Human-Machine Collaborative Inspection Through Mixed Reality

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Computer Vision for
Smart Structure

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Background

- Crumbling infrastructure is a major issue facing North American cities.
- 42% of US bridges were built 50 years ago.
- 7.5% are classified as structurally deficient by ASCE's 2021 report card.
- Risk to public must be mitigated through inspections/maintenance.

I-35W Mississippi River bridge collapse *(source: NPR)*

Visual Inspections

- Detect types of defects (spalling, cracks, corrosion, etc.).
- Measure their defects sizes (width, height, depth).
- Assign a rating to bridge according to inspection manual.

Current Visual Inspection Process

- Manual process for inspectors
- Use basic tools such as measuring tape.

Disadvantages:

- Inaccurate
- Expensive
- Time-consuming
- Inaccessible regions
- Dangerous

Vision-based Inspections

- Automated platforms: robots, drones.
- Use AI to automatically locate defects in images.
- Measure defect sizes using 3D sensors (LiDAR).

Problems

- **Are vision-based systems always reliable?**
- **How to incorporate inspector expertise (human-in-loop)?**
- **How to perform real-time collaboration between inspector and vision-based systems?**

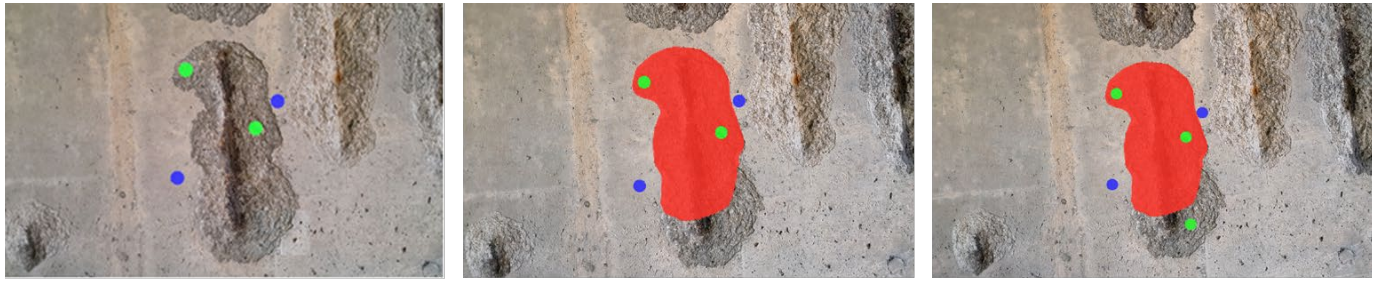
Opportunity (Mixed Reality)

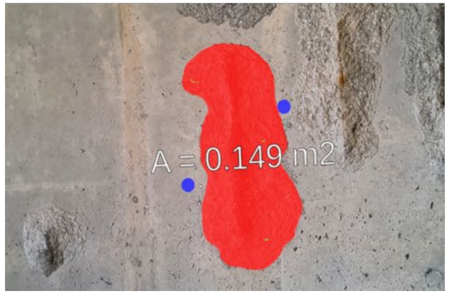
- **What is Mixed Reality (MR)?**
  - See through display: real world remains visible.
  - Visualize and interact with digital content over the real world (holograms) through wearable headset.

- **Microsoft HoloLens 2 (HL2)**
  - Head tracking
  - Hand gesture tracking
  - Spatial mapping
  - Voice commands

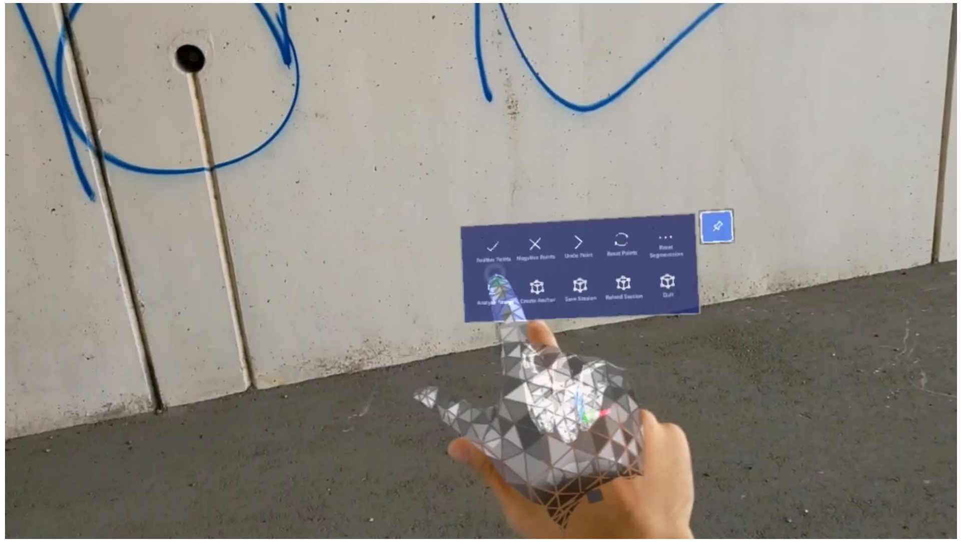
Previous Work: XRIV

- e**X**tended **R**eality **I**nspection and **V**isualization (XRIV).
- Localize and quantify defects.
- Interactive segmentation through MR.
- Limited Range: <5m.





