U.S. Department of Transportation
Federal Highway Administration
Turner-Fairbank Highway Research Center

Leveraging Pocket Lidar for Construction Inspection and Digital As-Builts—Phase II

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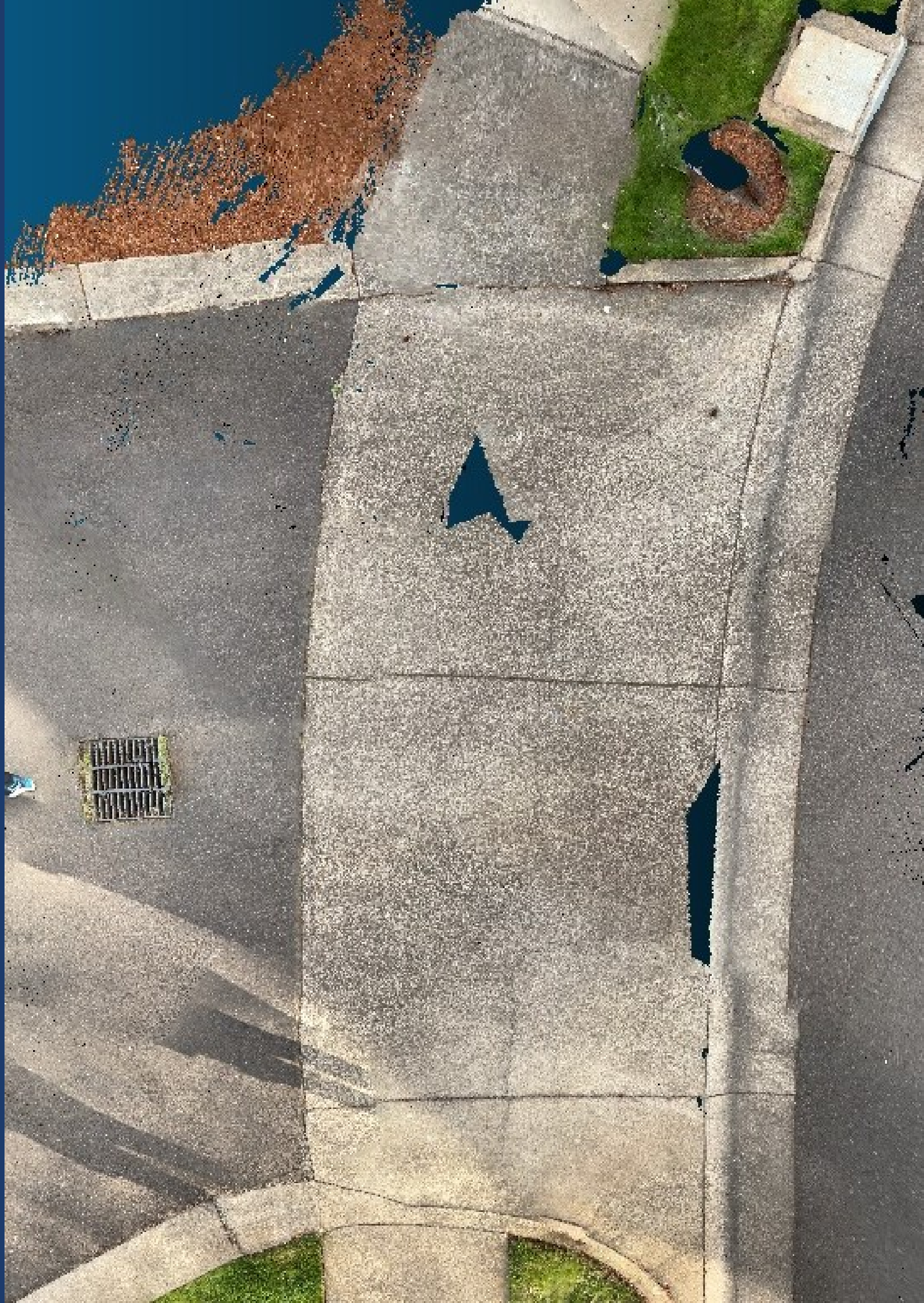

Photo source: Federal Highway Administration (FHWA).

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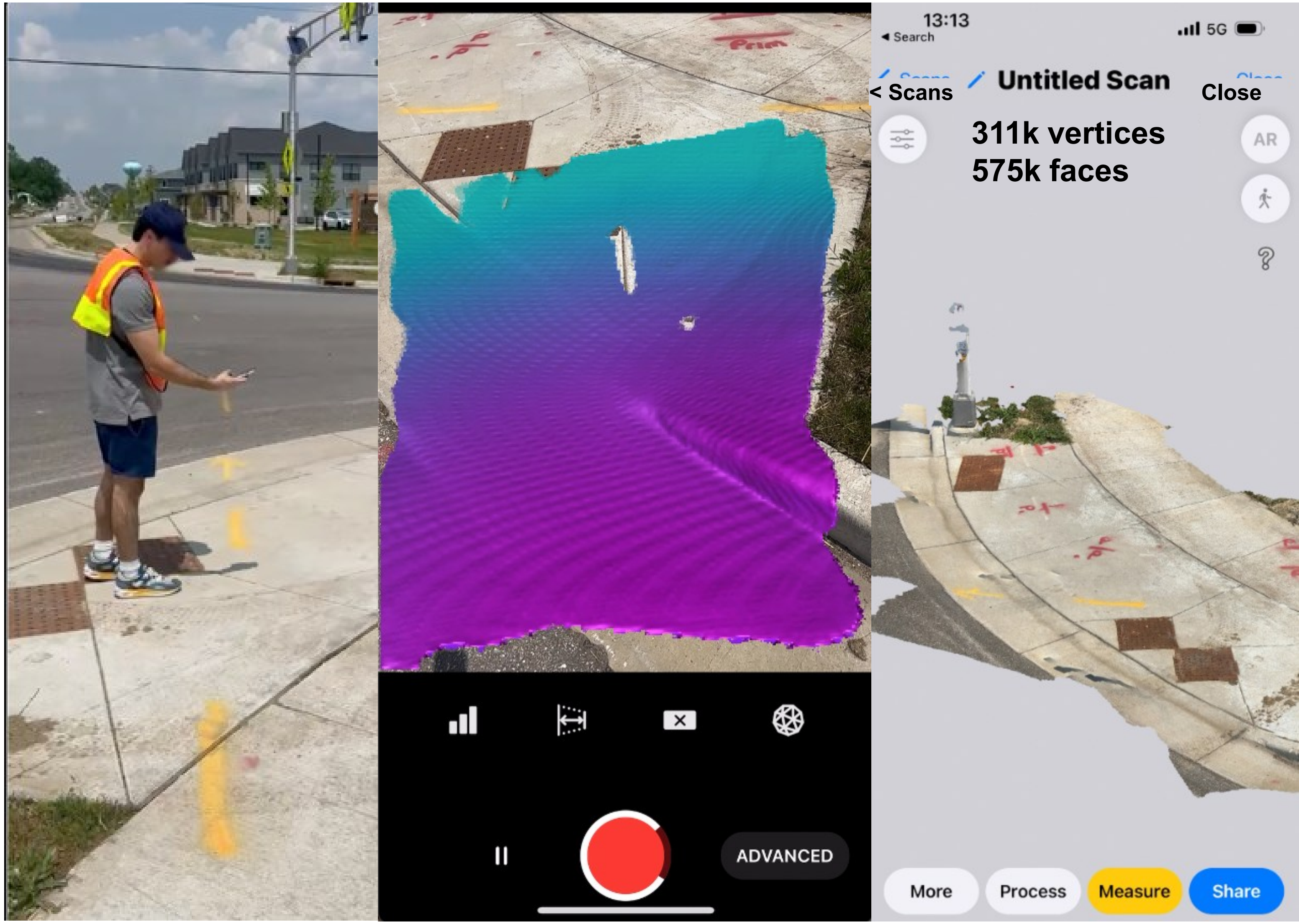
What Is Pocket Lidar?

