Width 312 mm***
  - ✓ ***Height 217.3 mm***
  - ✓ ***Weight 12 kg***
  - ✓ ***Load 7kg***
  - ✓ ***Drive:***
    - 4 motorized wheels
    - 3 motorized Eddy scan
- **Work well on a flat surface**



Prototype 1: Wheeled Mobile Climbing Robot

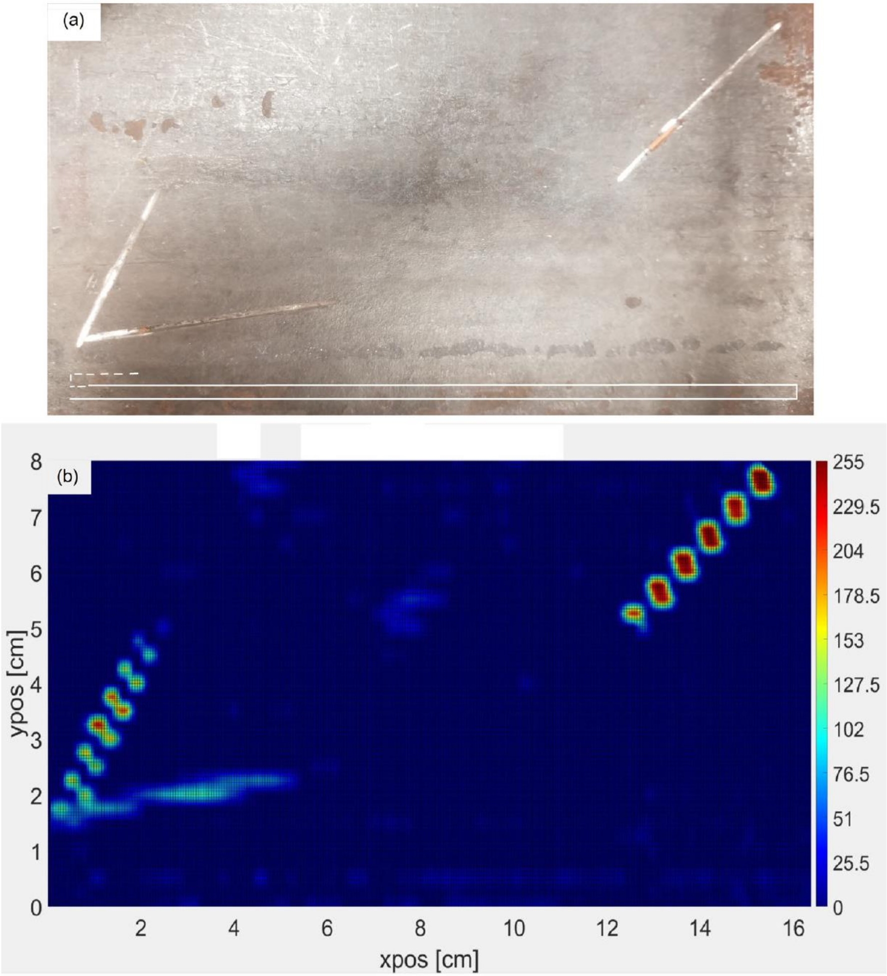
- **Adhesion Test**

Adhesion test: a woman (weight of 64kg) hanging from robot adhered to steel I beam. The robot's adhesion force is significantly stronger than the force that multiple people can exert combined is.

Prototype 1: Wheeled Mobile Climbing Robot

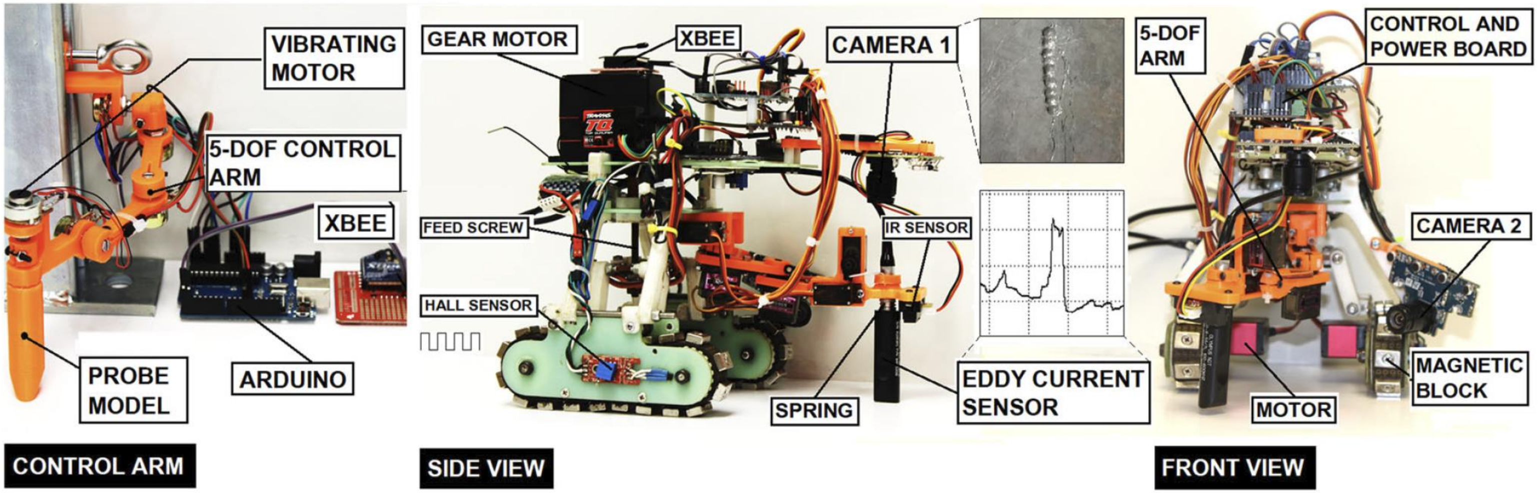
Prototype 1: Wheeled Mobile Climbing Robot

- **Eddy Current-based Defect Map**



Prototype 2: Tank-Liked Mobile Climbing Robot

- **Specifications:**
  - ✓ ***Length 163 mm***
  - ✓ ***Width 145 mm***
  - ✓ ***Height 198 mm***
  - ✓ ***Weight 3 kg***
  - ✓ ***Drive: 2 motorized roller-chains and 1 motorized transformation***
- **Work well on both flat and curving surfaces**



Prototype 2: Tank-Liked Mobile Climbing Robot

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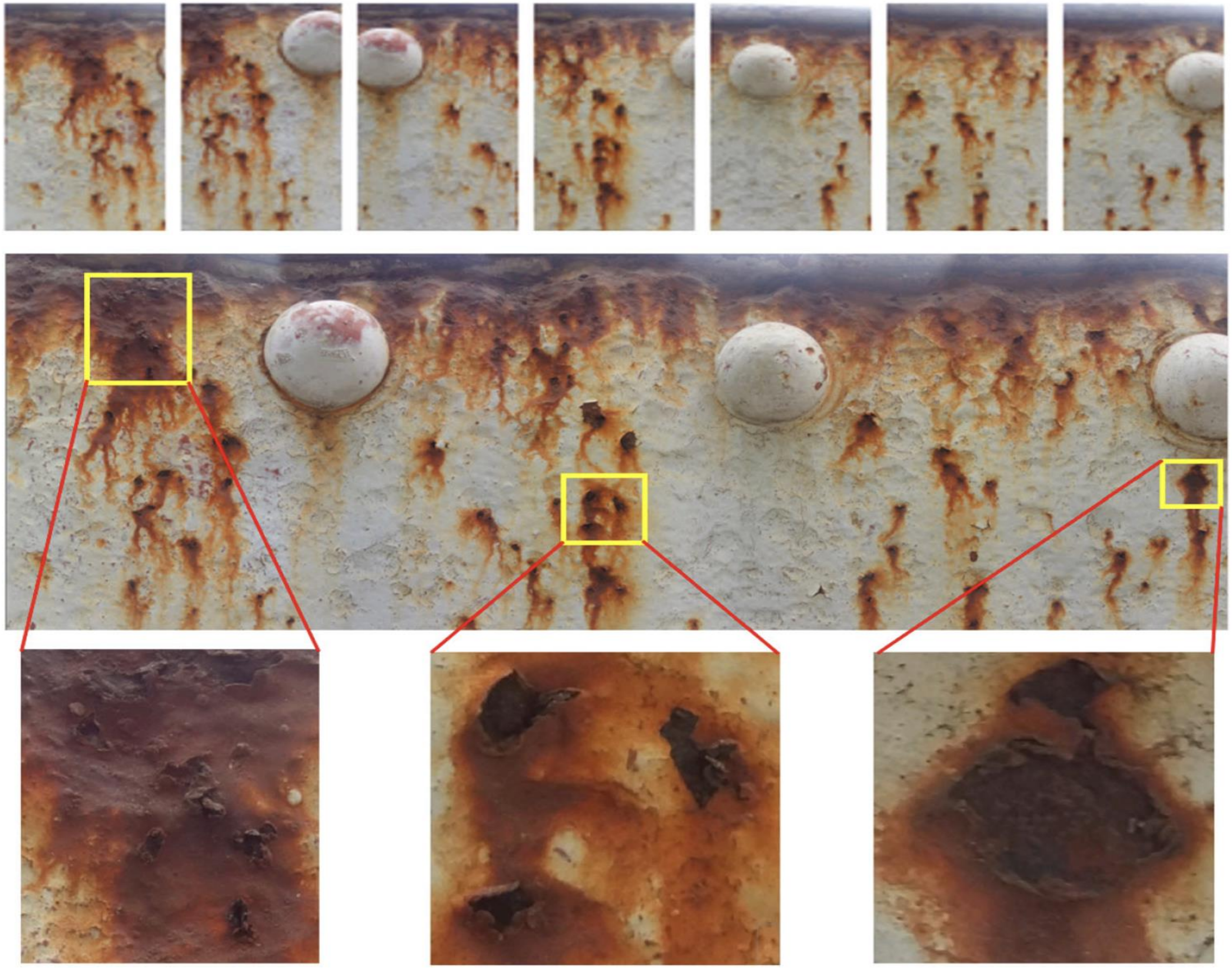
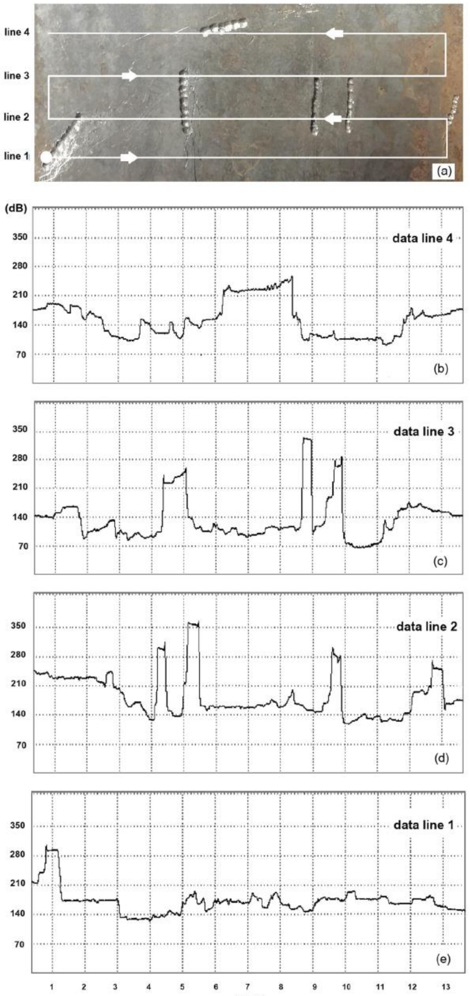
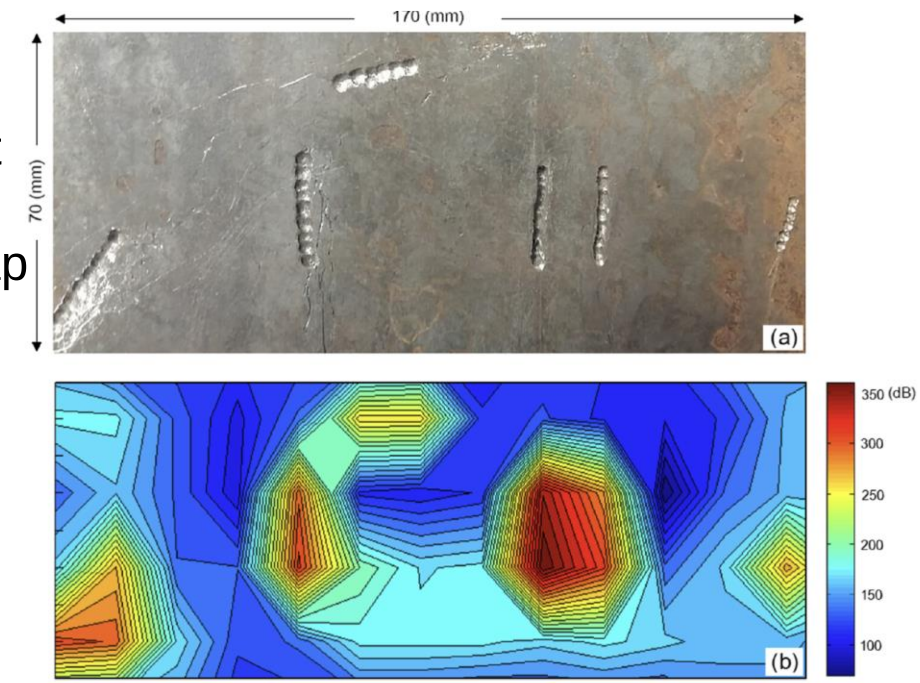