Al-Sabbag, Z. A., Yeum, C. M., & Narasimhan, S. (2022). Interactive defect quantification through extended reality. *Advanced Engineering Informatics*, *51*, 101473.

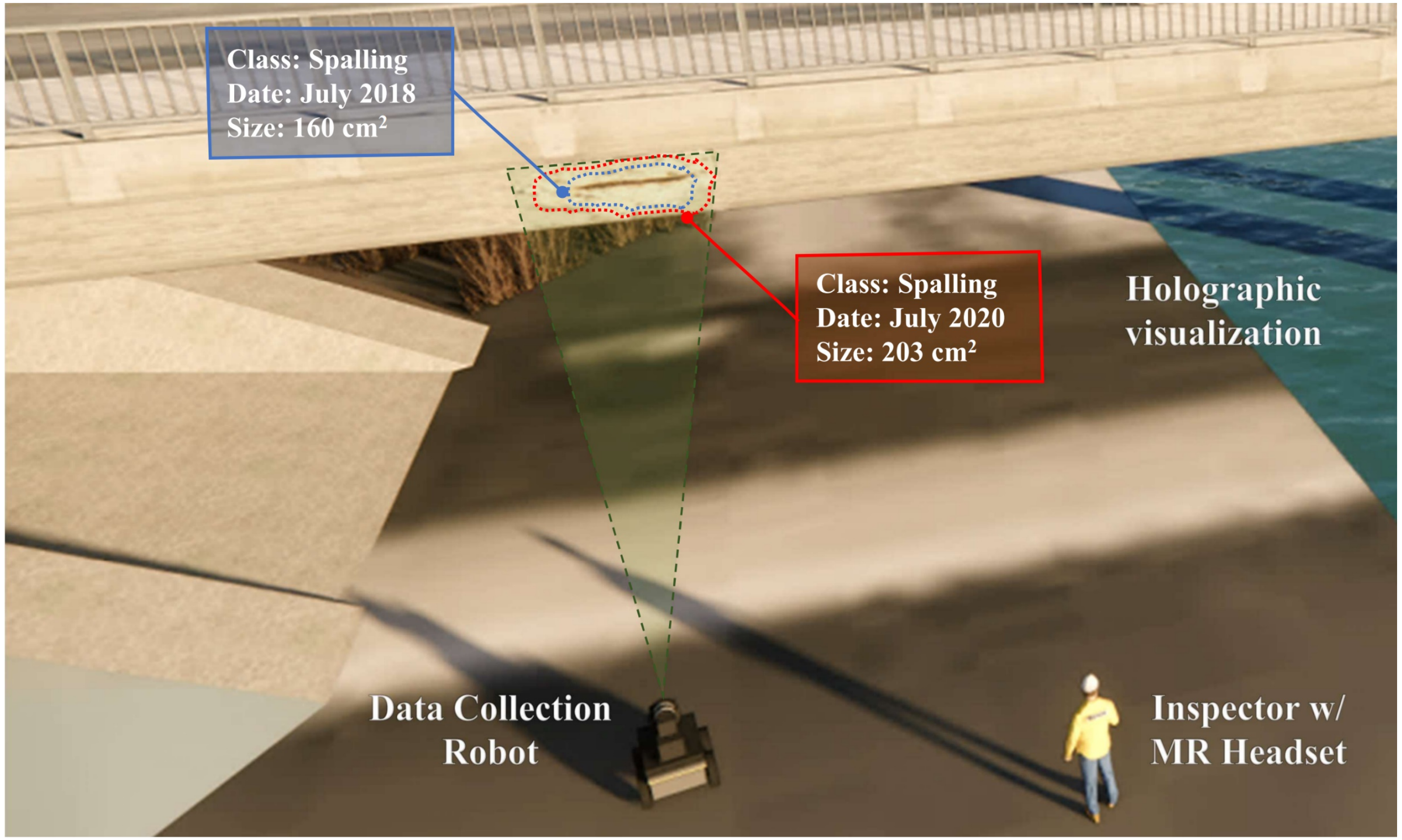


Objectives

1. Allow domain experts (inspectors, engineers) to use MR headsets to collaborate with robots during inspections.
2. Spatially align robot and MR headset in real-time using image-based localization.
3. Allow MR-equipped inspector to visualize defects located by robot and use interactive segmentation to refine damage region boundary.