- Available on iPhone 12, iPad Pro™ 13, and iPad Pro 14.
- Blend of lidar, photogrammetry, and artificial intelligence (AI).
- Flash lidar.
- Field of view ~60×48 degrees with 576 lasers.
- Depth map resolution 256×192.
- Maximum range 5 m.
- Apple Developer® ARKit™, RealityKit™, and RoomPlan™.(1,2,3)
- Real-time coverage feedback.



All images source: FHWA.

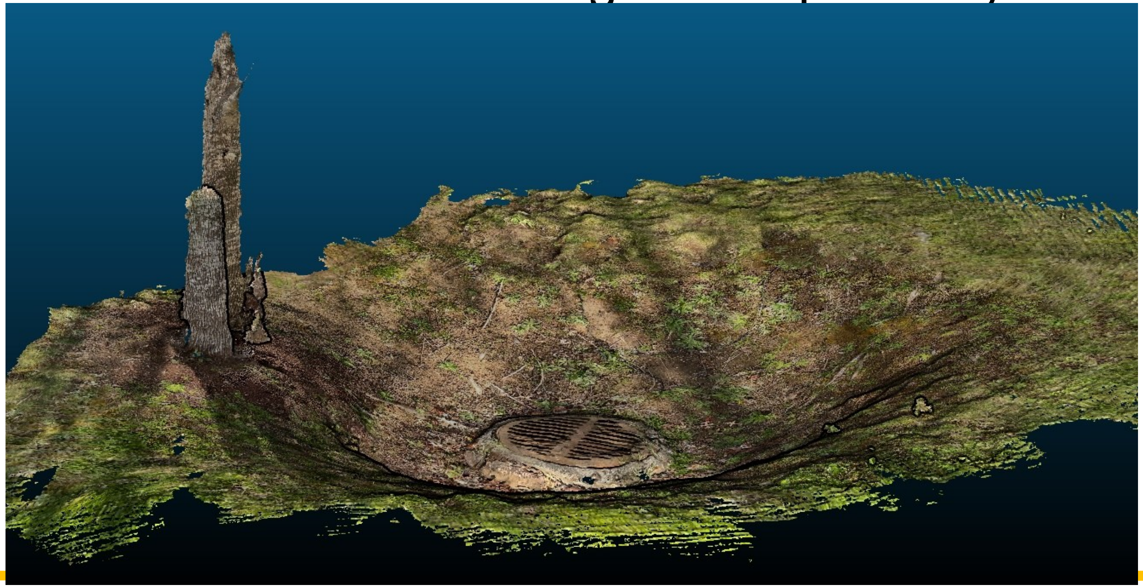
[1]Apple Inc. 2024. *ARKit* (software).
[2]Apple Inc. 2024. *RealityKit* (software).
[3]Apple Inc. 2024. *RoomPlan* (software).