Prototype 2: Tank-Liked Mobile Climbing Robot

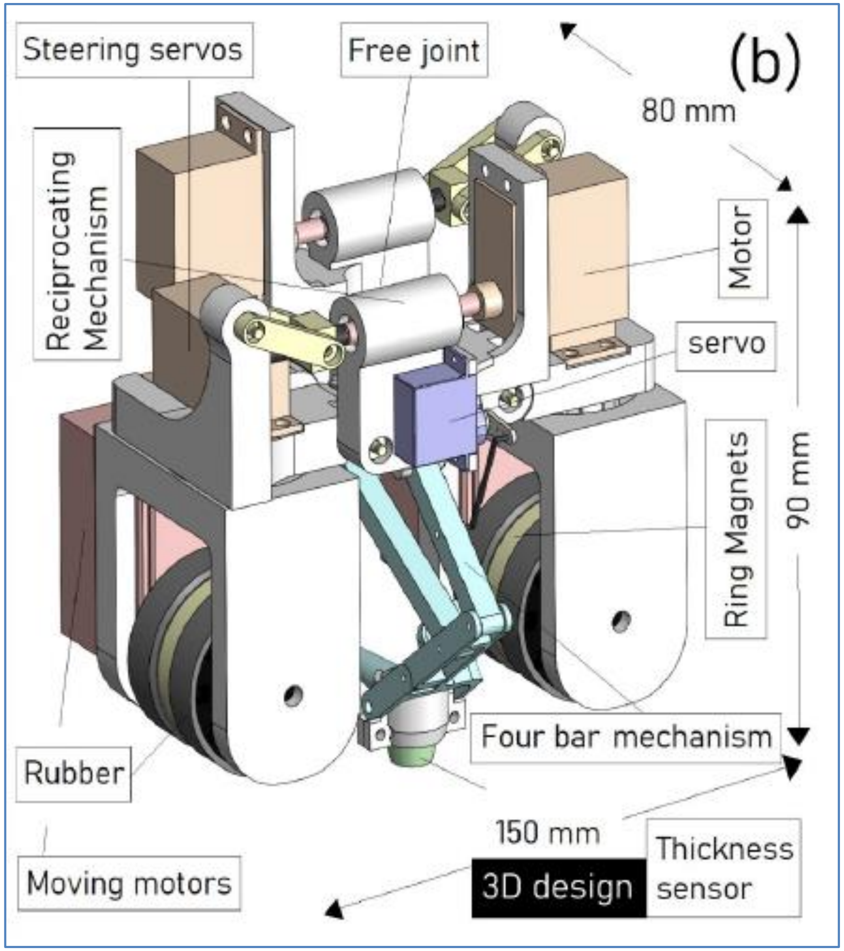


Eddy Current Reading to Condition Map

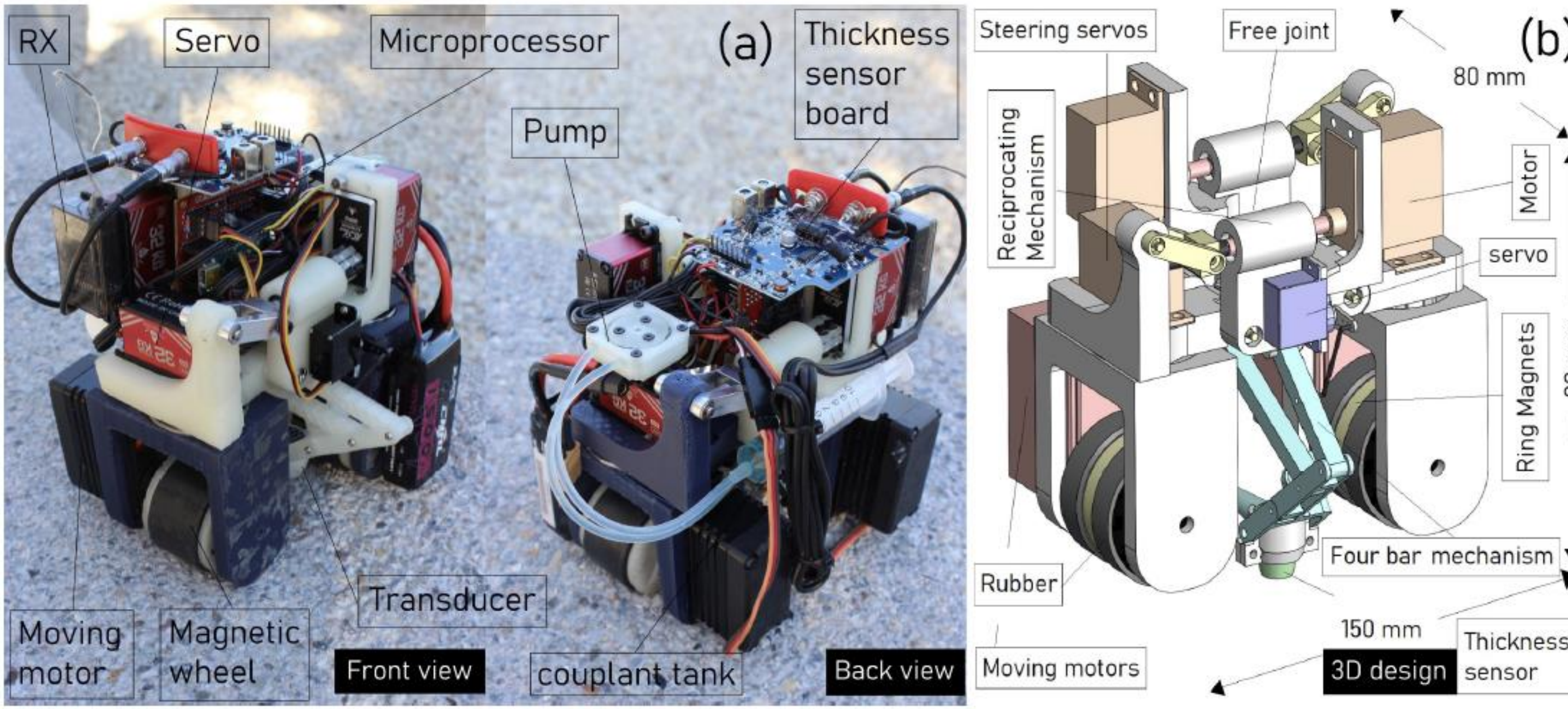


Prototype 3: Bicycle-Like Climbing Robot

- **Specifications:**
  - **Length 150 mm**
  - **Width 80 mm**
  - **Height 90 mm**
  - **Weight 1.2 kg**
  - **Drive:**
    - ✓ ***2 motorized wheels***
    - ✓ ***1 motorized steering***
    - ✓ ***2 motorized reciprocating mechanism***
- **Work well on both flat and curving surfaces**



Prototype 3: Bicycle-Like Climbing Robot



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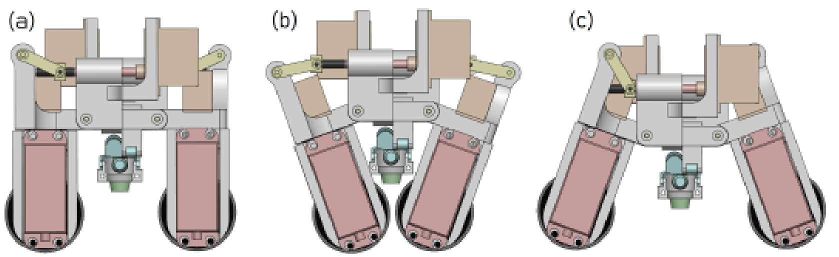
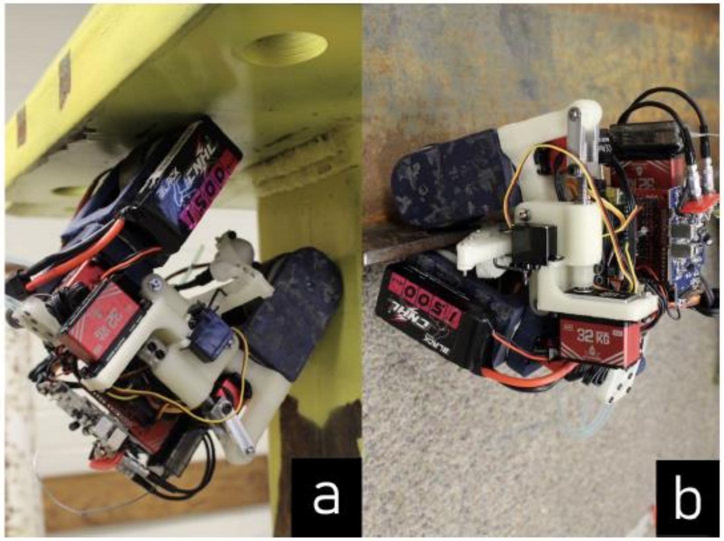


The robot's shape when applying reciprocating mechanisms. a) in normal conditions, b) when passing thin edges, c) when passing acute internal corners.



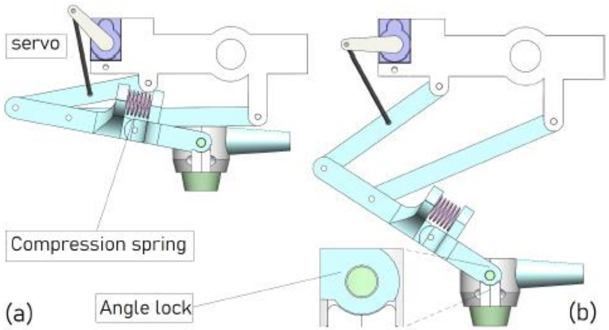
The robot is passing convex and concave surfaces: a) It makes a turn of 90 degrees on internal corners. b) It transforms the wheels to pass a thin edge on a U-shaped beam.

TABLE I

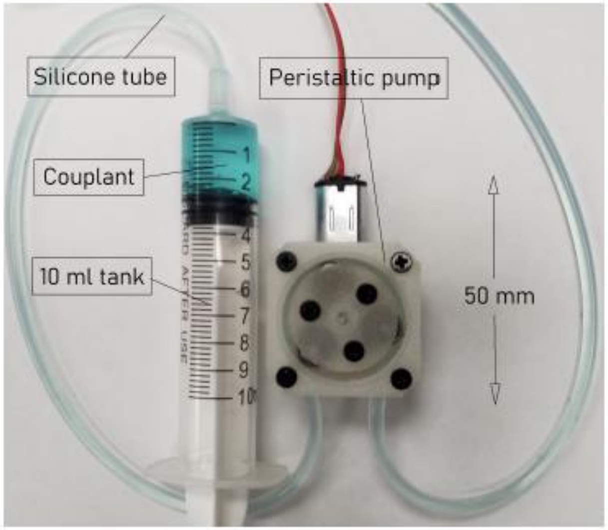
SPECIFICATIONS OF OUR TESTING CONDITIONS.

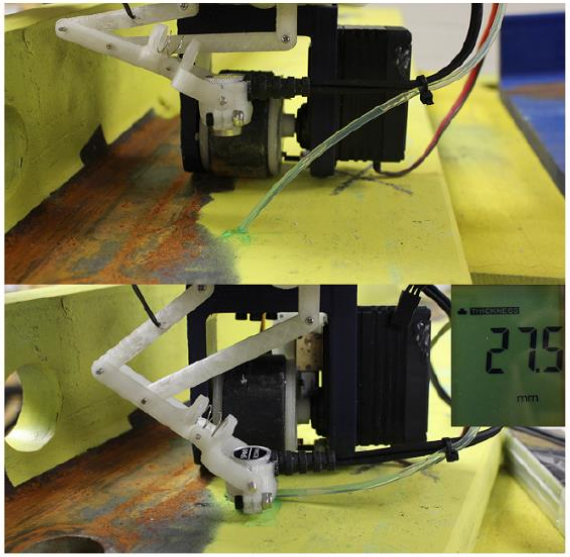
Structural parameters	Dimension (mm)
Thinnest steel surface	2
Smallest steel cylinder diameter	100
Thickest coated paint	3
Highest nut or bolt area	4

Prototype 3: Sensor Deployment Mechanism



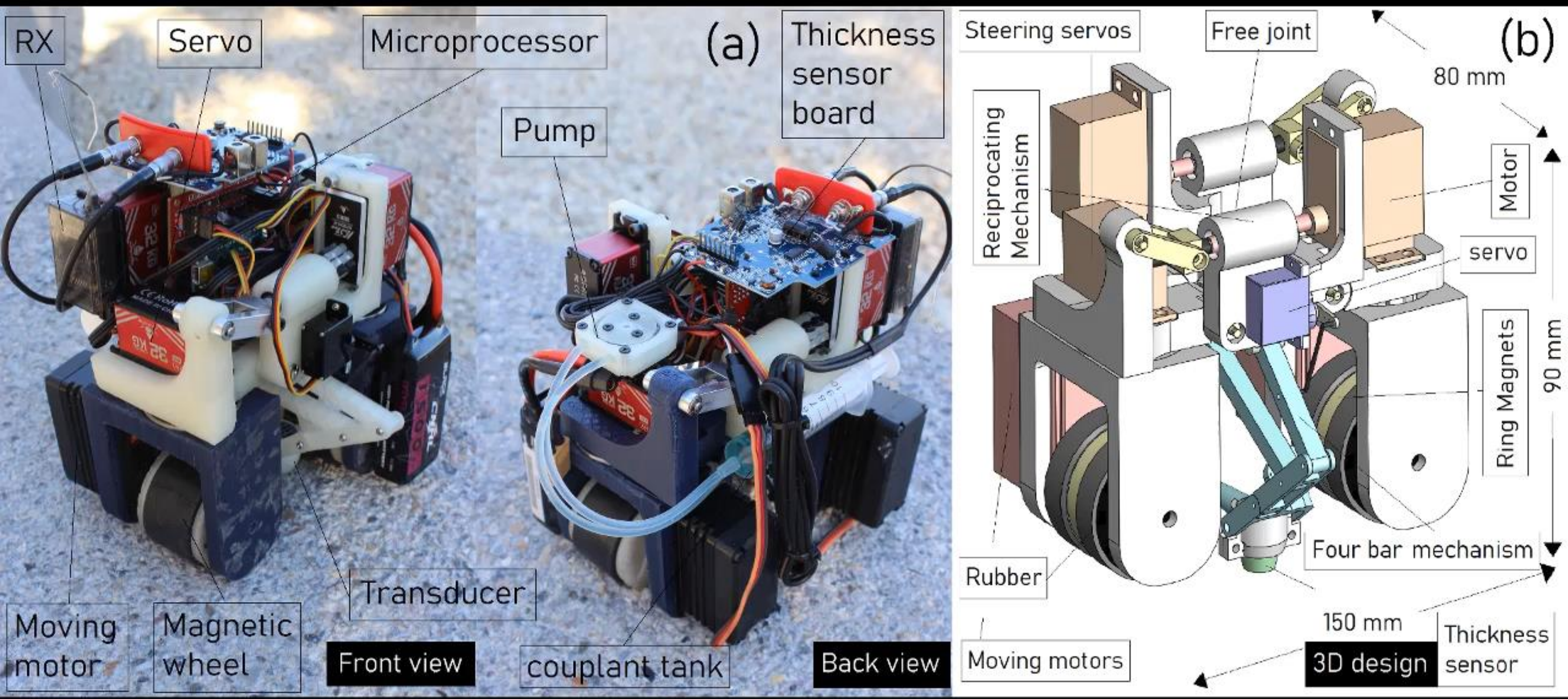
The four-bar mechanism. A compression spring acts as a soft contact with the surface. An angle lock is added to create a free movement of the probe when approaching uneven surfaces.