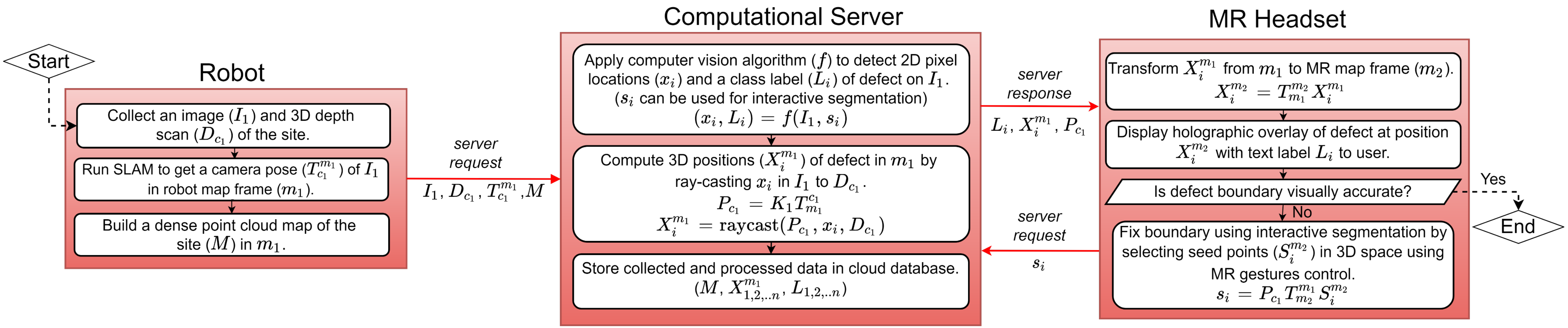
Human-Machine Collaborative Inspection (HMCI)

- **Robot** scans bridge using cameras and LiDAR to build a 3D map.
- **Remote server** analyze images to locate defects using deep learning.
- **Inspector** visualizes defect region on the real structure using MR.
- Inspector can re-visit structure and compare changes of defect region size over time.



HMCI System Overview

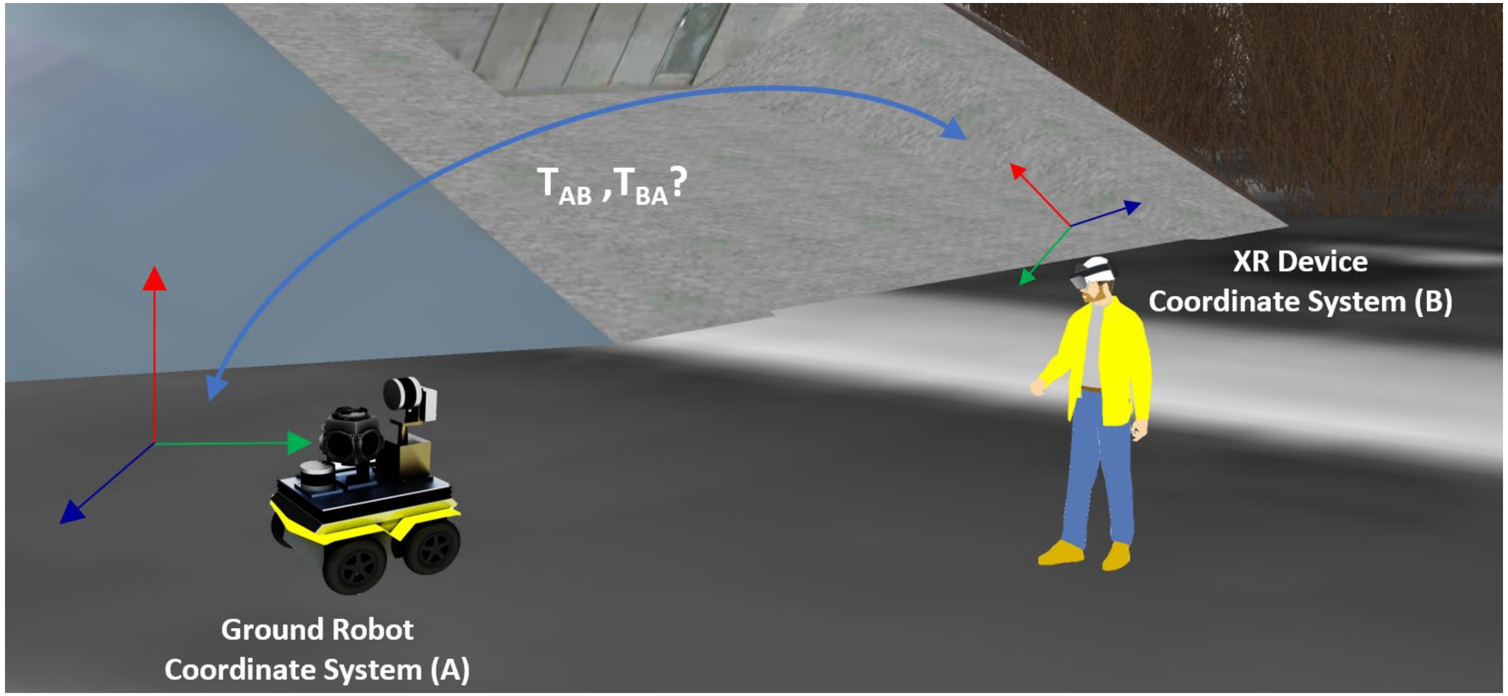
- *Robot*:
  - Capture images + lidar scans of site
  - Run visual-lidar SLAM to track pose and build 3D map
- *Server:*
  - Offloads heavy computations
  - Analyse image to locate defects
  - Use 3D map to quantify defects
  - Store result in database
- *MR headset:*
  - Visualize defect boundary
  - Use interactive segmentation to refine boundary (iterative process).