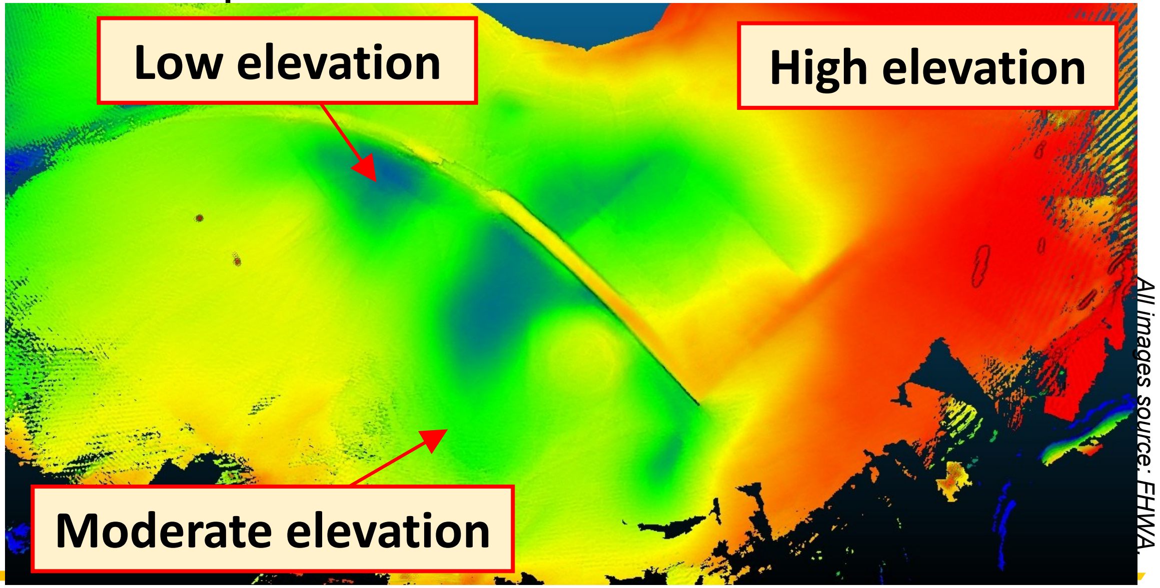
Phase I Research Project

- FHWA "Leveraging Pocket Lidar for Construction Inspection and Digital As-builts"
  - 2022 – 2024
- Objective: Determine the suitability and feasibility of using pocket lidar in highway construction applications.
- Tasks:
  - App Screening
  - Lab Testing
  - Field Testing
  - Case Studies x 4
  - Presentations
  - Webinars
  - Reports

Key Takeaways—Field Testing

- Portable and easy to use in the field.
- Effective in small spaces (e.g., maintenance holes) or small areas (e.g., stockpiles).
- Not too far, not too close. (0.3–4 m).
- No loops! No more than 10 m.
- Can supply sufficiently accurate measurements for many applications (few cm).
- Results vary by apps and settings.
- Note that field testing was exploratory—Case studies perform more detailed assessments.





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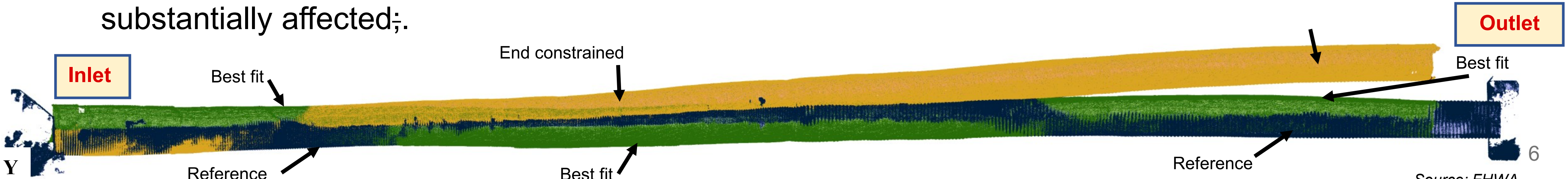
Culvert- Utah DOT/LTAP

- Capture damages and debris
- Feasible for culverts 48” and larger
- Requires low flow rates
- Lighting sources heavily influenced data quality
- Challenges with corrugated pipes.
- Measurements generally obtained for length (few cm RMS), radius (<1 cm RMS), slopes (0.5 percent), and area (within 8 percent RMS).
- Substantial lateral drifting occurs in pocket lidar data for culvert sections beyond 10 m:
  - Relative measurements such as the area and radius or the length measurements are not substantially affected;.

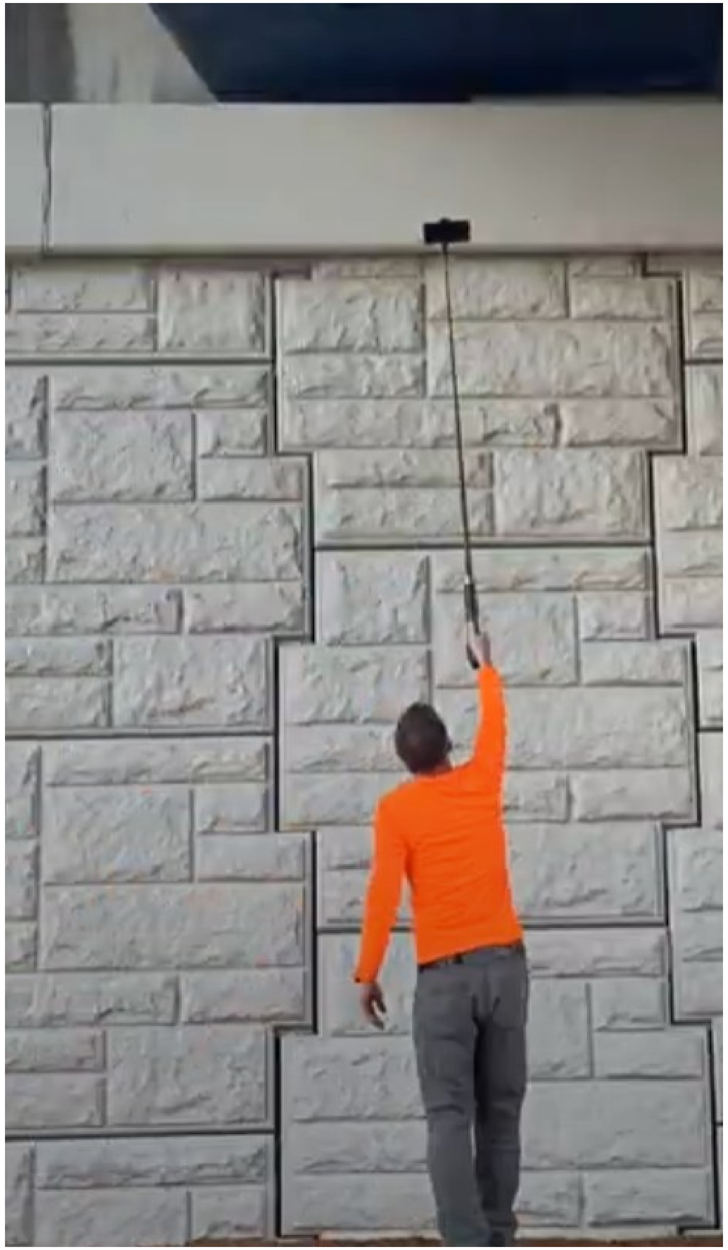


Source: FHWA.

databases. However, the GNSS does not work inside the culvert.

