# Distributed Collaboration in Infrastructure Assessment through Augmented and Virtual Reality

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UNIVERSITY OF WATERLOO
FACULTY OF ENGINEERING

Computer Vision for Smart Structure

# 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
- Inspector must be on-site
- Not all stake-holders (owner, engineers, etc.) can be present on-site


**Problems:**

- **Expensive**
- **Time-consuming**
- **Inaccessible regions**
- **Dangerous**

# Opportunity (Metaverse)

- **What is the Metaverse?**
  - Allow multiple remote users to interact and collaborate with each other in a simulated environment using Augmented Reality (**AR**) and Virtual Reality (**VR**) headsets.
- **Industrial Metaverse:**
  - Importing digital twin models of real environments (construction sites, bridges, etc.) to the Metaverse to enable efficient remote collaboration between stakeholders.

Image source: Microsoft HoloLens 2

Image source: Shutterstock/is.a.bella

# Difference Between Augmented and Virtual Reality

- **Augmented Reality (AR):**
  - Overlay digital holographic content on the user's real environment
  - User is physically present on-site and can visualize and interact with information
- **Virtual Reality (VR):**
  - User is immersed in a virtual environment
  - User is present remotely in a reconstructed environment

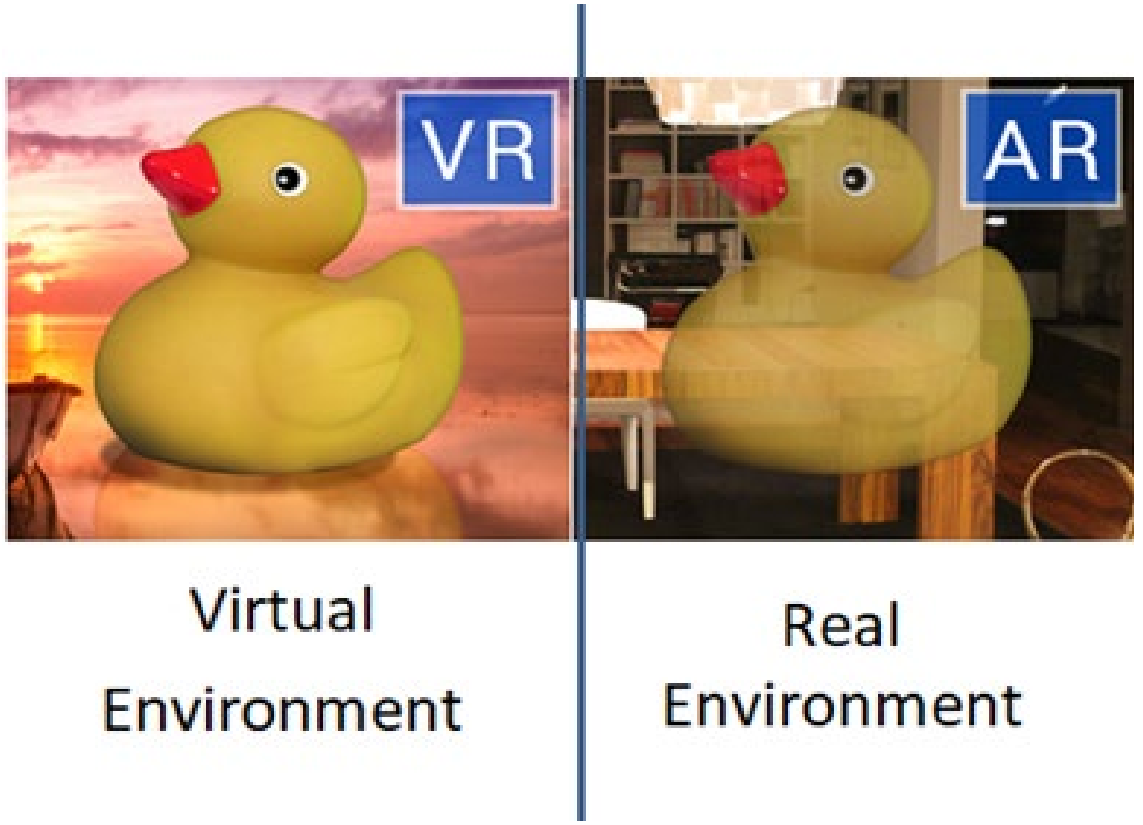



Image source: Avi Barel / iBarel.com

# Research Progress

## Previous works

- e**X**tended **R**eality **I**nspection and **V**isualization (**XRIV**)
  - AR and AI-aided visual inspection technique
  - Zaid Abbas Al-Sabbag*, Chul Min Yeum, Sriram Narasimhan, “Interactive Defect Quantification Through Extended Reality,” Advanced Engineering Informatics, 51, 101473, (2022).

Inspector w. AR

- **H**uman-**M**achine **C**ollaborative **I**nspection (**HMCI**)
  - Computation and sensing offloading to a machine and enchasing visualization to human using AR
  - Zaid Abbas Al-Sabbag*, Chul Min Yeum, Sriram Narasimhan, “Enabling Human-Machine Collaboration in Infrastructure Inspections through Mixed Reality,” Advanced Engineering Informatics, 53, 101709, (2022).