Spatial Alignment between Robots and Inspectors

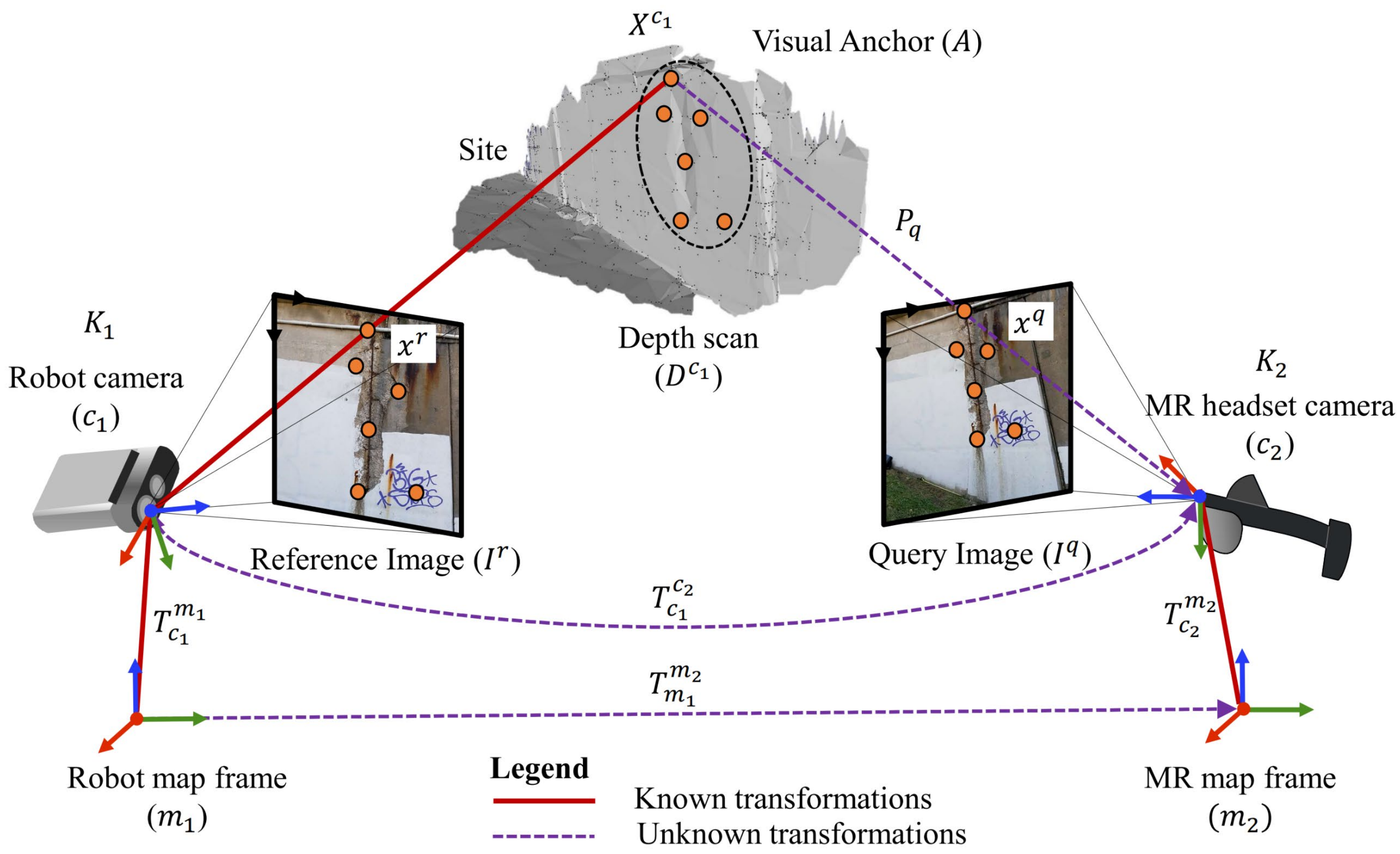
- How to align coordinate origins of MR headset and robot?

- **Image-based localization:** Utilize natural visual features in the scene from images from robot and MR headset cameras to calculate relative pose.



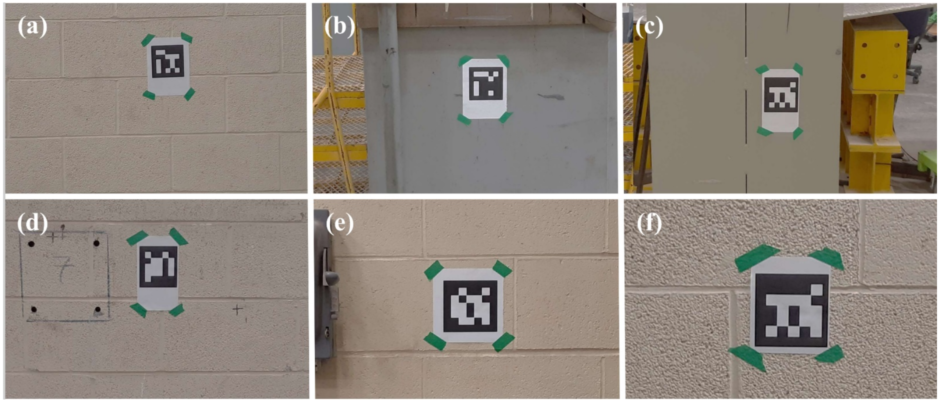
Single-shot Localization for Spatial Alignment

- **Single-Shot Localization:** real-time image-based localization.
- Robot and MR headset capture one image each of scene.
- Use feature detection + matching to find common features.
- Project 2D features to 3D scene using lidar scans from robot.
- Estimate relative pose of MR headset to robot using Perspective-n-Point (PnP) and Random sample consensus (RANSAC).