MSE Walls- FDOT

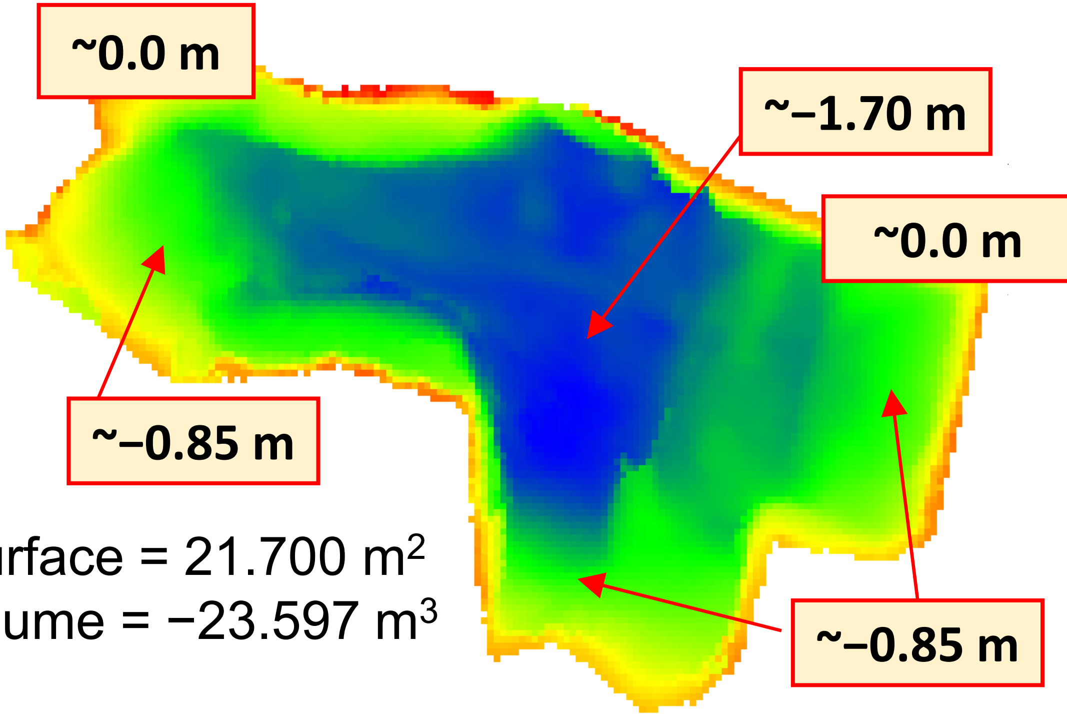
- Can be used to evaluate global surface characteristics such as vertical and horizontal alignment (e.g., tilting) of the entire wall or for a panel.
- Use an extension pole to capture the upper sections of the wall (PL range is 5 m) with similar geometry.
- Can detect effects such as bulging.
- Cannot effectively distinguish features less than 0.05 m in the point cloud; however, certain features such as cracks can be captured in the texture map.
- Can use scans and photographs to locate the cracks on the wall so that observations can be made in context with the entire wall for evaluating patterns or the severity of cracking.



Trenches-PennDOT

- Accurate (few % difference) results can be achieved in calculating the volume and surface area.
- The diameter needs to be 0.10 m or larger for the pipe to be adequately captured.
- AR and mixed reality technologies enable visualization of the data on site even after the trench or pit is filled given that GNSS georeferencing information can be captured during the scan. Future maintenance and construction can greatly benefit from such 3D visualization, which can help minimize guesswork in excavation.
- Extension pole use has the following benefits:
  - Significantly increases the coverage and access in the trench while allowing the inspector to work from a safe location outside the trench.
  - Minimizes field-of-view blockage by the pocket lidar while the inspector navigates the rough terrain.

Pocket lidar (3D Scanner App)(1)



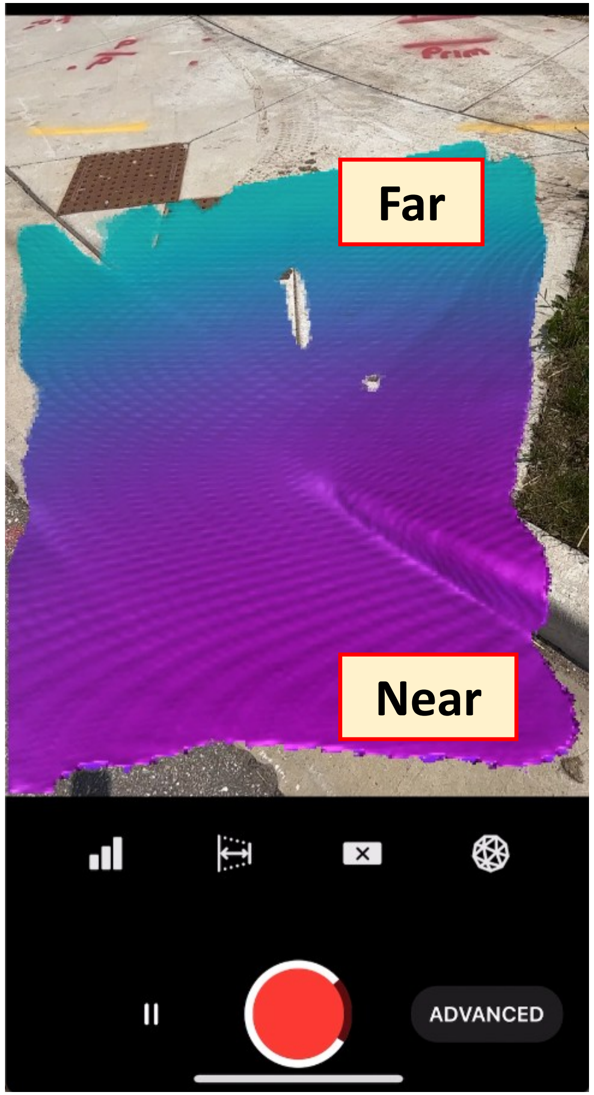
Surface = 21.700 m^2
Volume = −23.597 m^3