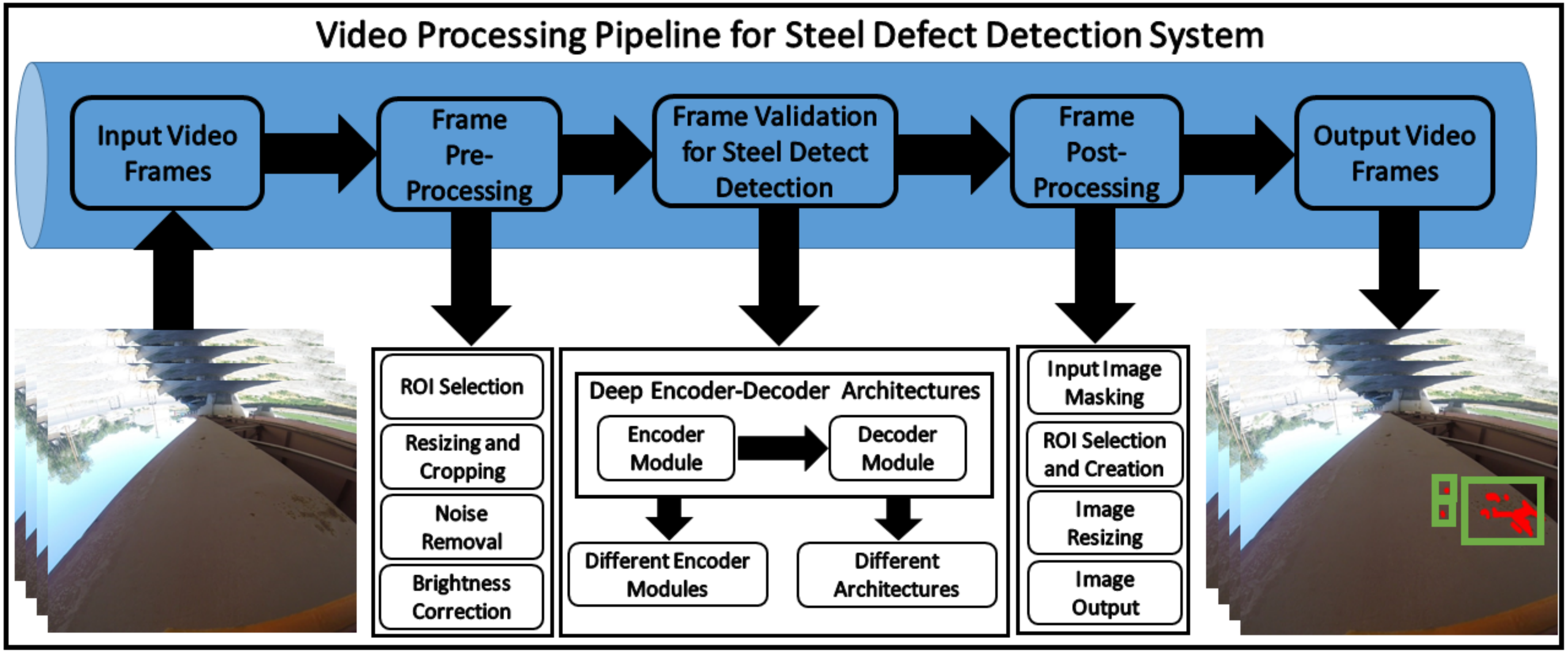
A demonstration of measuring the thickness of a steel surface. The transducer is well contacted to the surface thanks to the compression spring and angle lock. The final result is averaged over three times.

Prototype 3: Robot Climbing Testing

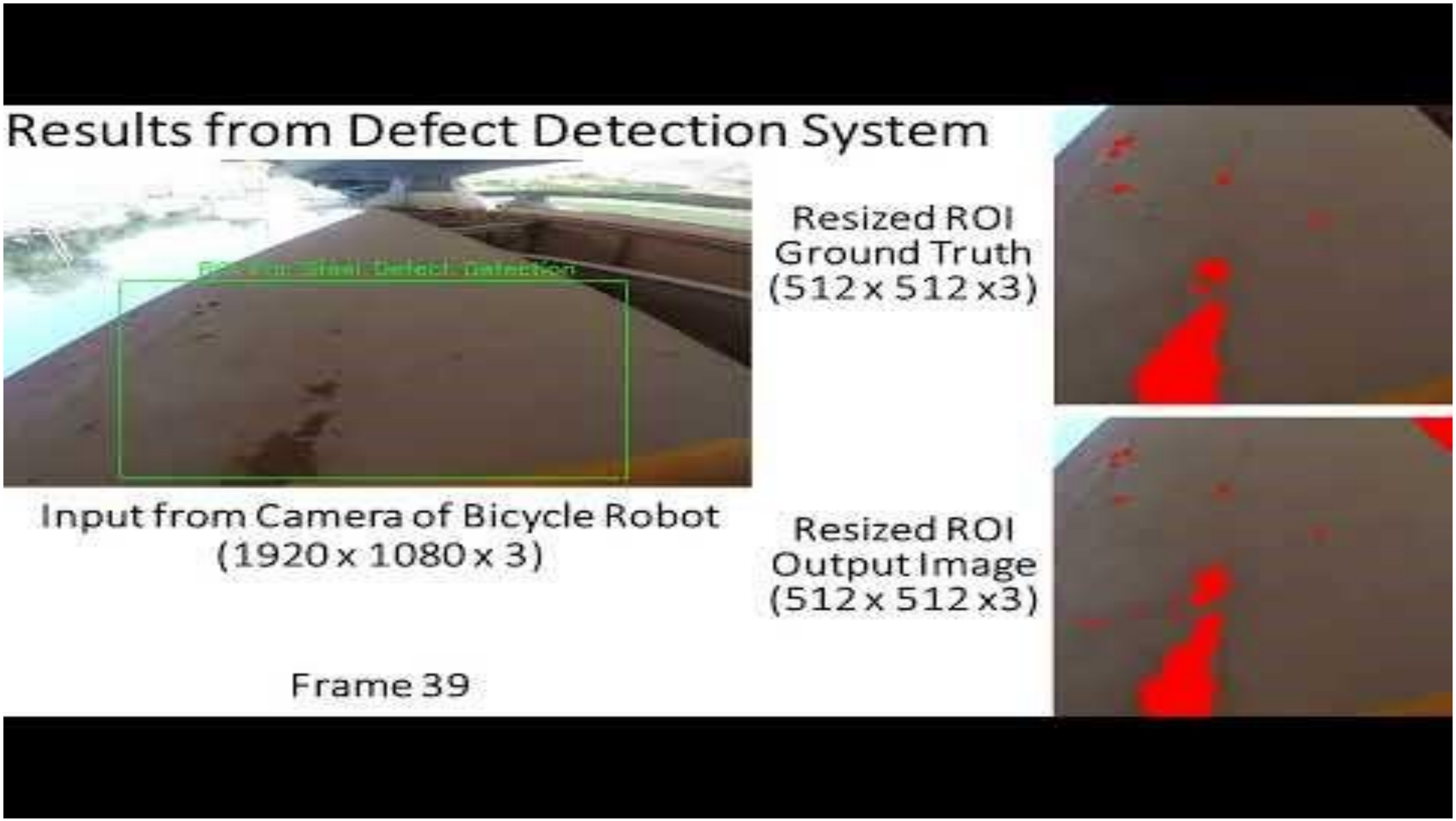


Prototype 3: Bicycle robot with defect detection test

Prototype 3: Bicycle Robot with Steel Defect Detection



Real-time Defect/Rust Detection



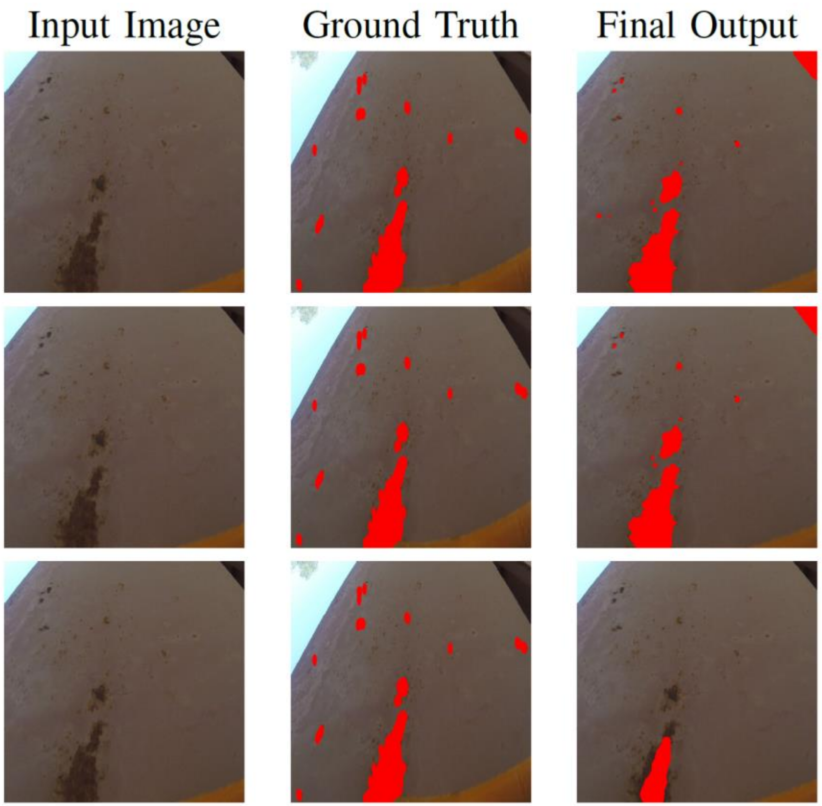
Steel Defect Detection

TABLE III

UNet [37] Architecture					
Encoder		**Dice Loss**	**mIOU**	**Precision**	**Recall**
ResNet-18 [40]	Max.	31.80	91.86	**99.92**	91.59
	Min.	4.37	54.87	99.54	54.86
	Avg.	12.59	80.88	99.73	81.02
ResNet-34 [40]	Max.	28.11	96.40	99.83	96.57
	Min.	1.96	59.40	99.56	59.43
	Avg.	11.11	83.47	99.72	82.13
RegNet-X-2 [42]	Max.	18.81	97.13	99.78	**99.35**
	Min.	1.59	71.56	99.55	71.71
	Avg.	7.26	88.01	99.65	87.06
Efficient-b0 [41]	Max.	32.17	**97.33**	99.80	97.53
	Min.	**1.41**	55.85	99.53	55.92
	Avg.	11.44	83.26	99.61	83.46
Efficient-b2 [41]	Max.	47.25	96.06	99.75	96.36
	Min.	2.18	43.56	99.56	43.60
	Avg.	14.39	69.84	99.65	81.87