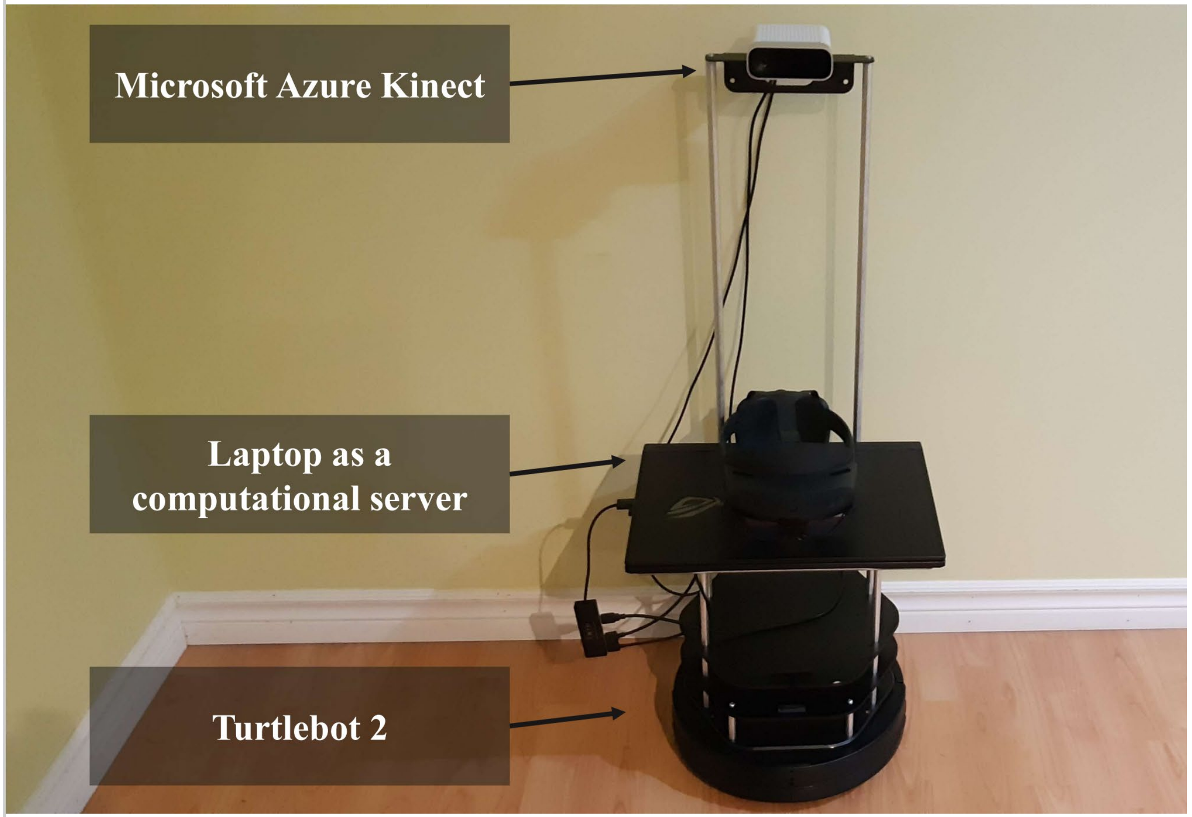
Experiment

- **Use Aruco markers to simulate structural defects.**
- Robot automatically scans site to locate structural defects.
- Visualize defects to MR user.