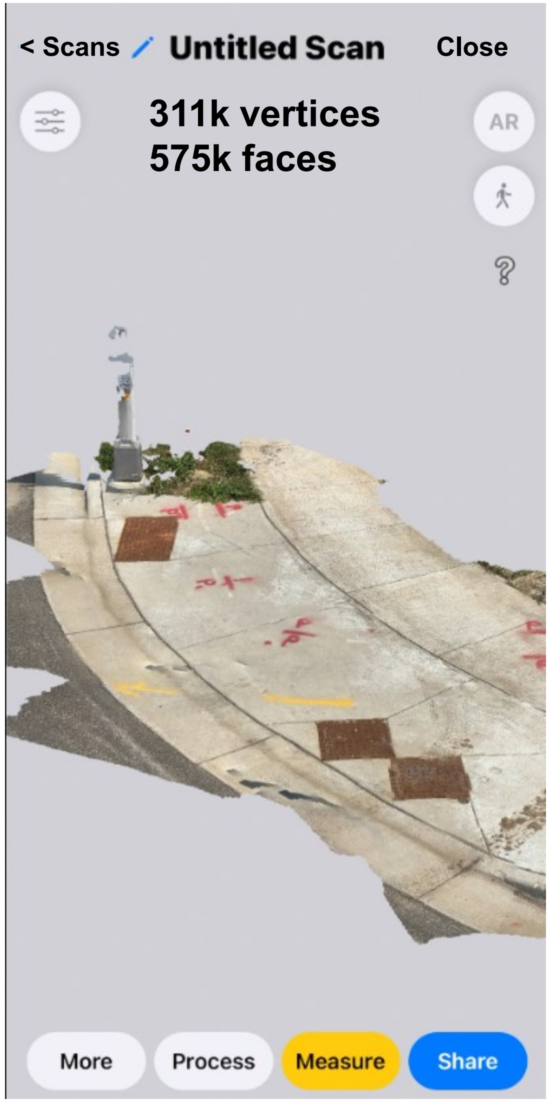
All images source: FHWA.

[1]LAAN Labs. 2024. *3D Scanner App* (software).

Curb Ramps- MNDOT

- Reasonable data quality to estimate slopes within 0.7 percent and dimensions within a few cm.
- Capture of a 3D model provides additional information and context (e.g., debris, condition).
- GNSS data ensure the same ramp is investigated if different inspectors are performing measurements or asset management.
- More systematic and repeatable processes to extract the slope measurements from the data compared with measurements on arbitrary locations on the ramps.
- Less strenuous process on the inspector, who does not need to crouch or be on hands and knees to obtain the data.

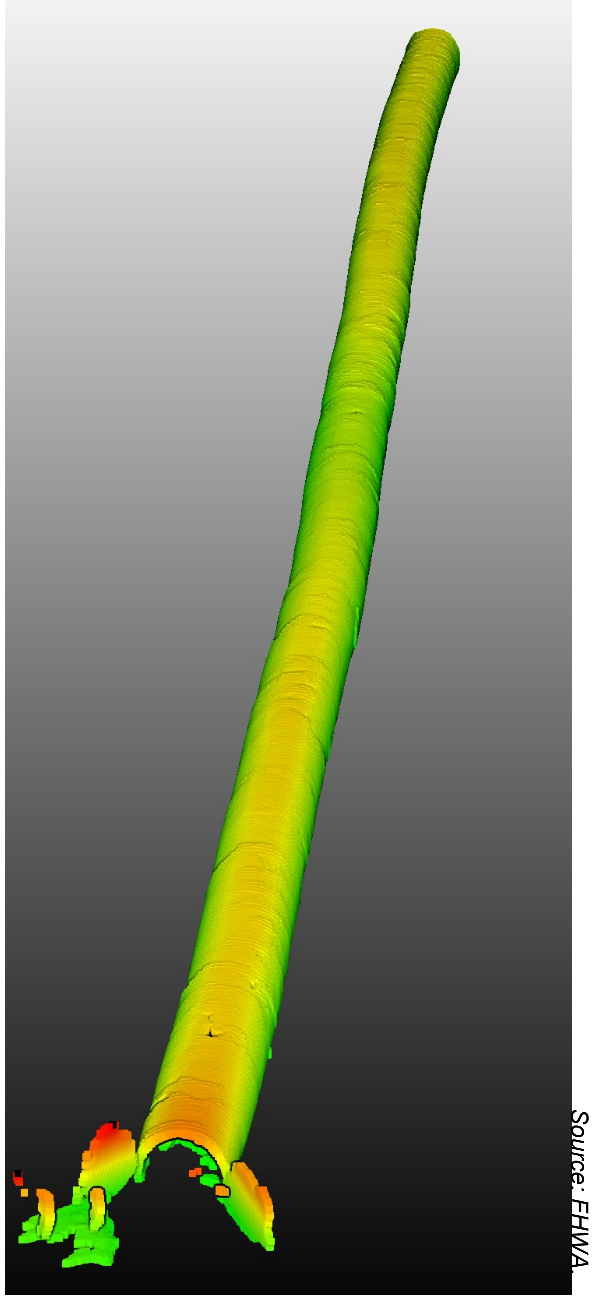




All images source: FHWA.