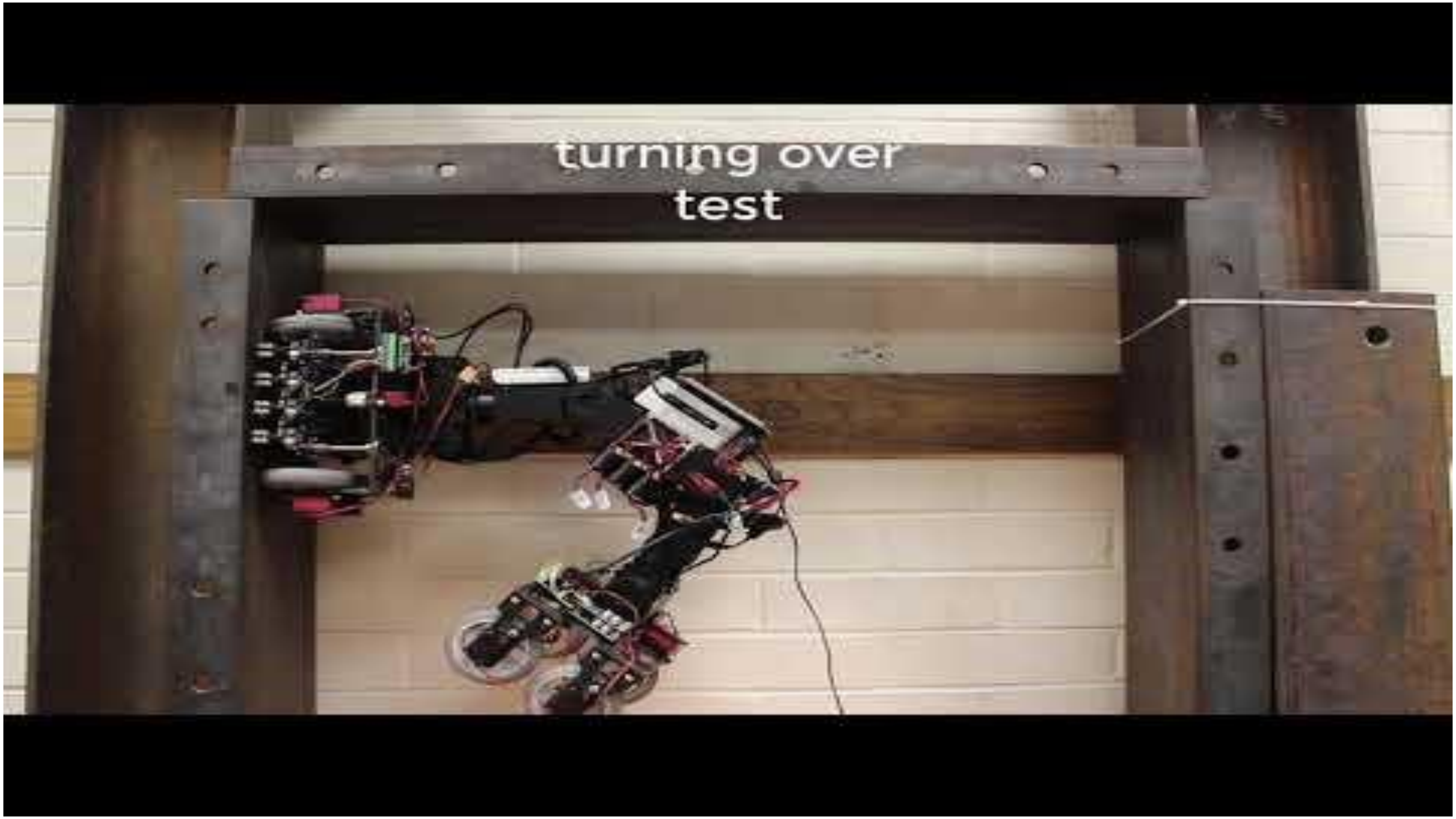
TABLE IV

DeepLab [39] Architecture					
Encoder		**Dice Loss**	**mIOU**	**Precision**	**Recall**
ResNet-18 [40]	Max.	26.46	95.50	**99.80**	95.58
	Min.	2.52	62.24	99.55	62.02
	Avg.	9.05	86.26	99.68	86.26
ResNet-34 [40]	Max.	26.46	93.76	99.82	93.82
	Min.	3.36	61.19	99.55	61.06
	Avg.	10.45	84.30	99.68	64.14
RegNet-X-2 [42]	Max.	15.36	**97.58**	99.78	**97.85**
	Min.	**1.30**	75.79	99.56	75.94
	Avg.	6.71	89.41	99.69	90.02
Efficient-b0 [41]	Max.	22.89	96.21	99.59	96.56
	Min.	1.99	65.52	99.55	65.57
	Avg.	9.40	85.13	99.55	85.39
Efficient-b2 [41]	Max.	40.91	90.06	99.85	90.24
	Min.	5.76	48.12	99.46	48.16
	Avg.	17.12	75.38	77.17	55.55



- The first column: original images.
- The second column: ground truths annotated with red color.
- The third column: final outputs of LinkNet ResNet-18, Unet ResNet-18, and DeepLab ResNet-18.

Other climbing prototype



Other climbing prototype

Acknowledgment

- This project is supported by the U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology (USDOT/OST-R) under Grant No. 69A3551747126 through INSPIRE University Transportation Center (http://inspire-utc.mst.edu) at Missouri University of Science and Technology.

- This work is also supported by the National Science Foundation under Hung La’s NSF CAREER #1846513 and NSF-PFI # 1919127awards.

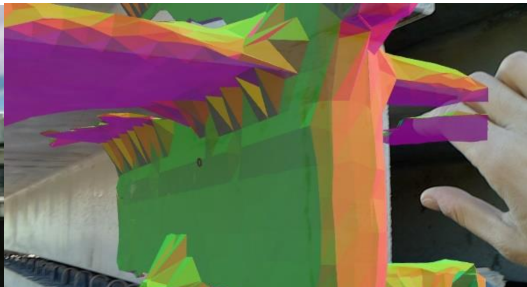
TRB Webinar: Robot-Enabled Sensing and Augmented Learning for Bridge Inspection

Tuesday March 29th 2022

Augmented learning through augmented reality and artificial intelligence

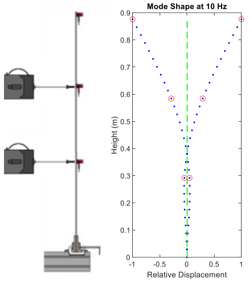
Fernando Moreu[1,2,3,4]

[1]Department of Civil, Construction & Environmental Engineering (CCEE)
[2]Department of Electrical & Computer Engineering (CEC)
[3]Department of Mechanical Engineering (ME)
[3]Department of Computer Science (CS)
University of New Mexico

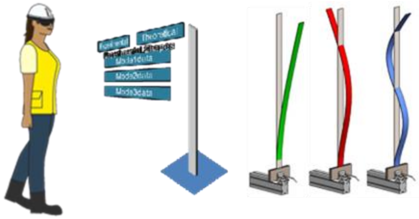


Highlights

Outdoor Field Monitoring
Railroads, Bridges, and Tramways
Structural Health Monitoring
Crack Sensing

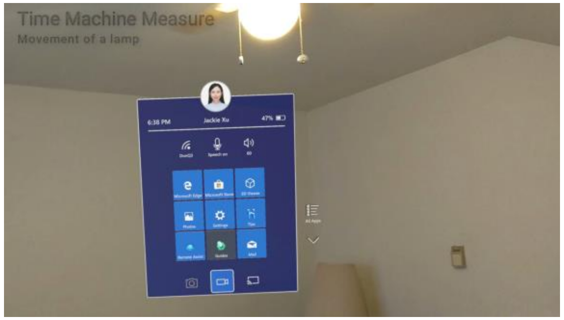


Non-linear Dynamics
Earthquakes & Disasters
Random Vibrations

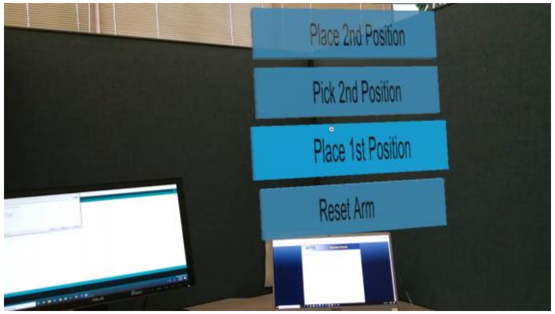


Human-Infrastructure Interfaces

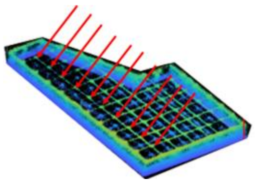
smilab
Smart Management
Infrastructure Laboratory

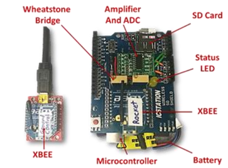


Human-Infrastructure Interfaces
Human Factors in Engineering



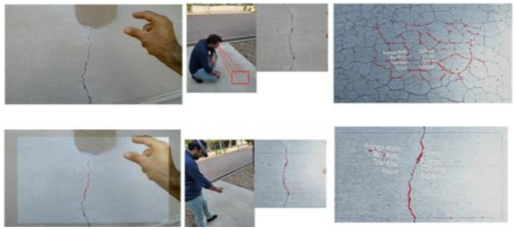
Human-Machine Interfaces
Emergency Rescue





Autonomous Sensing
Wireless Smart Sensors
LEWIS Sensors
Rockets Sensors

Cyber Physical Systems
Cybersecurity



AI AR for automatic crack measurement

Outline

AR Overview

Eye Gazing

Steel Fatigue Crack Finder (SFCF)