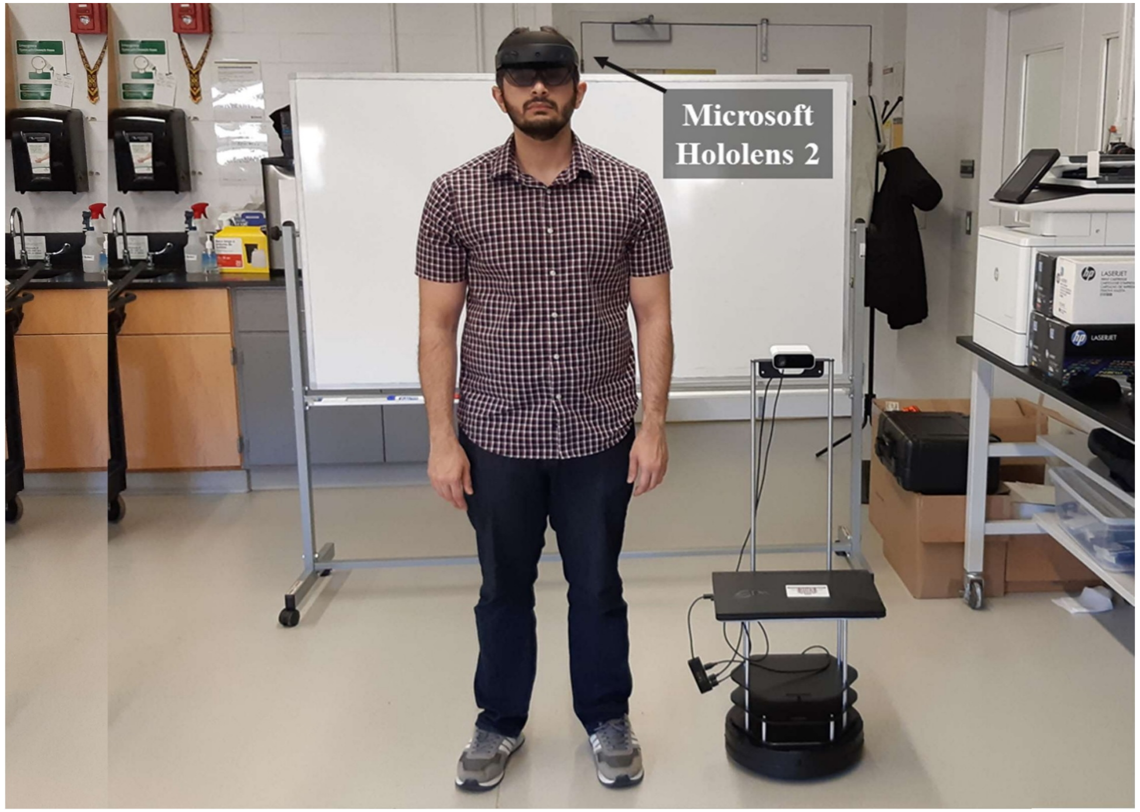


Experiment hardware

Robot



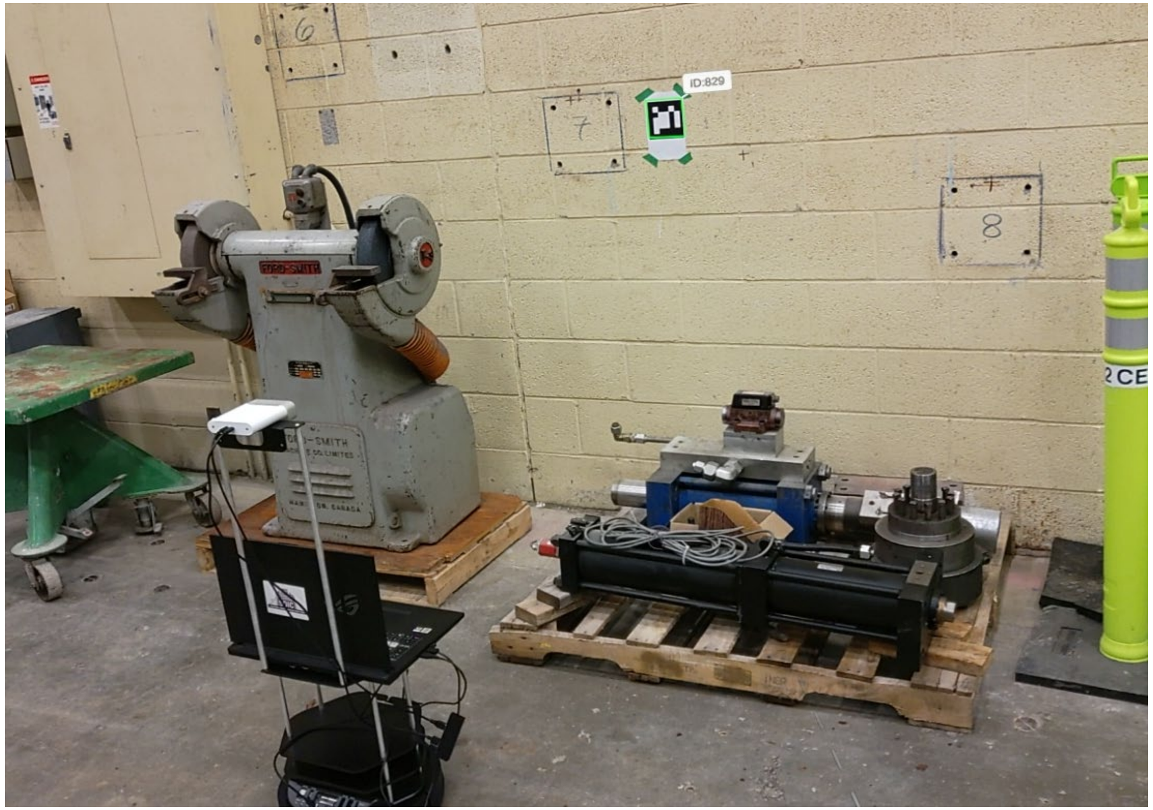
MR-equipped user



Video Demonstration

Visualization of Defects ROIs

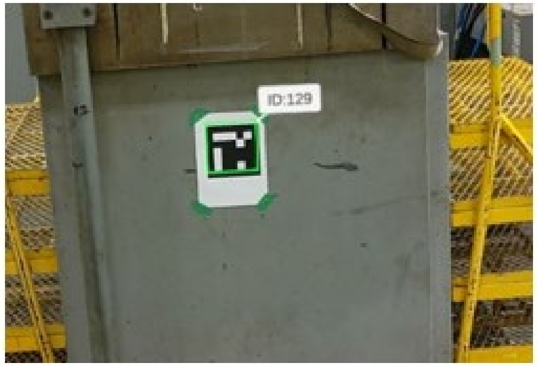
- After robot captures defect, it is visualized to MR user as Region-of-Interest (ROI) bounding box.
- User can then interact with bounding box and fix potential errors through hand gestures.