Inspector w. AR

Robot

## This Presentation

- Distributed Collaboration in Infrastructure Assessment
  - Leveraging and engaging remote users for inspection using industrial metaverse

Remote Expert w. VR

Inspector w. AR

Robot

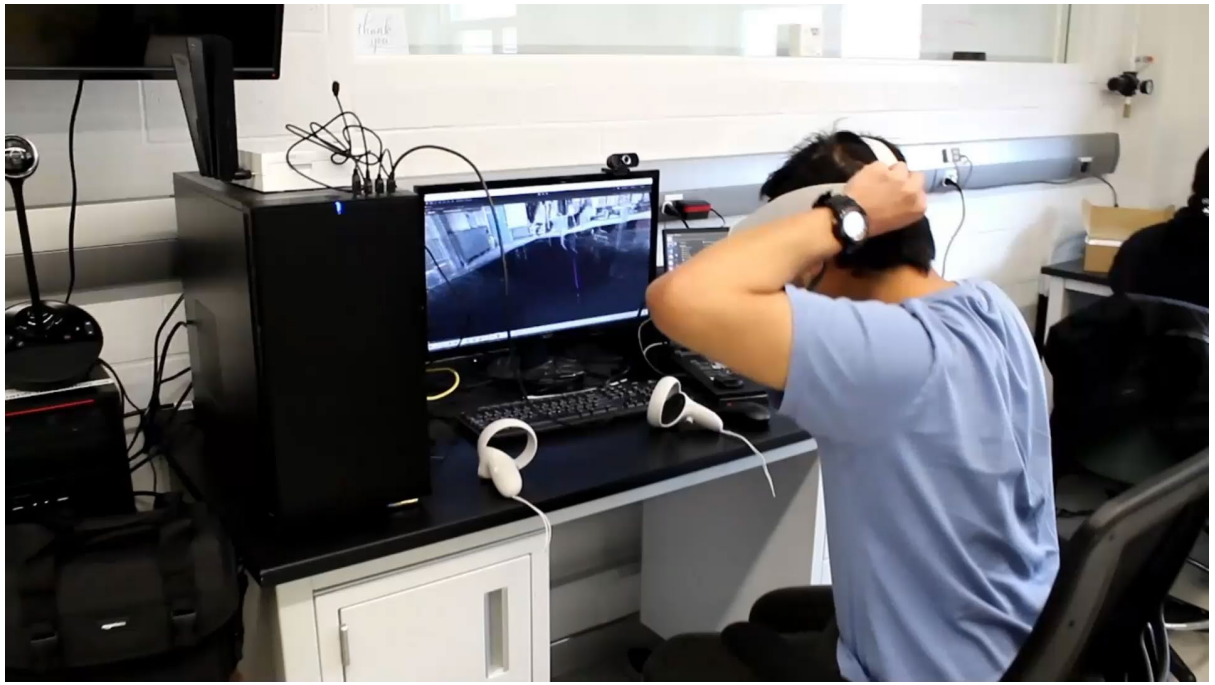
# XRIV: Video

# Objectives

1. Enable multiple domain experts (inspectors, engineers) to collaborate in real-time using AR and VR headsets
2. Utilize panoramic images to provide photorealistic view of inspection sites to remote users, while prebuilt 3D maps allows measuring and quantification of defects to scale
3. Propose image-based localization algorithm to spatially align multiple AR and VR users together in the same shared metaverse environment

# Proposed Solution: Distributed Collaborative Infrastructure Metaverse (DCIM)

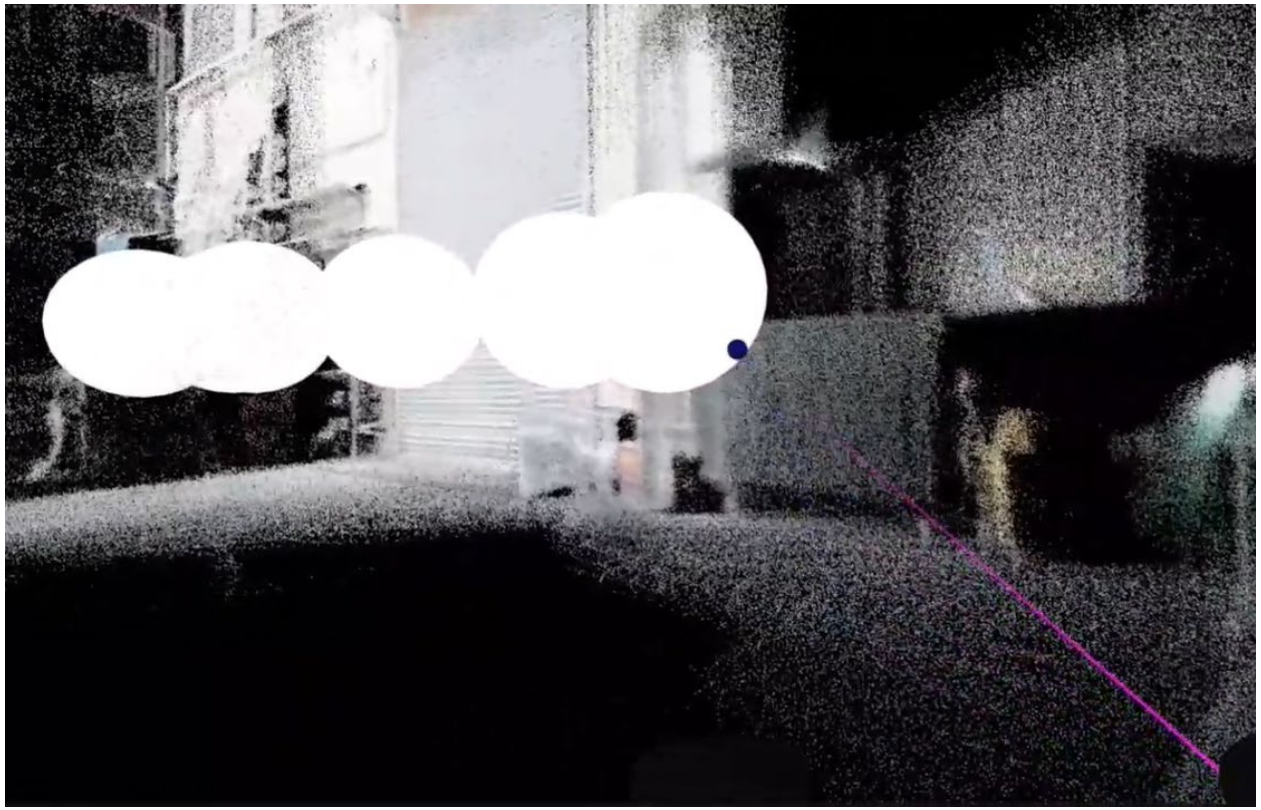
- **VR Remote User:**
  - View 3D prebuilt map using VR headset
  - VR user interacts with AR users remotely
- **AR On-site User:**
  - AR headset is automatically localized to 3d map
  - AR user interacts with remote VR users in real-time