Concrete Crack Characterization

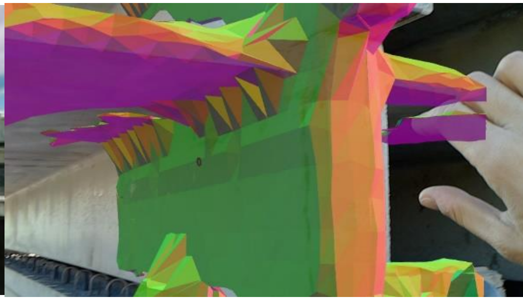
Vibration Monitoring in AR

Robot Control Application for sensor placement with AR

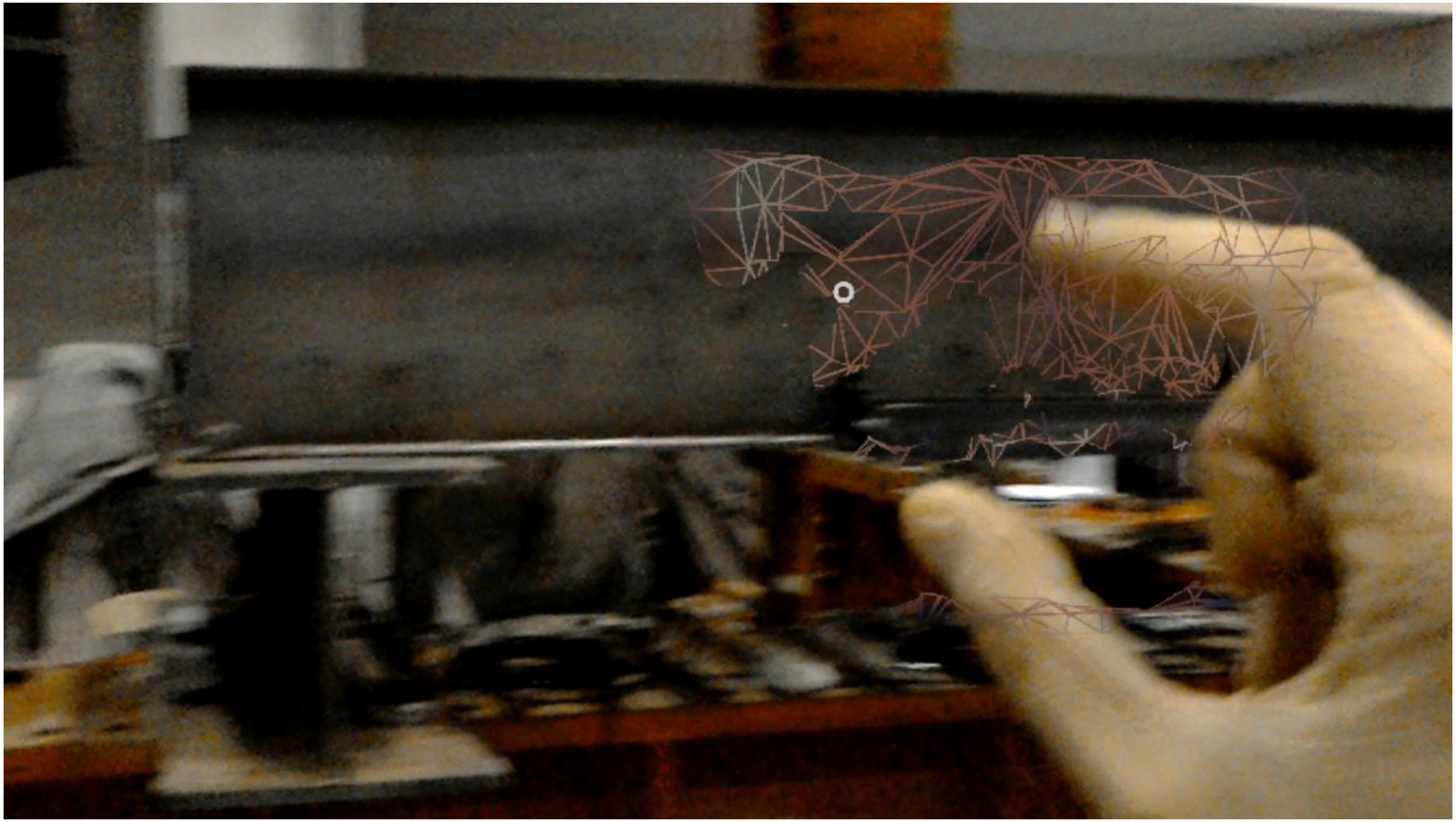
Conclusions

AR Overview

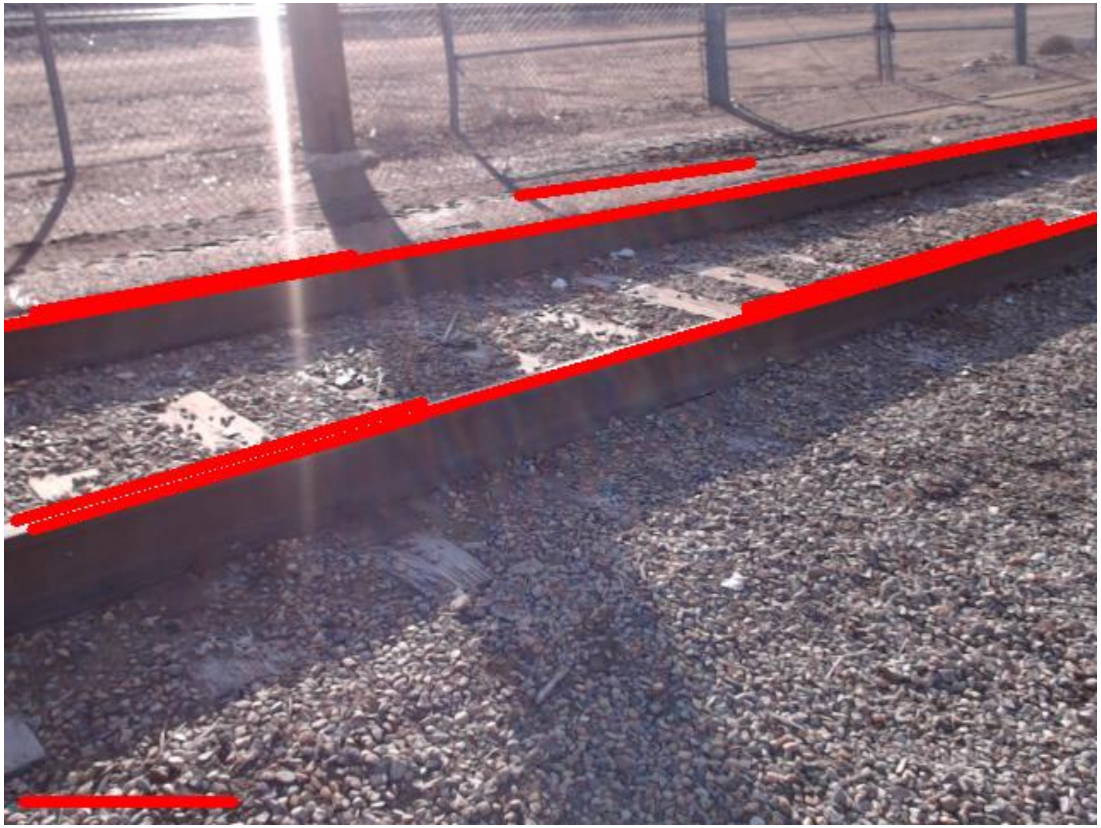


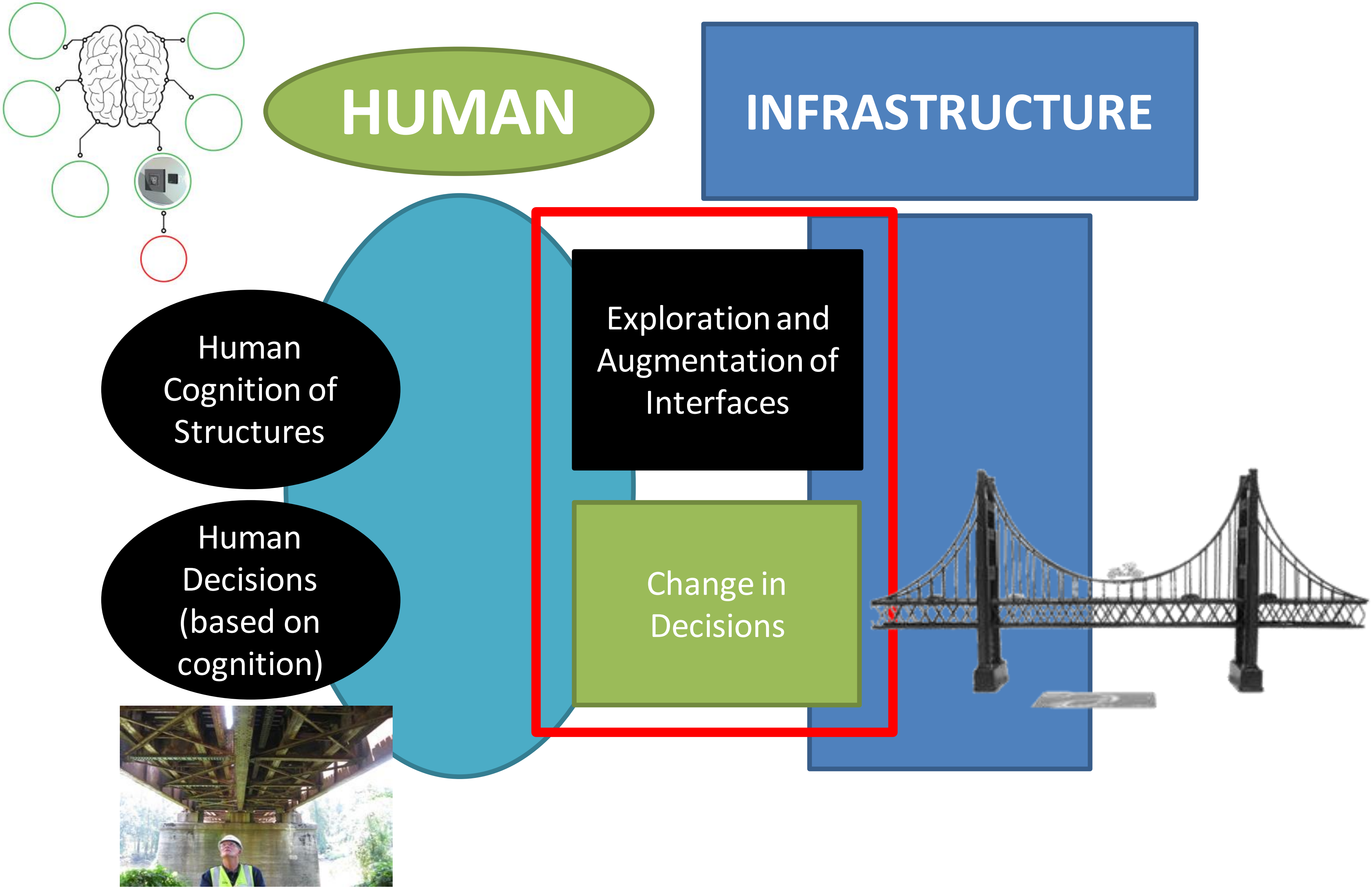


Overview of using AR: what the inspector sees

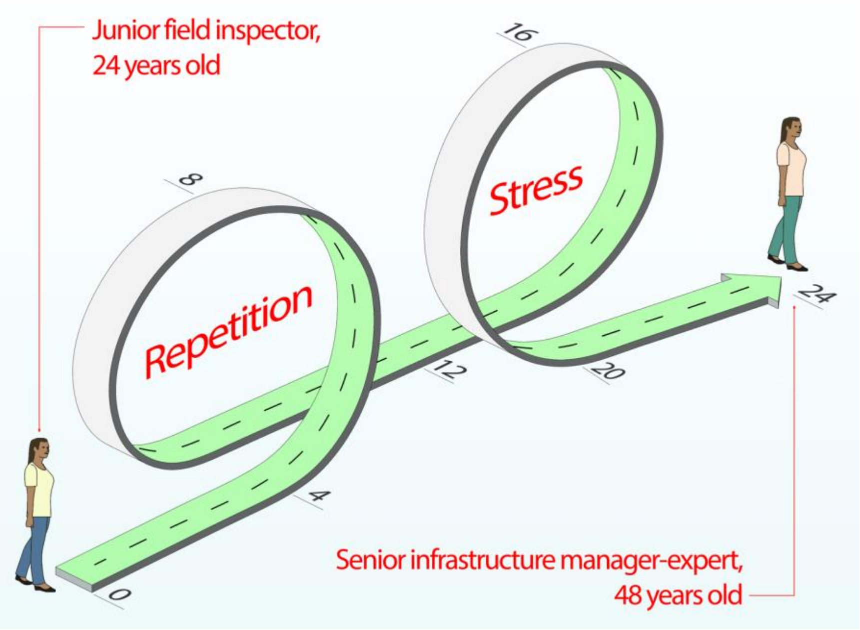


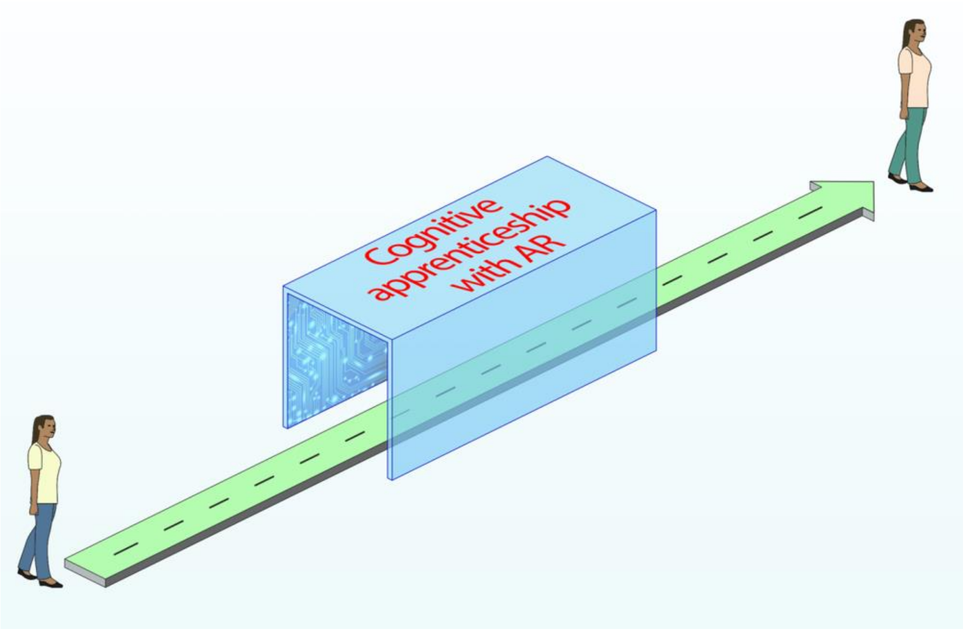
Overview of using AR: rail detection




HUMAN
INFRASTRUCTURE
Human Cognition of Structures
Human Decisions (based on cognition)
Exploration and Augmentation of Interfaces
Change in Decisions

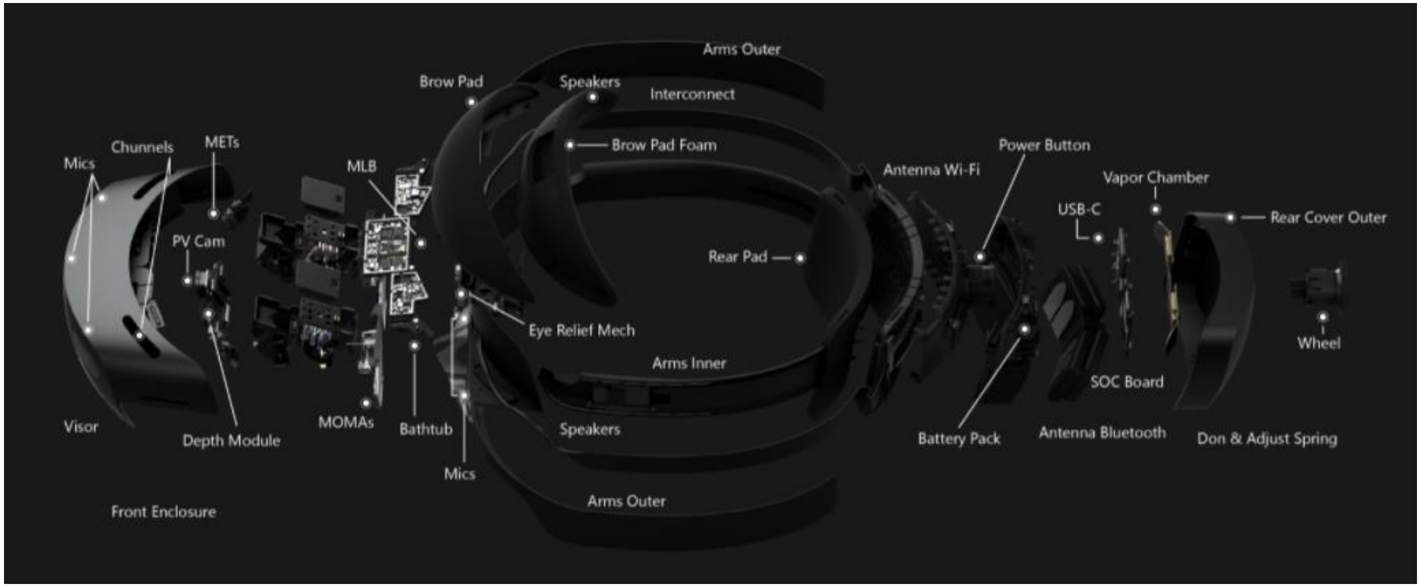
New Learning in Engineering





Augmented Reality – Head Mounted Device (HMD)