Evaluation of ROI Localization Errors

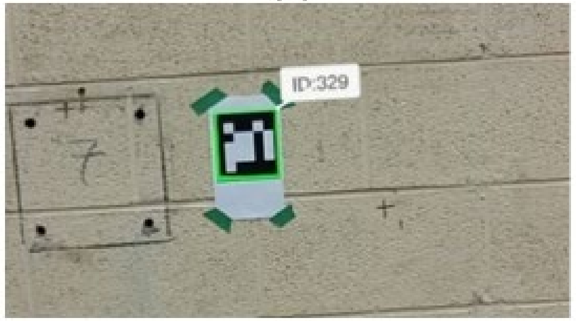
- We evaluated the spatial alignment error between robot and MR headset by measuring marker offset from detected ROI.
- Measured error when using SuperPoint (feature detector) +SuperGlue (feature matcher):
- **Mean Error ± std. dev = 1.11 ± 0.91 cm (30 samples)**

(a)



(b)

(c)



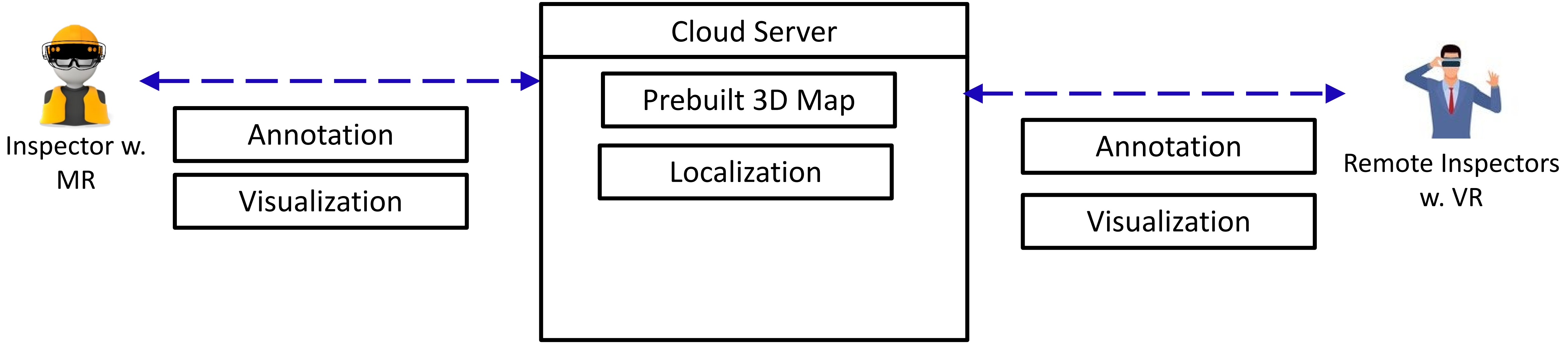
(d)

(e)

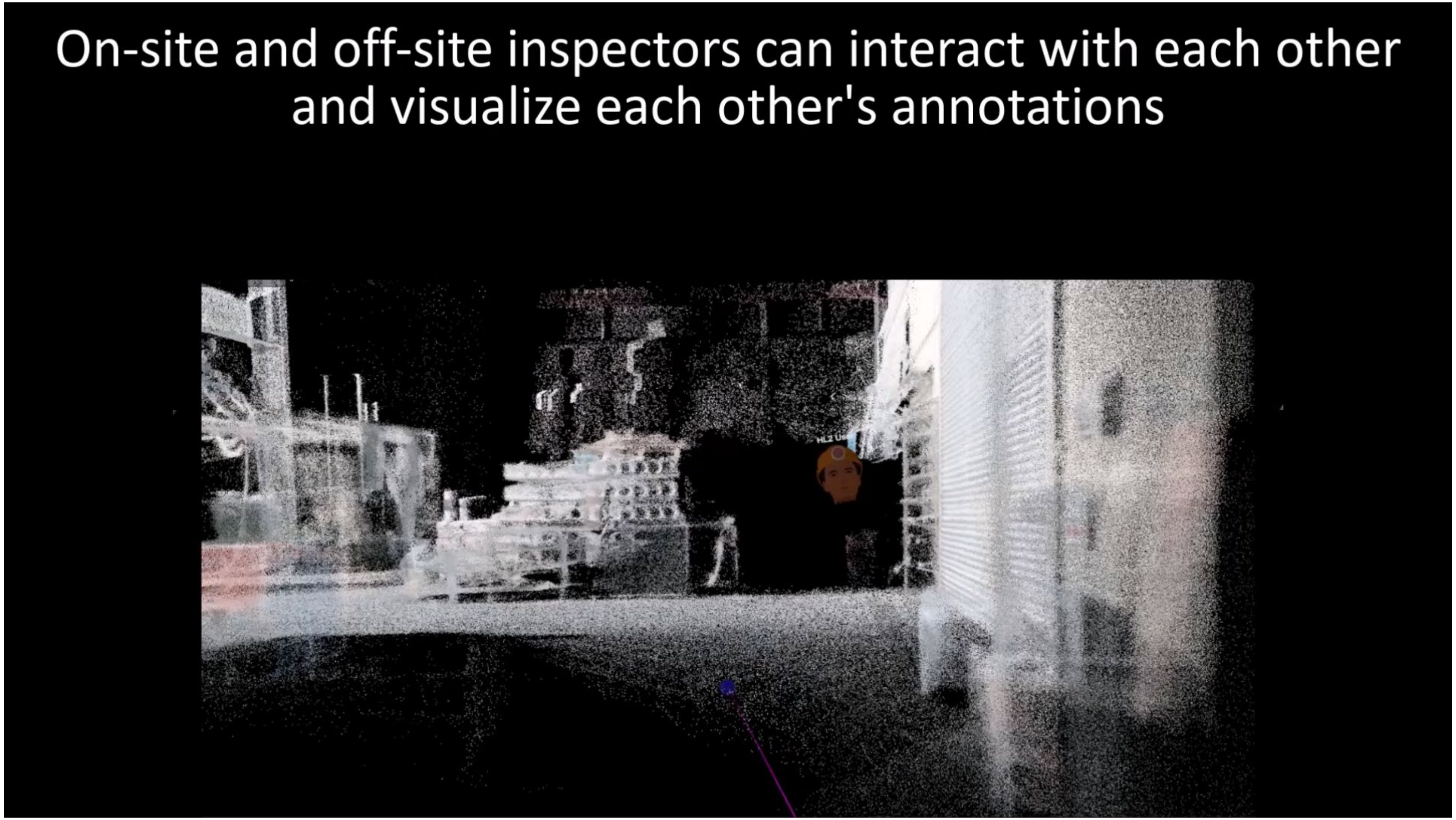
(f)