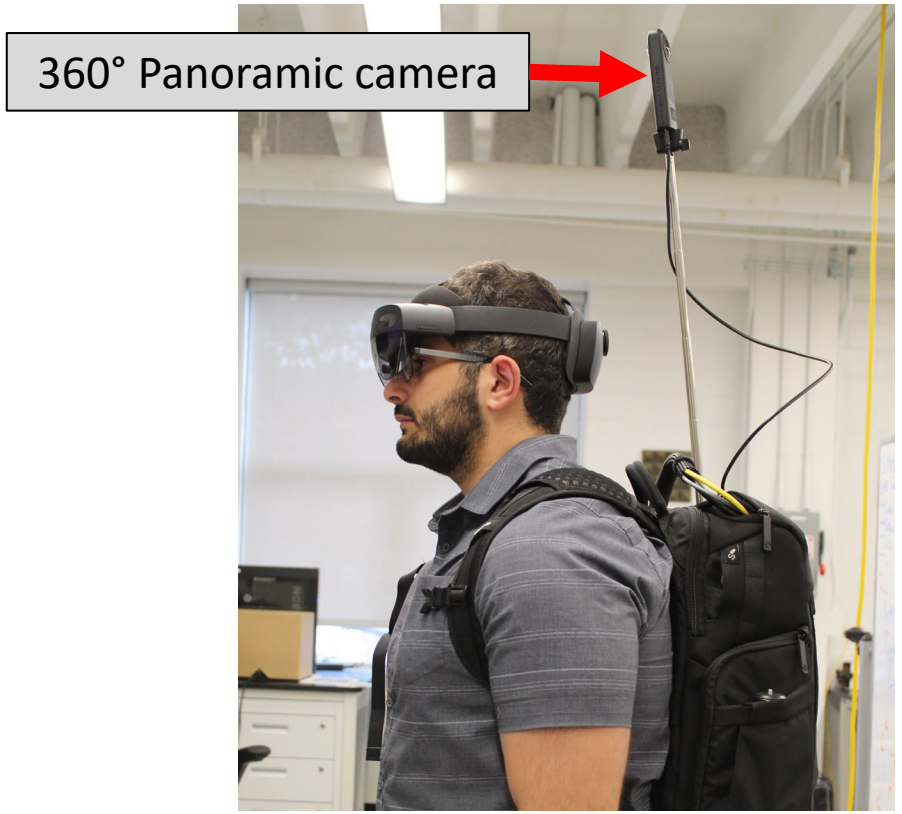
# Panoramic Camera

- **Panoramic camera**
  - Remote VR user views 360° images of the site for photorealistic inspection and annotating of defects
  - On-site AR user carries panoramic camera in backpack which automatically sends images to remote VR user