Microsoft HoloLens 2



Microsoft HoloLens 2 features

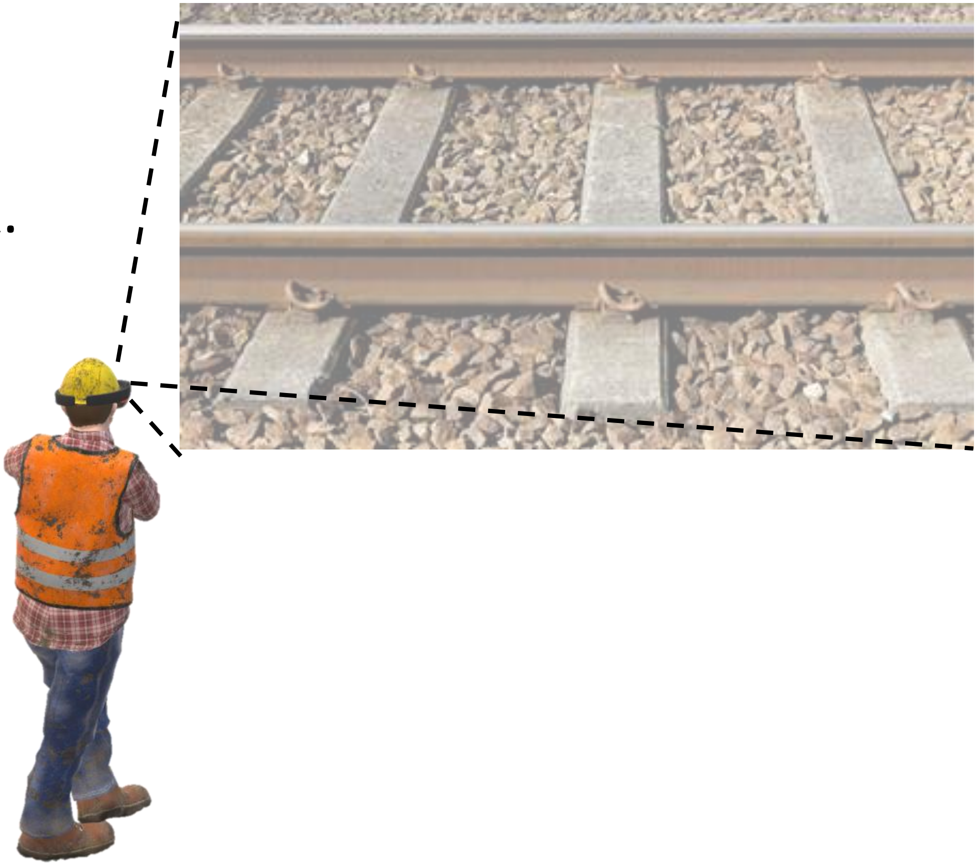
Image courtesy of Microsoft https://docs.microsoft.com/en-us/hololens/hololens2-hardware


KOBALT

Eye Gazing for inspections

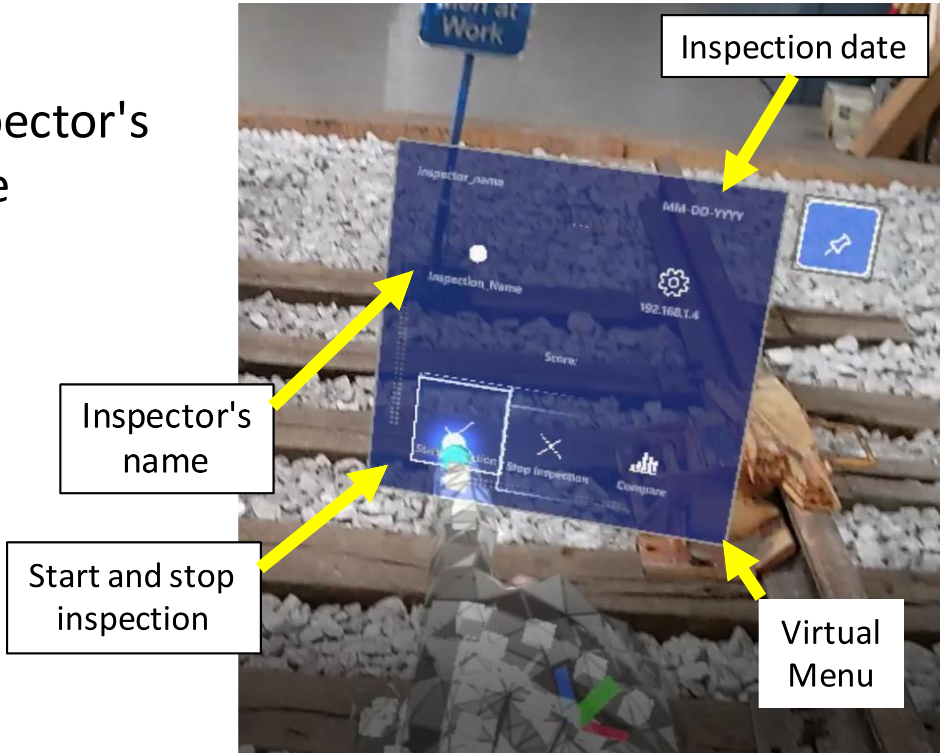
Visual Inspection Quality

- Important to ensure comprehensive visual coverage of the rail track.



EyeRR Software for inspection accuracy quantification

- Quantifies the inspection accuracy and records inspector's visual coverage during the inspection.



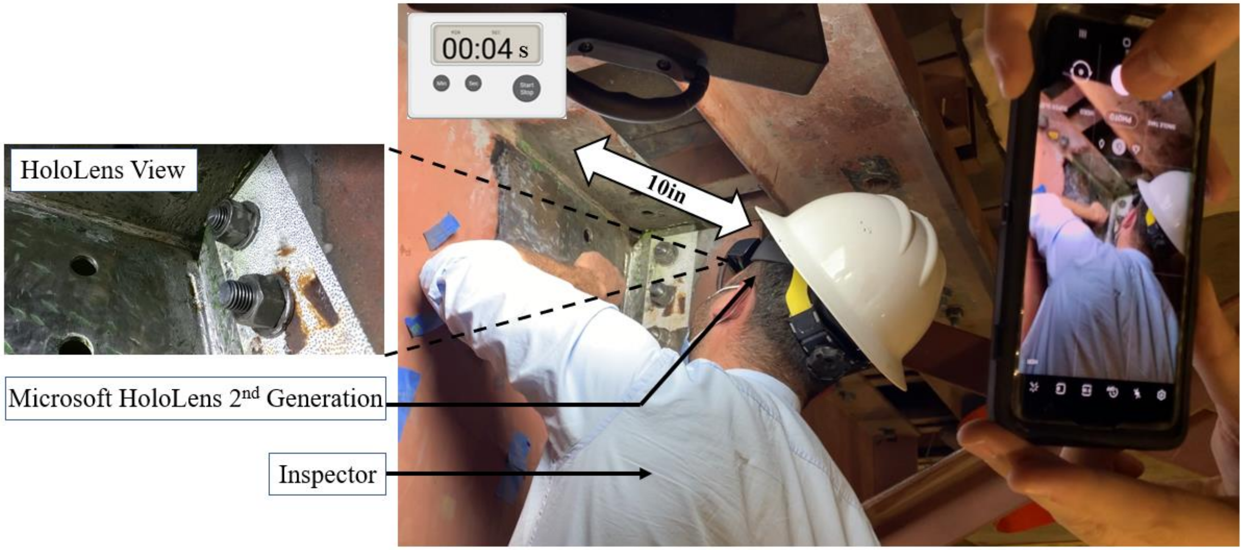
EyeRR's application in rail track inspection

Steel Fatigue Crack Finder (SFCF)

Fatigue Cracks

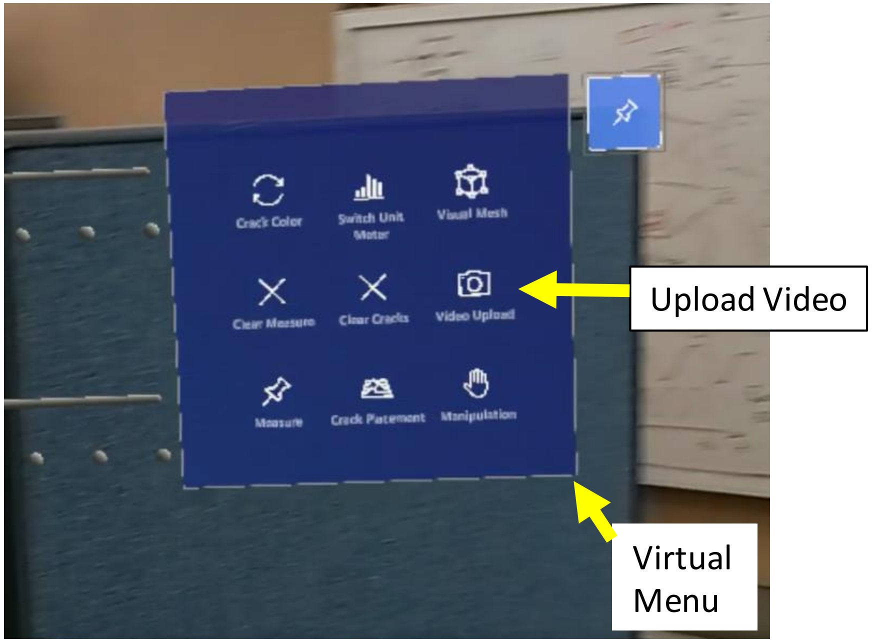
Those are Important because they are:

- Hard to find
- Could propagate and contribute to bigger problems.

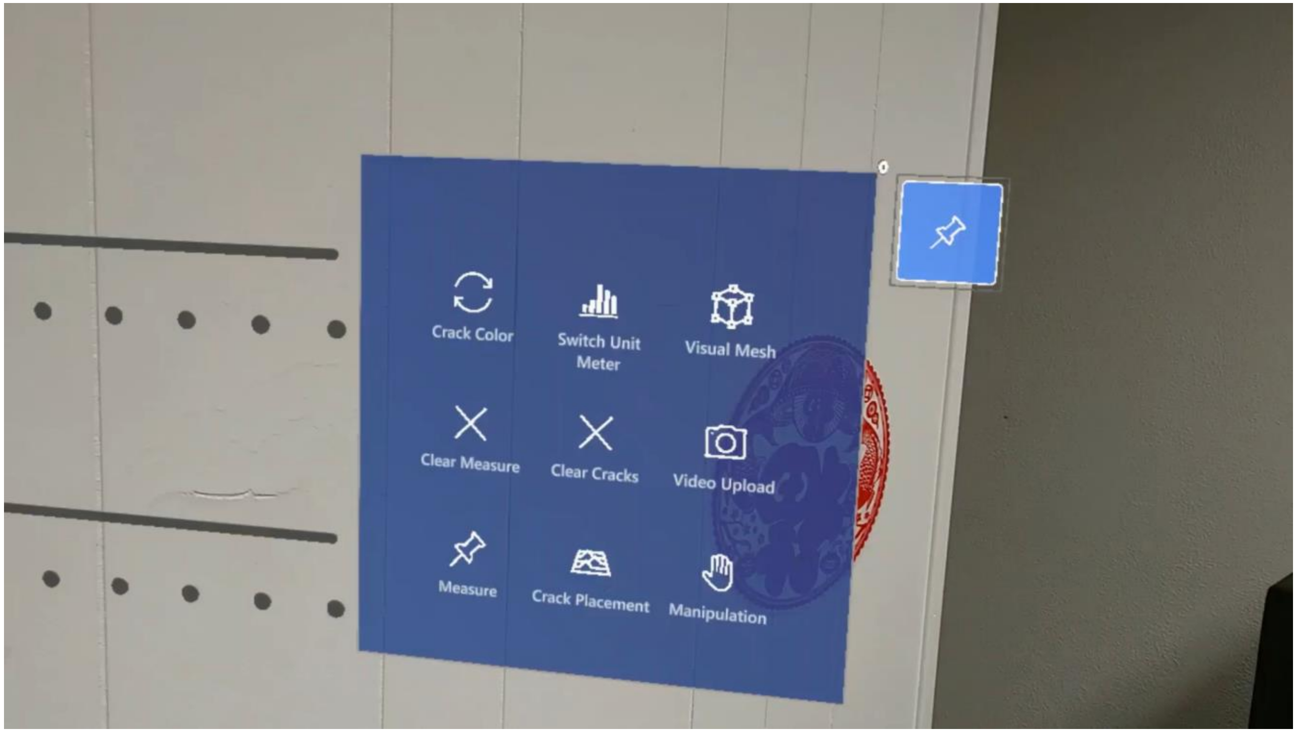


Steel Fatigue Crack Finder (SFCF) software

- Improves the inspector's perception during the inspection to find tiny fatigue cracks