Ongoing Work: MR-VR Collaboration

- Allow on-site inspectors (MR) and off-site inspectors (VR) to **collaborate remotely** with each other on a prebuilt 3D map to annotate defects in real-time.
- MR inspectors are localized to 3D map using Single-Shot Localization to spatially align MR headset with 3D map.



Video Demonstration: MR-VR Collaboration



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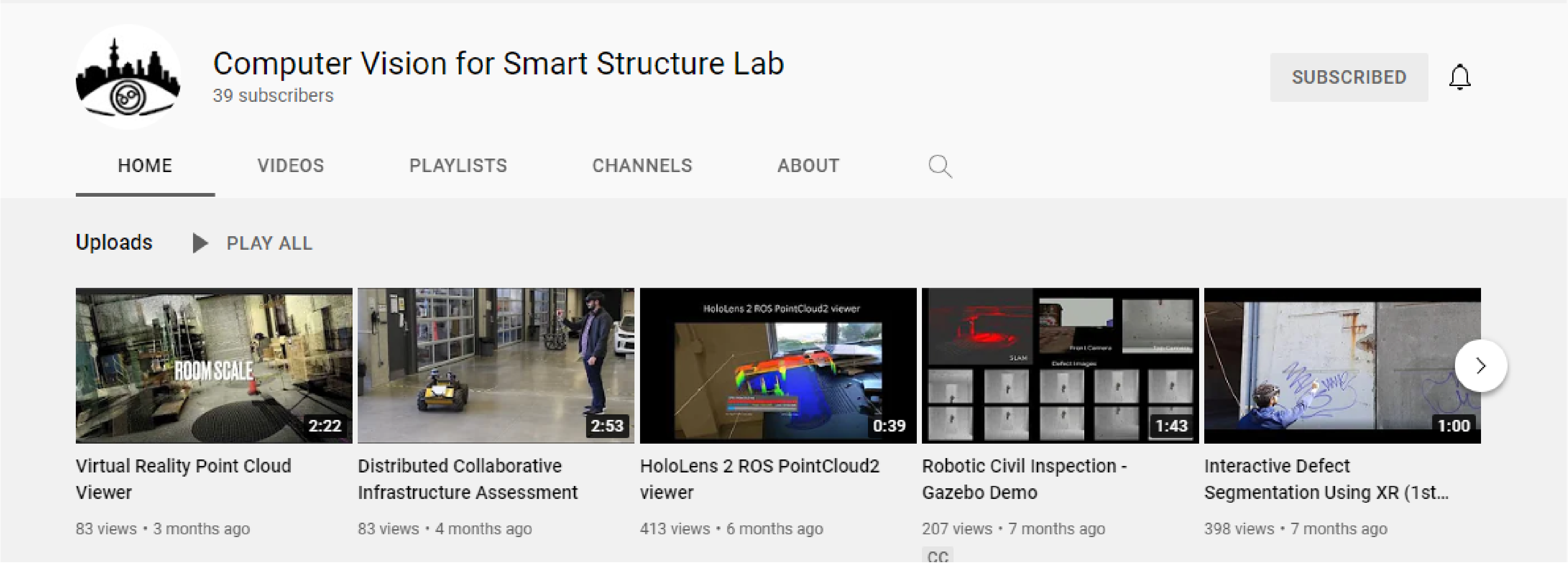

Thank You!

Questions?

https://cviss.net

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