## Remote VR User Perspective



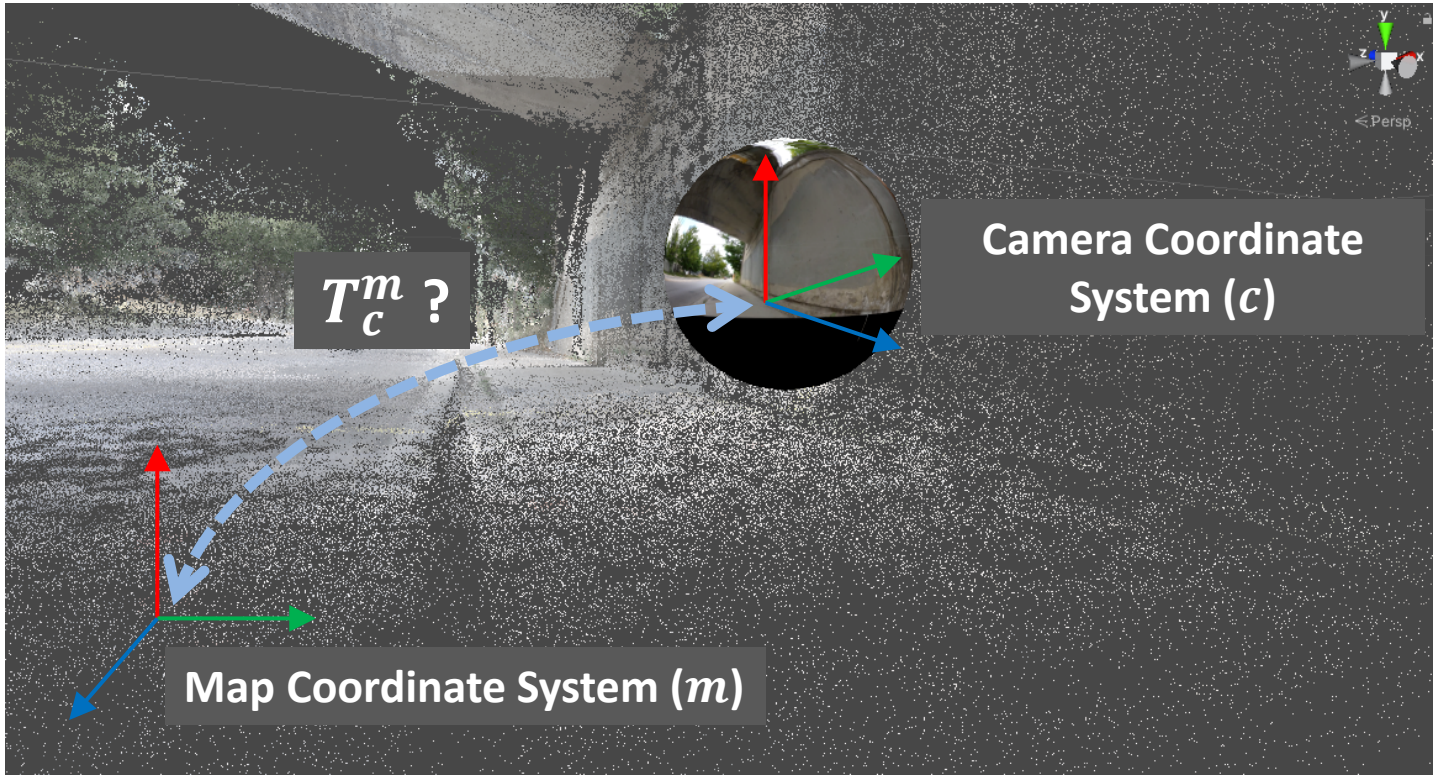
## On-site AR User



# Localization of Panorama Images into the Prebuilt map

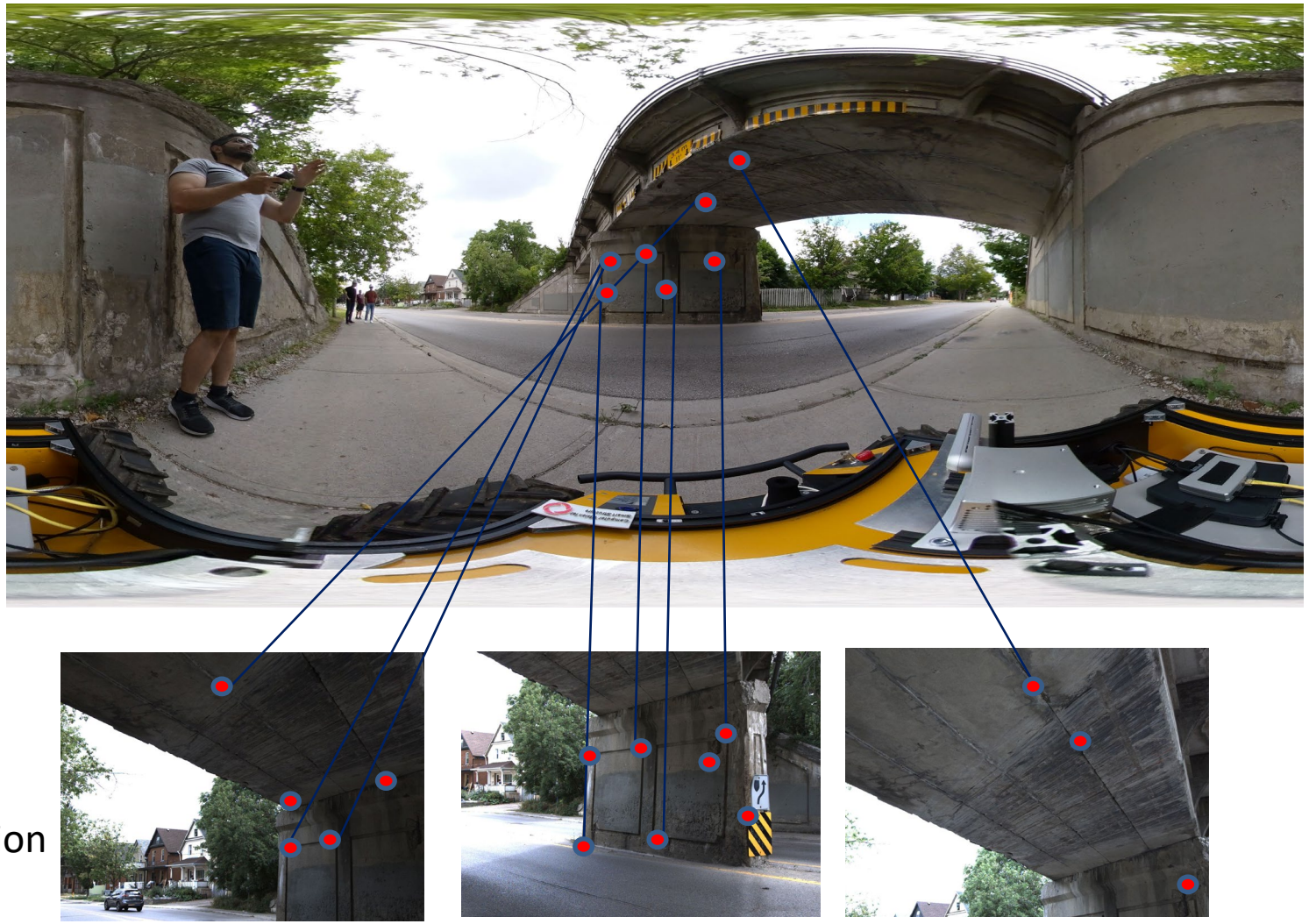
- How to align coordinate origins of panorama images to prebuilt map to share them with remote users?

- **Image-based localization:** Utilize natural visual features in the scene from panorama images to calculate relative pose ($\boldsymbol{T_c^m}$) to prebuilt map.