Key Takeaways-Phase I

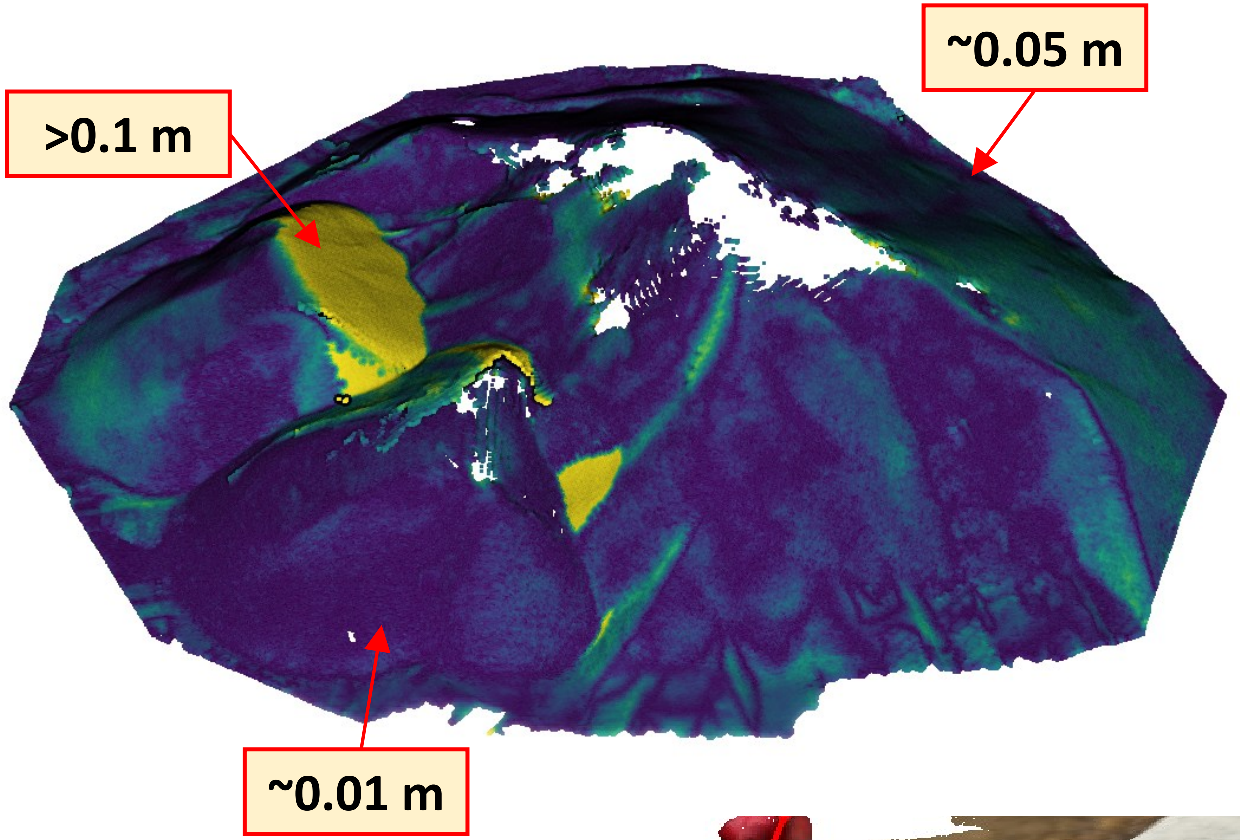
- Eager app developers: Apps and capabilities change rapidly.
- Results vary significantly by app: Minor changes in parameter settings affect results substantially.
- Apps help identify coverage gaps but still miss objects in the scene.
- iPhone provides much higher point density than iPad:
  - iPhone has a much higher quality camera, potentially better IMU and GPS.
  - iPad has more processing power.
  - iPad is generally more accurate.
- Results best in short, limited area scans (10x10 m) and planar surfaces: poorer performance on rougher surfaces.
- Safety considerations:
  - Too much looking at the screen rather than surroundings.
  - Good for tight spaces with limited access.
  - Less work on hands and knees.
- Fill in gaps: Less accurate data can be better than no data or interpolation.



Source: FHWA.

Why Phase 2?

- In Phase 1:
  - New models were released
  - Focused on lidar-based apps
  - Reliant on existing apps
- In Phase 2:
  - Test the latest pocket lidar device
  - Improved hardware enhancements
  - More photogrammetry-based apps
  - Better SLAM-based optimization
  - Detailed investigation into the APIs
  - Additional case studies and engagement

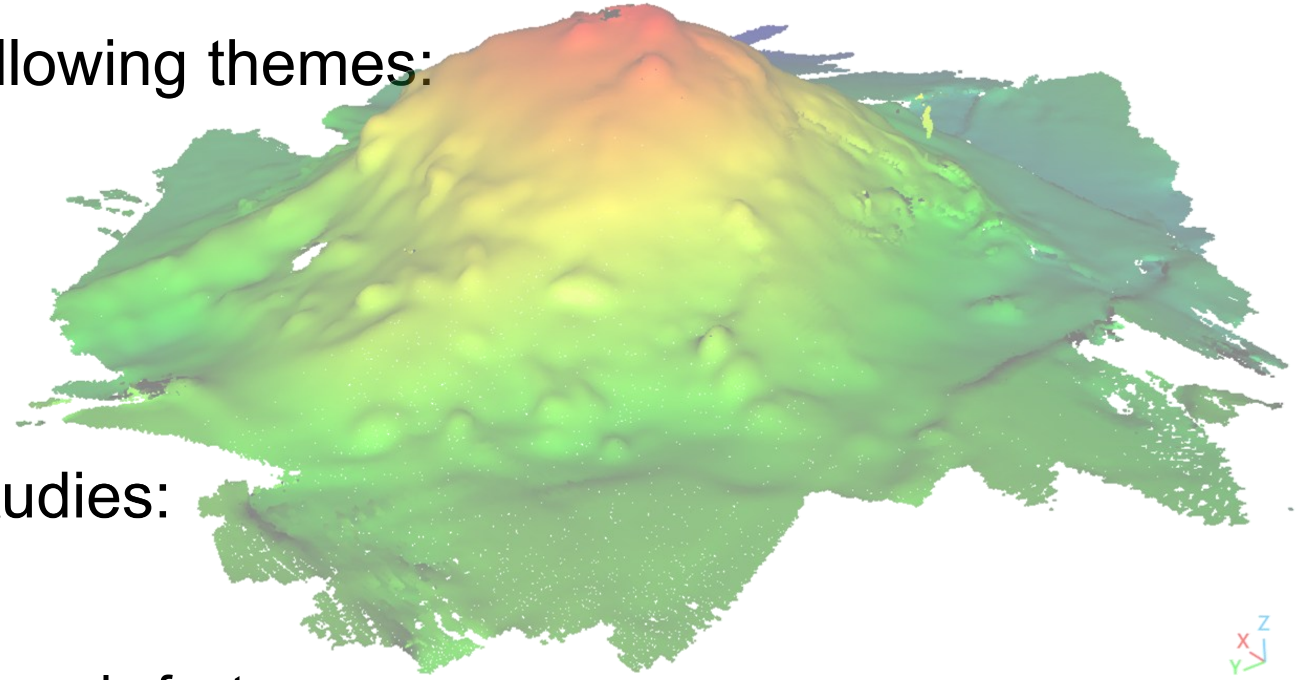


Stage 1: Evaluation and Development

- Task 1: Desktop Scan
- Task 2: Detailed Sensor Characterization
- Task 3: App Testing
- Task 4: Pocket Lidar API Testing
- Task 5: Field Protocol Development

Desktop Scan

- Summarized key findings and case studies from Phase I
- Summarized most recent studies in following themes:
  - Buildings and architectural heritage
  - Pavement and road surface damage
  - Transportation infrastructure
  - Underground construction
  - And others
- Common limitations identified in the studies:
  - Scanning range limit
  - Drift for long or complex trajectories
  - Insufficient resolution and accuracy for fine scale features
  - Many considerations that can impact the data quality (e.g., texture, lighting, apps, etc.)