SFCF's indoor test



SFCF's test on a steel structure

Preprocessed

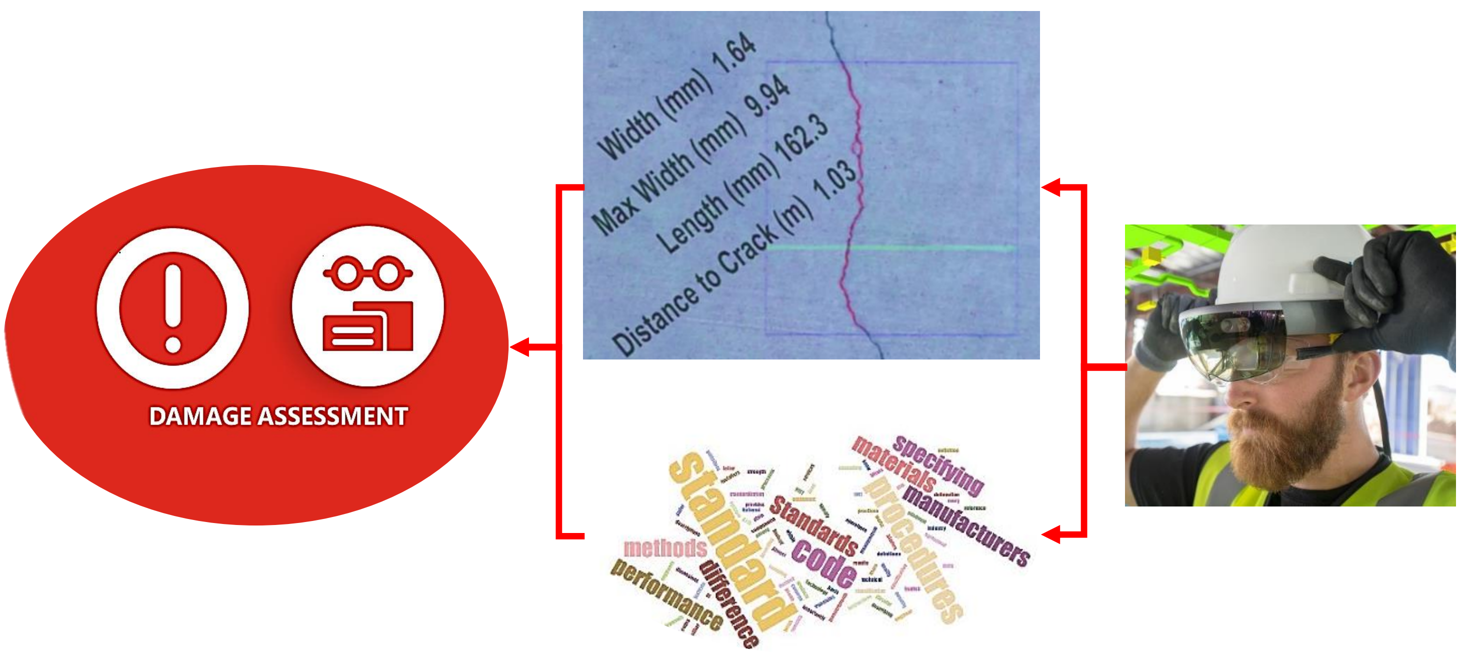
Post-Processed

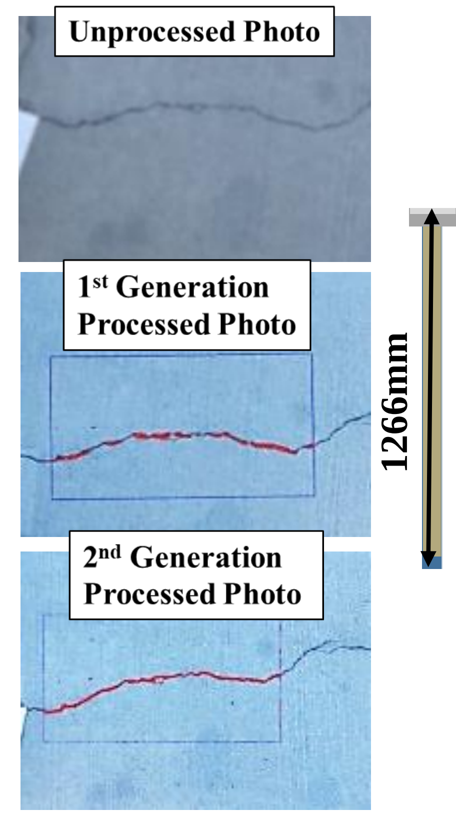
Concrete Crack Characterization

Objective

This project seeks to provide the inspectors with :

- A crack-detection assistant tool for concrete structure inspection
- A faster and more accurate substitute for traditional crack measurement
- An estimate damage assessment and prognosis tool



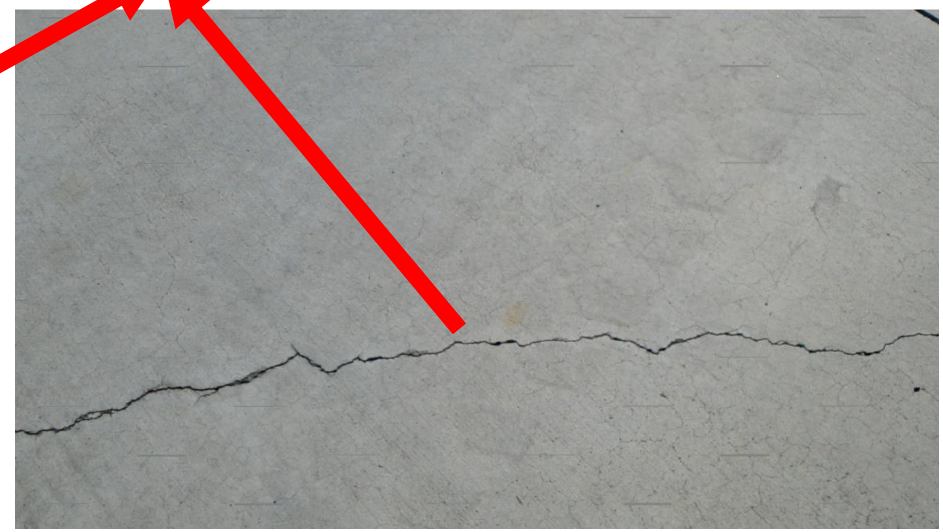


Results

- **Crack Field Sensing Using AR**

Crack Detection

to reduce the processing time, we limits the image processing to the user's field of view



processing time ≅ 1.5 s

by applying a simplification Kernel to the algorithm, the processing time is less than 0.8 in the newer versions

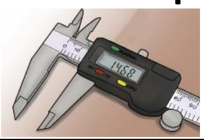
processing time ≅ 1.5s

Results

- **Crack Field Sensing Using AR**

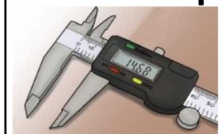
Crack Measurement

Caliper Measurement



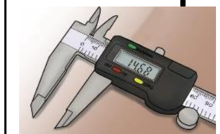
Crack Average Width
2.15 mm

Caliper Measurement

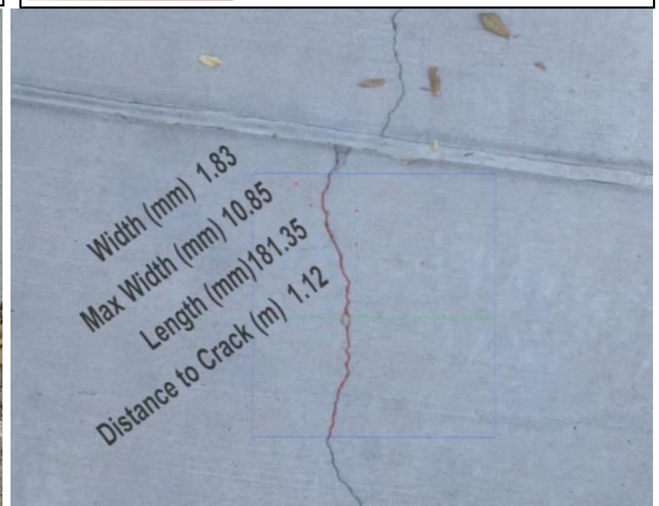


Crack Average Width
1.61 mm

Caliper Measurement



Crack Average Width
1.23 mm



AR Measurement

Average Width:2.10 mm
Relative Error: 2.4 %
Abs Error: -0.05 mm
Max Fluctuations: 0.19 mm

AR Measurement

Average Width:1.73 mm
Relative Error: 7.3 %
Abs Error: 0.12 mm
Max Fluctuations: 0.22 mm

AR Measurement

Average Width:1.35 mm
Relative Error: 7.5 %
Abs Error: 0.095 mm
Max Fluctuations: 0.11 mm

Usability Evaluation

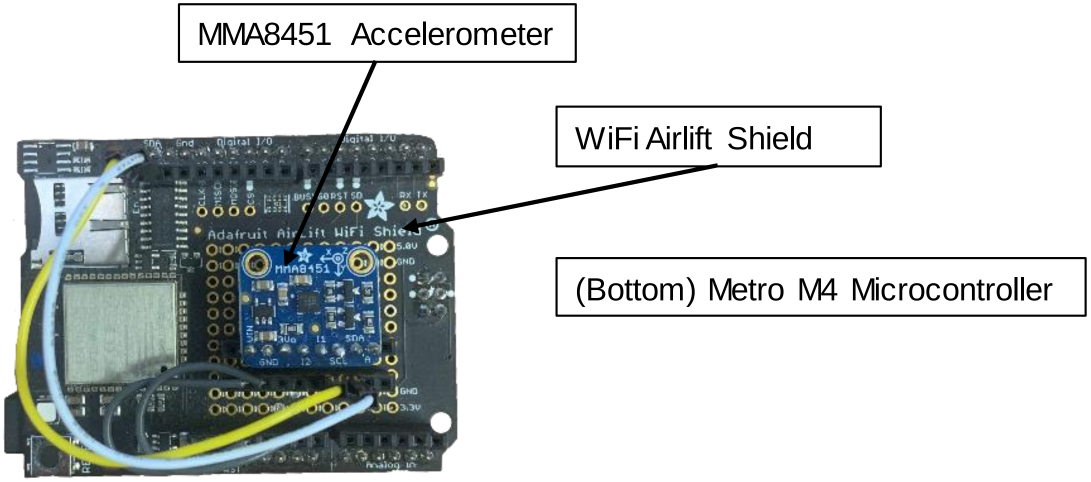
- **Evaluation with bridge engineers from NMDOT**

Vibration Monitoring in AR

Measuring Vibrations and AR

- The LEWIS5 (Low-cost Efficient Wireless Intelligent Sensor) is built with a Metro M4 microcontroller programmed in Arduino.

- Sensor is equipped with an accelerometer to read acceleration data and a WiFi shield for wireless capabilities, which allows it to connect to the HoloLens. Requires a power source connected via micro-USB.

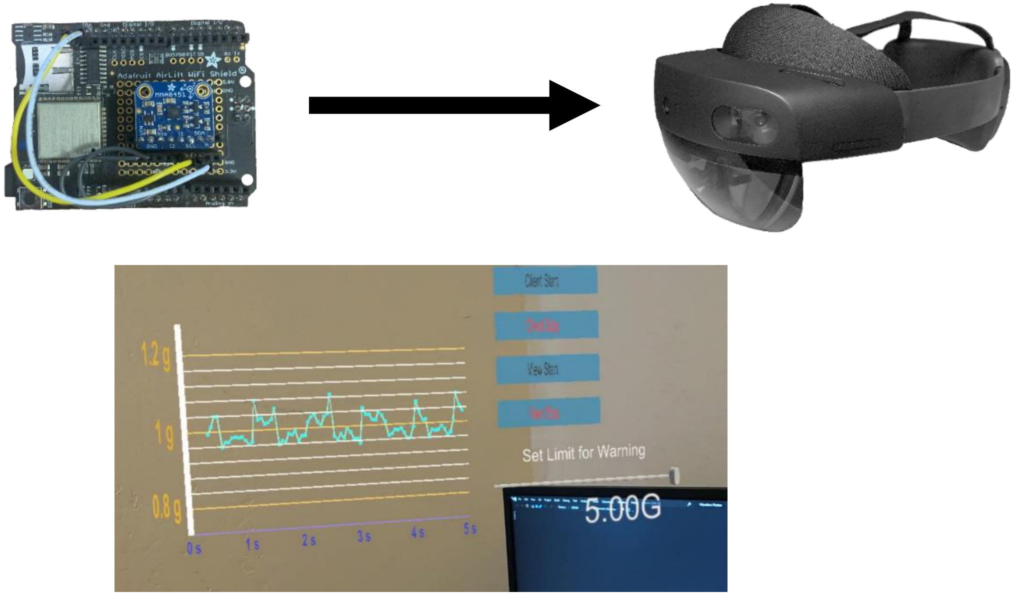


LEWIS5 Sensor

Measuring Vibrations and AR

- AR can be used as an interface for sensor feedback to enable a higher level of understanding of dynamic events and experiments.

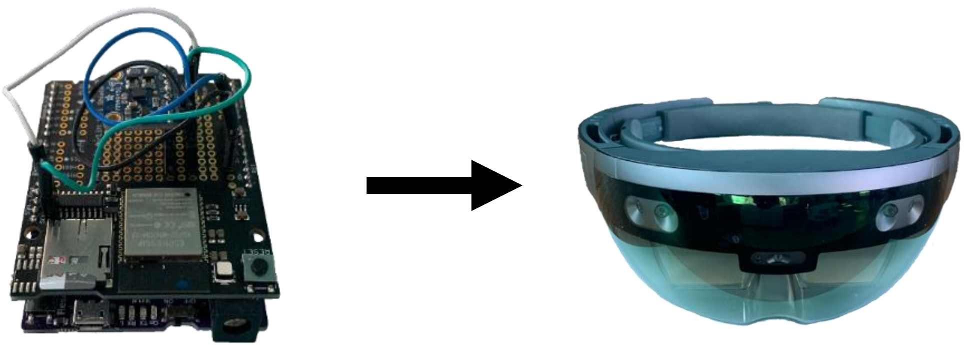
- An application is developed to send acceleration measured by the LEWIS5 to the HoloLens over WiFi and the data is plotted in the AR interface.

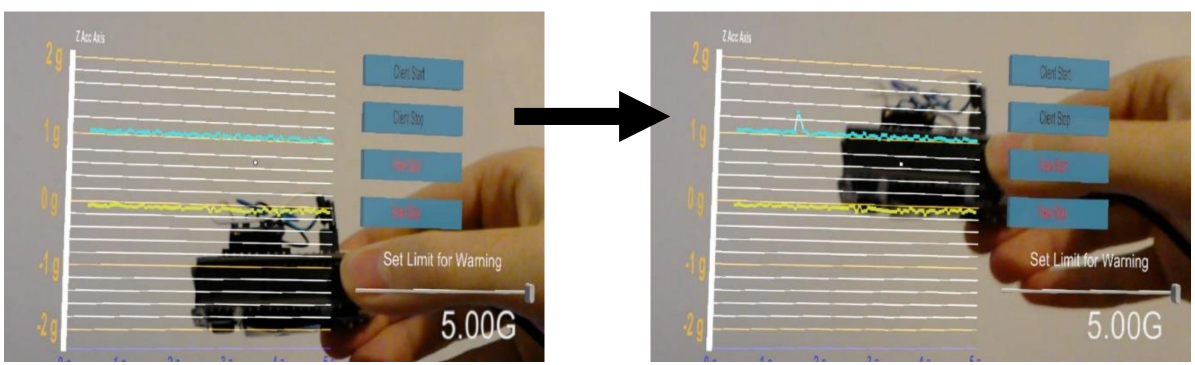


LEWIS5 Sensor sends data to HoloLens and data is plotted in AR

Summary - Overview

- Augmented Reality (AR) can provide a mode of amplifying human cognition of structural response.
- Create AR application to send and graph sensor data in AR headset close to real-time.
- Problem statement: Time delay is a barrier to implementing the app.
- Quantify and compare time delay over a local WiFi network versus a mobile WiFi hotspot.