# Localization Procedure (Step 1: Feature Detection & Matching)

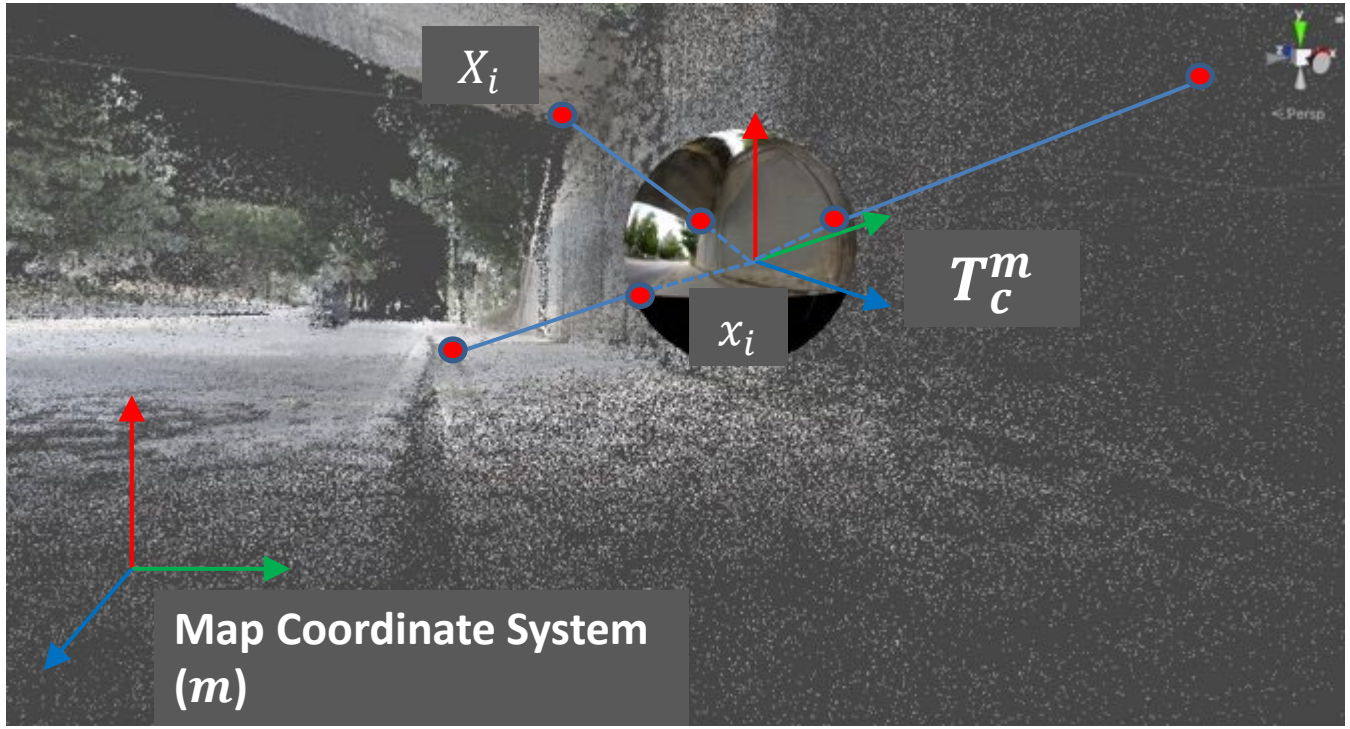
- **Step 1:** Feature detection and matching
  - Traditional feature detectors such as SIFT or ORB or learned features such as SuperPoint are deployed
  - Detect and match local 2D features between panorama image and database images



Images in prebuilt map's database for point colorization

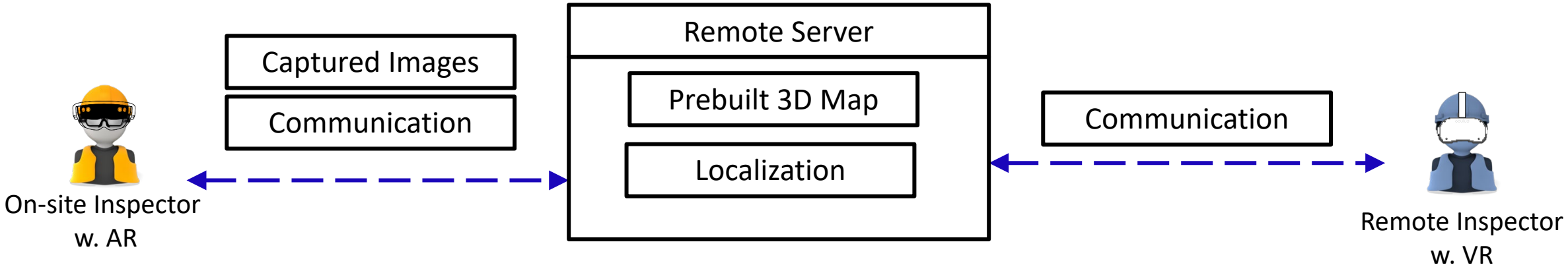
# Localization Procedure (Step 2: Pose Estimation)

- **Step 2:** Pose estimation
  - Need minimum of 3 points to estimate pose using Perspective-n-Point (PnP) algorithm
  - Use RANSAC to select the best 3 points among matched 2D features that minimize reprojection error in panorama image
  - Further refine result using least-squares optimization



# System Diagram

- **Remote Server**
  - Images captured using AR headset's front camera and panoramic camera are localized to the prebuilt map
  - Server performs image-based localization by localizing all captured images to prebuilt map to offload computational cost
  - Localization results are communicated to all users connected to server so that users are spatially aligned