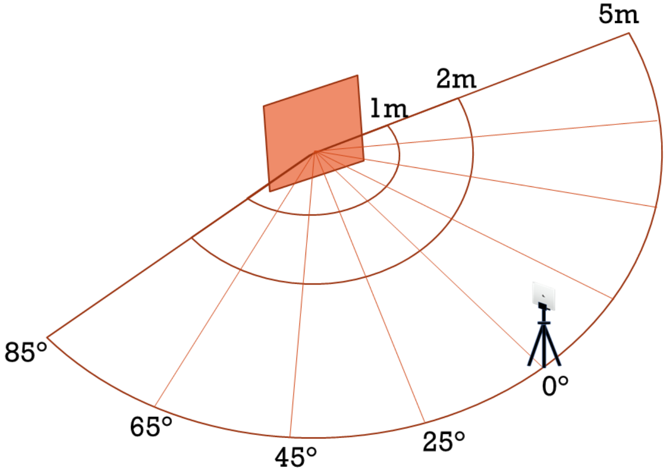


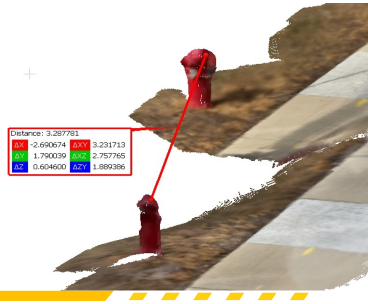
Pocket Lidar Device From 2022 to 2025

	NEW	PREVIOUS
	Apple iPhone 17 Pro Max	**Apple iPhone 14 Pro Max**
Release Date	09/19/2025	09/16/2022
Main Camera 1	48 MP, f/1.8, 24mm (wide)	48 MP, f/1.8, 24mm (wide)
Main Camera 2	**48 MP**, f/2.8, 100mm (telephoto)	**12 MP**, f/2.8, 77mm (telephoto)
Main Camera 3	4x optical zoom **48 MP**, f/2.2, 13mm, 120˚ (ultrawide)	3x optical zoom **12 MP**, f/2.2, 13mm, 120˚ (ultrawide)
Lidar	Sony IMX591 (since 2023)	Sony IMX590

Sensor Characterization

- Selected Lab Testing (based on findings in Phas
  - Scanning Geometry
    - Range
    - Angle of incidence





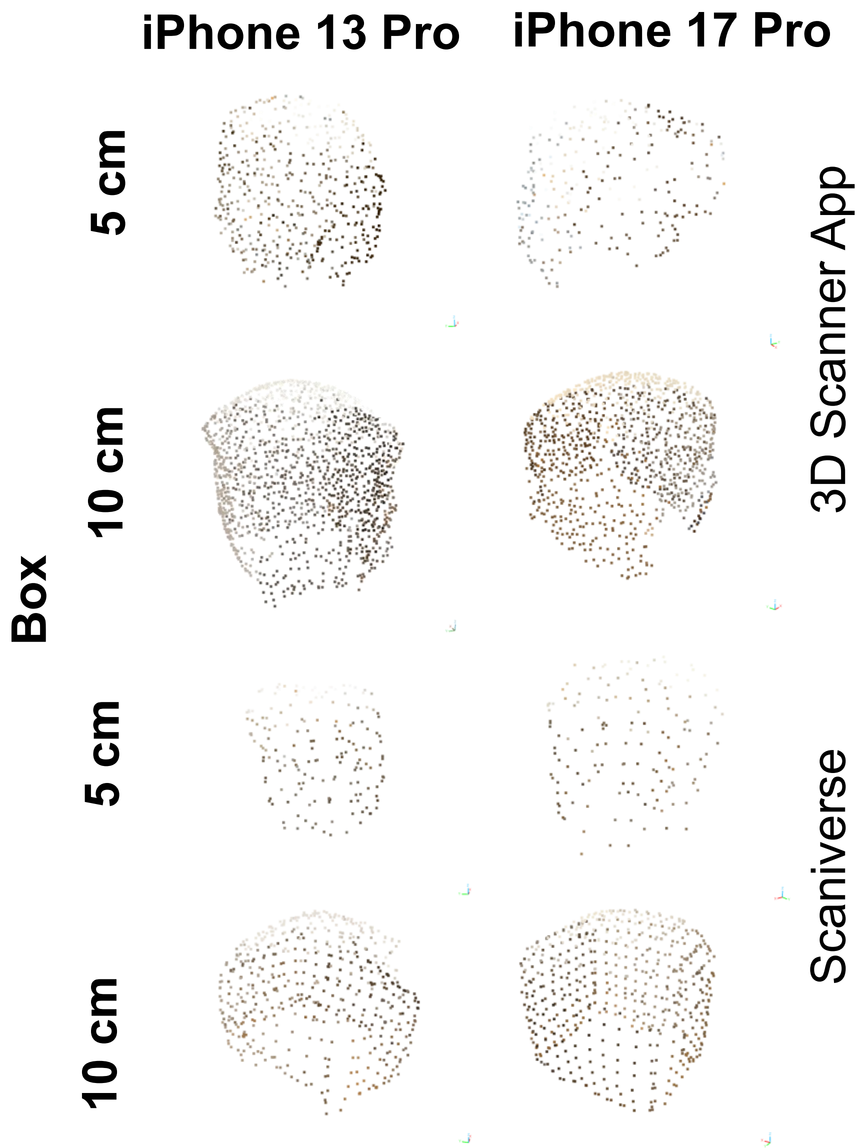
Accuracy Assessment

- RMSE values from ICP registration between geometric primitives and point clouds