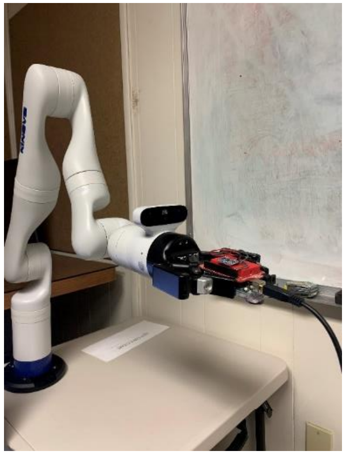


Time delay in sensor movement and response in graph

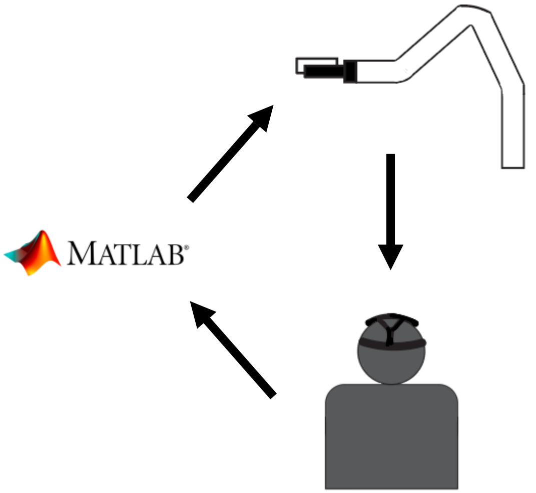
Robot Control Application for sensor placement with AR

Applying robotics to dynamics with AR

- Human intuition often allows humans to solve various tasks faster than robots.
- When these human capabilities are coupled with the repeatability and endurance of robots, full potential can be realized.
- A 7-degree-of-freedom robotic arm (kinova gen3) can be controlled in AR through a pipeline of Hololens and MATLAB code.



Kinova gen3

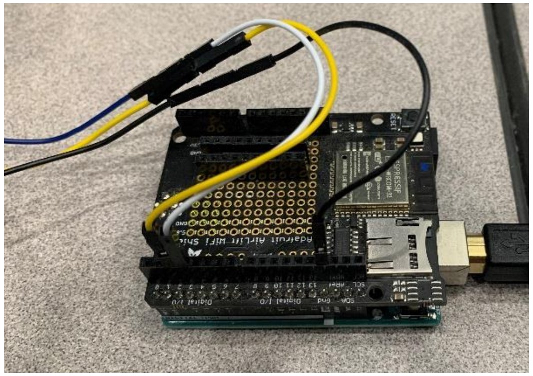


Control framework

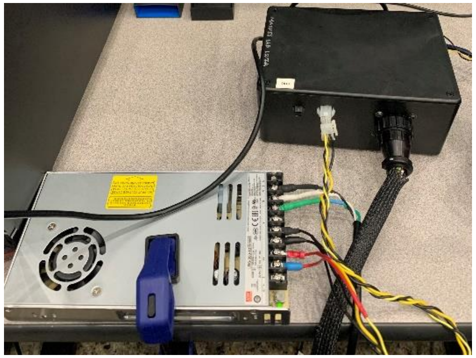
Applying robotics to dynamics with AR

- A preliminary AR application is developed to define a set path for pick-and-place commands for an older model of robot (Cyton Alpha).

Cyton Alpha



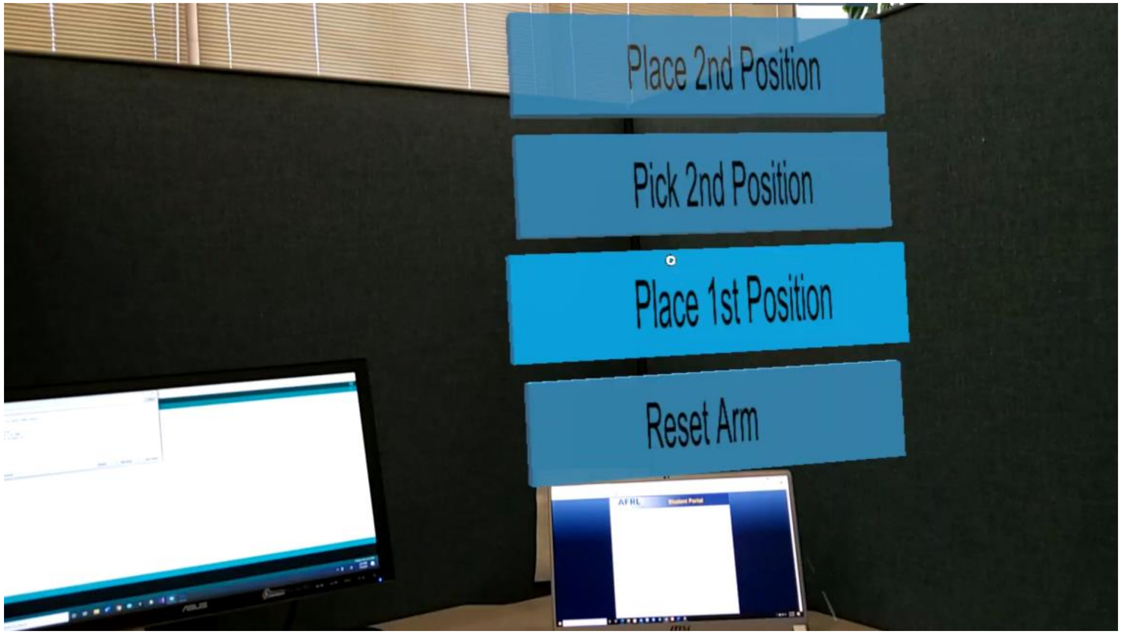
Arduino board with WiFi shield



Power supply and control box

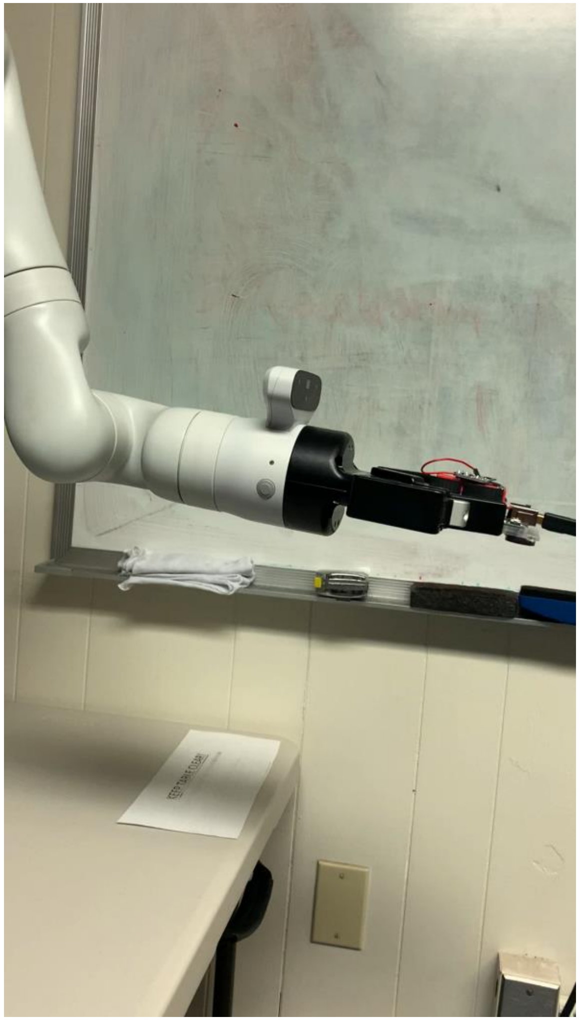
Applying robotics to dynamics with AR

- In the AR interface the user has the option of selecting the position and pick or place. The robot reacts to command, which is sent over WiFi from Hololens to the board.



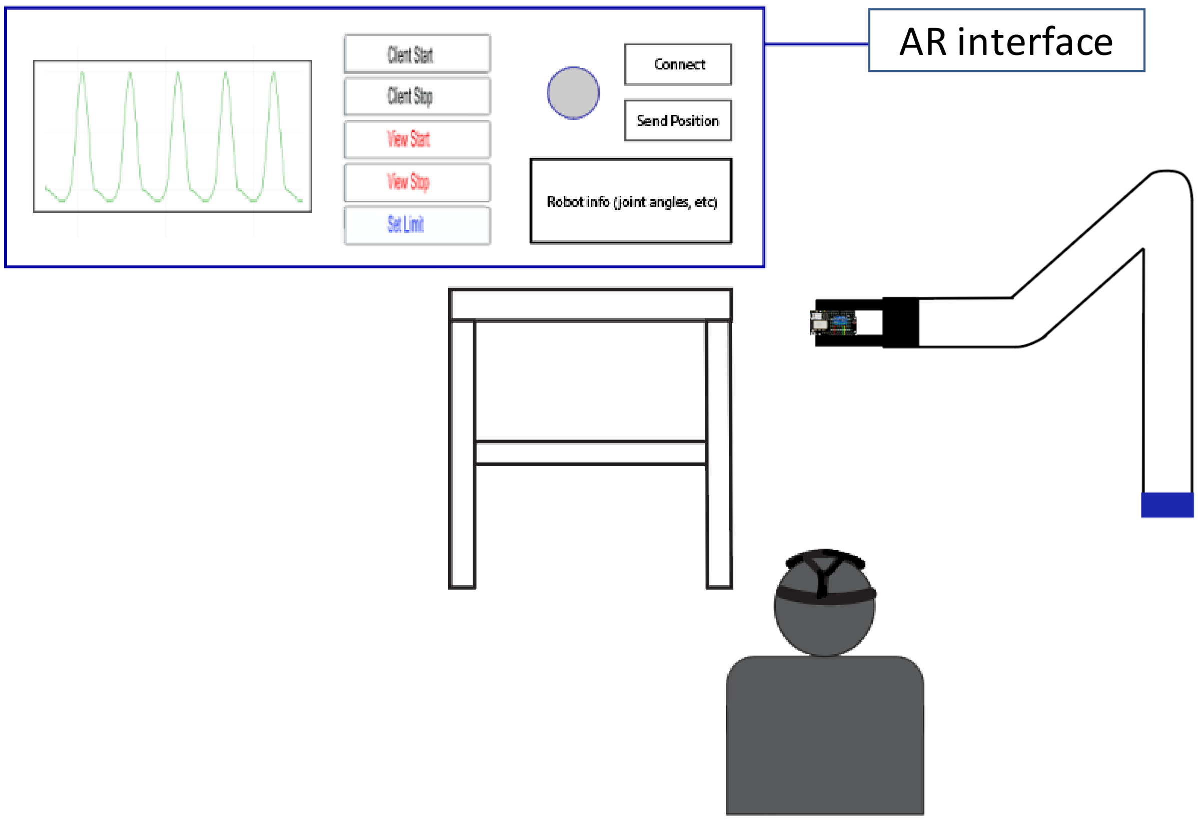
Applying robotics to dynamics with AR

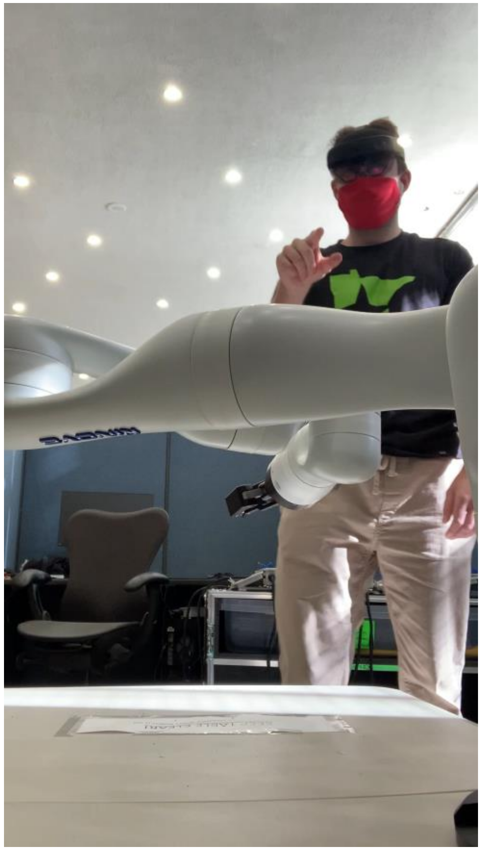
- The robot arm is capable of moving and placing sensors both securely and safely.



Applying robotics to dynamics with AR

- Combining the kinova gen3 consistency and durability with sensors and human intuition enables high-level control for application to manufacturing, sensing, inspection, and other tasks related to railroads.





Conclusions

- New advances in technology can contribute to objectively inform humans of their surroundings

- The future bridge engineer, manager, inspector will be collecting and analyzing data to inform decisions enhanced by human-infrastructure new interfaces

- Our future inspector will see/measure/collect data faster and change decisions about their surroundings

- Research opportunities for multidisciplinary engineers interested in AR and Human-Infrastructure Interfaces