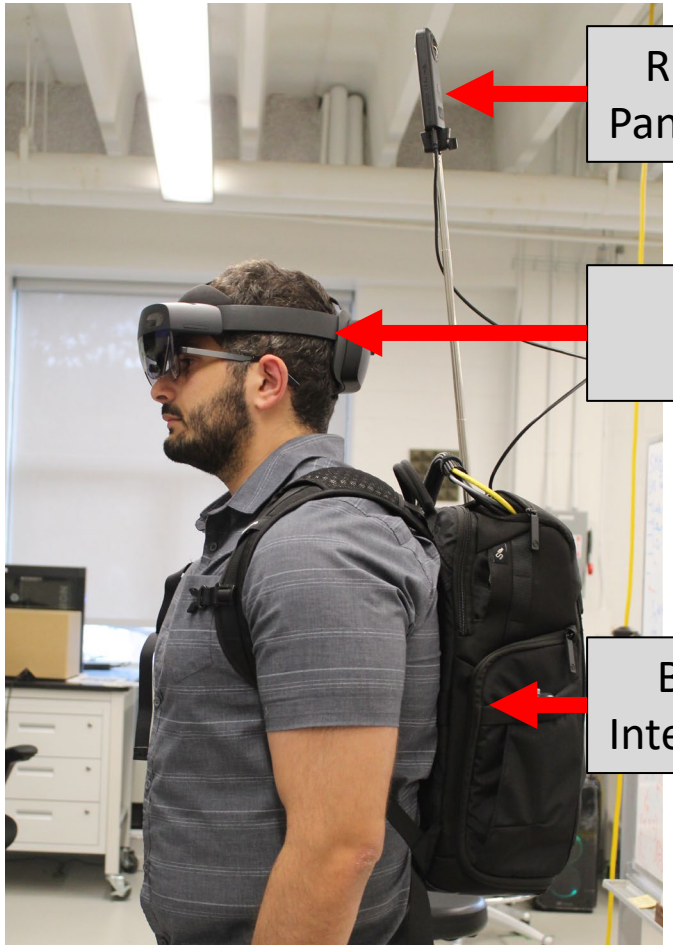
# Experimental Demonstration

- Experiment performed to validate proposed system
- **Location**: Park St bridge, Waterloo, ON

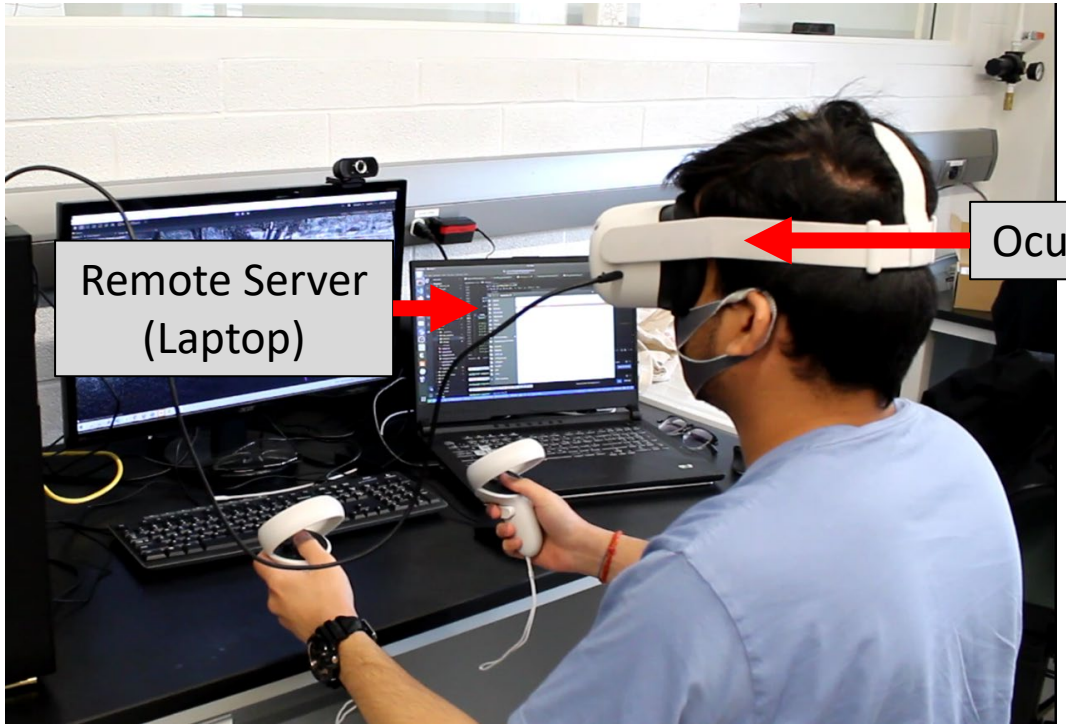
Park St bridge

# Hardware Setup

## **On-site** AR user



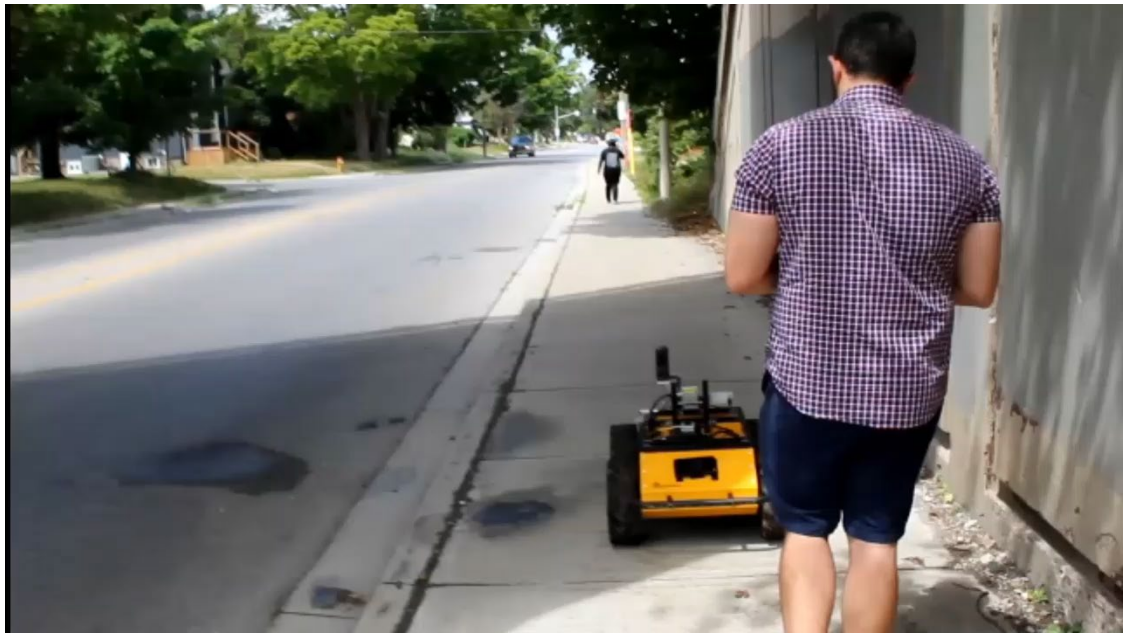

## **Remote** VR user

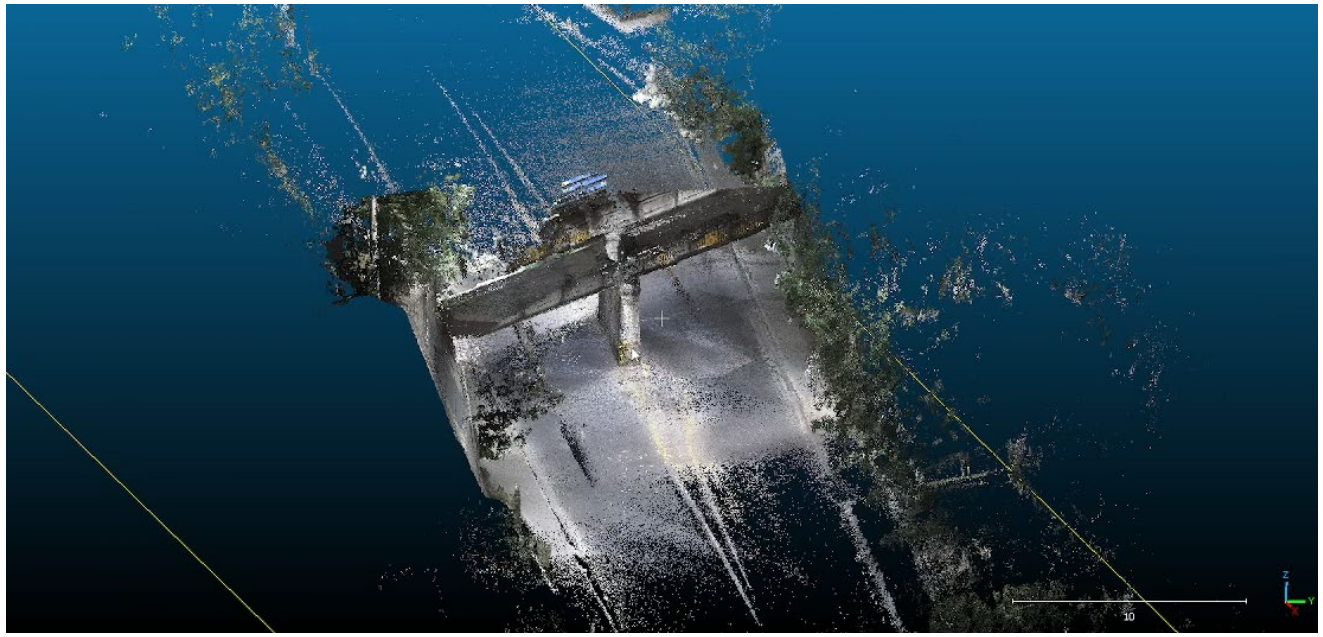


# Reconstruction of a Prebuilt Map using a Robot

## Prebuilt Map

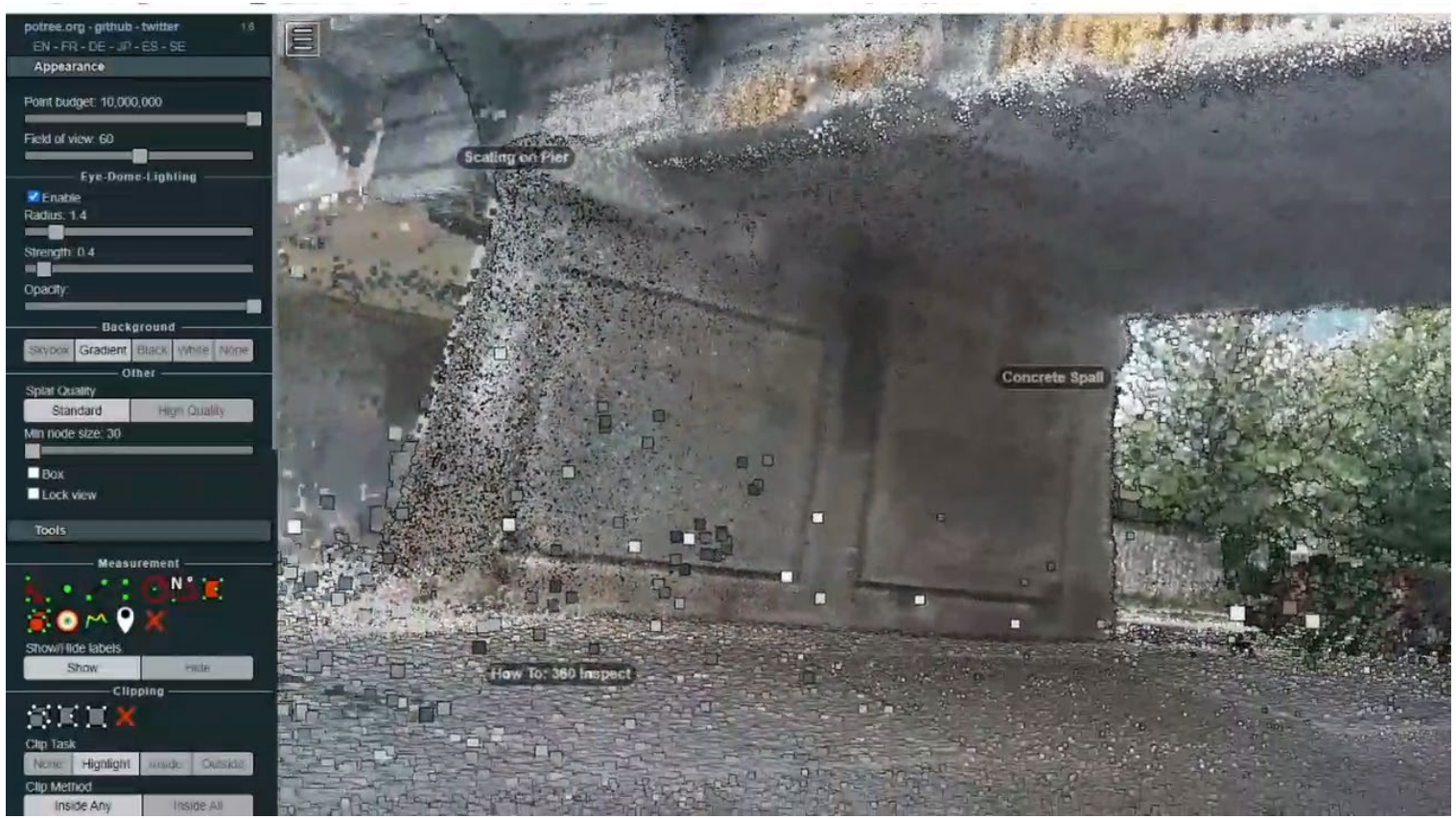
- Robot equipped with lidar and camera was used to scan bridge
- We created a colorized 3D pointcloud of site





# Integration of Panorama Images into the Prebuilt Map

- Overlaying panorama image on pointcloud to visualize localization error
- **Minimal error between image and pointcloud**




Use this link below to visualize pointcloud on our website:
https://macillas.github.io/potree/360_ParkSt/park_st_bridge.html

# Defect Annotation Using Panorama

- **Why we need accurate localization result?**
- Pointcloud is not precise enough for defect annotation
- Panorama image enables VR user to annotate defects clearly

# Onsite and Remote User Interaction

- AR and VR users interact with each other in **real-time**
- Defect annotations are **anchored to their physical locations**
- Annotations are **visible** to AR users on-site



**Annotation placed in the physical location**

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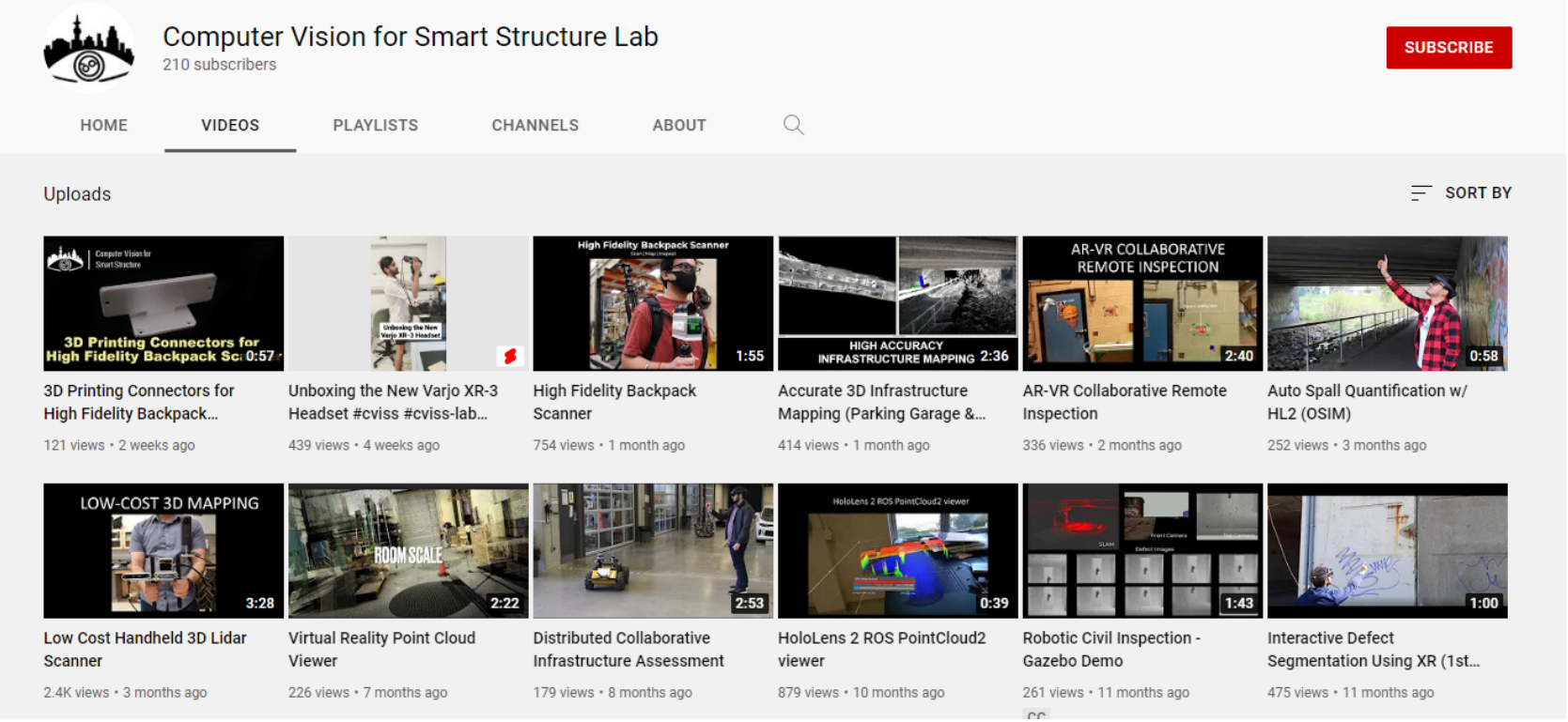
# Thank You!

# Questions?

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https://cviss.net

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