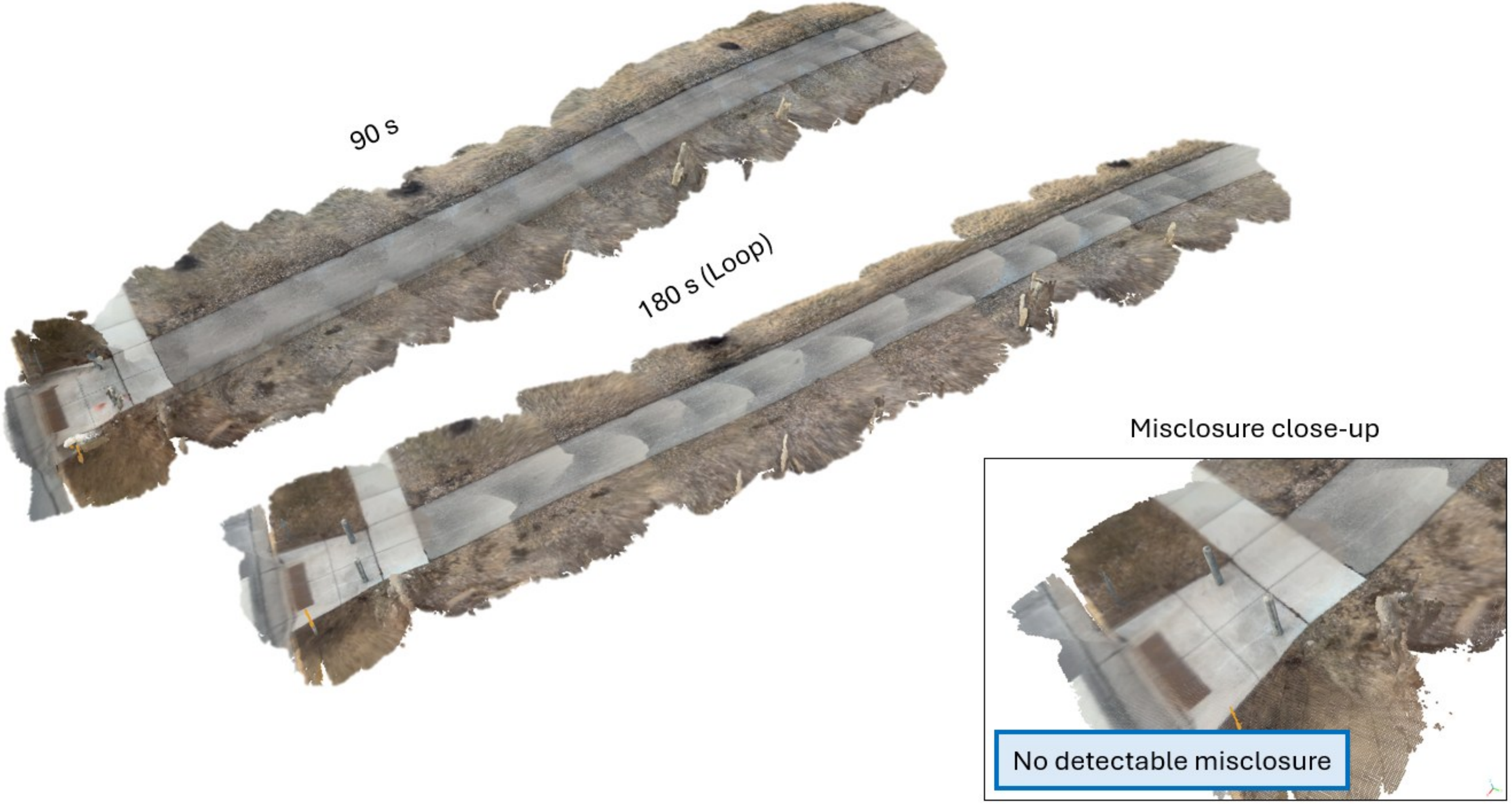
App	Device	Ball		Box		Cylinder	
		5cm	10cm	5cm	10cm	5cm	10cm
3D Scanner	iPhone 13 Pro	12.8 mm	8.4 mm	13.4 mm	16.7 mm	14.9 mm	13.3 mm
	iPhone 17 Pro	Failed	**5.3 mm**	7.6 mm	12.6 mm	**5.3 mm**	**5.0 mm**
Scaniverse	iPhone 13 Pro	Failed	5.5 mm	**6.3 mm**	**9.5 mm**	14.1 mm	11.2 mm
	iPhone 17 Pro	**7.9 mm**	6.7 mm	12.0 mm	12.9 mm	6.1 mm	5.9 mm

Key Takeaways

- Data quality is strong affected by scan geometry (i.e., range and incidence angle)
  - Resolution degrades beyond 2 m range.
  - Data quality drops when incidence angle is over 60°
- Smaller objects (less than 10 cm in any dimension) are difficult to capture.
- iPhone 17 Pro shows improved performance on cylindrical objects than iPhone 13 Pro.
- No clear performance difference between iPhone 17 Pro and iPhone 13 Pro in other testing cases.
- Need to adjust scan parameters in a real-world data acquisition.



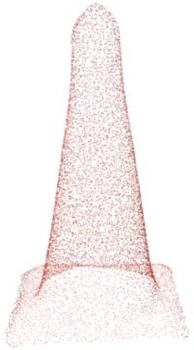
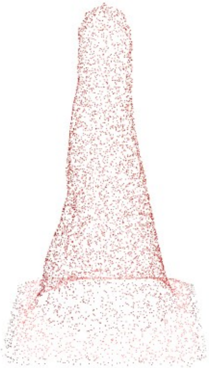
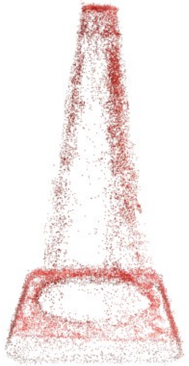
Loop closure



App Testing

- Screen New Apps
  - Include photo scanning apps
  - Validate apps tested in Phase 1 on new device
    - SiteScape
    - Polycam 3D Scanner
    - Scaniverse
    - 3d Scanner App
    - Dot3D
    - Pix4Dcatch
    - RealityScan Mobile
    - KIRI Engine:3D Scanner & Lidar
    - Abound 3D Scanner
    - RTAB-Map
    - ...

Lidar Scan (Point Cloud)

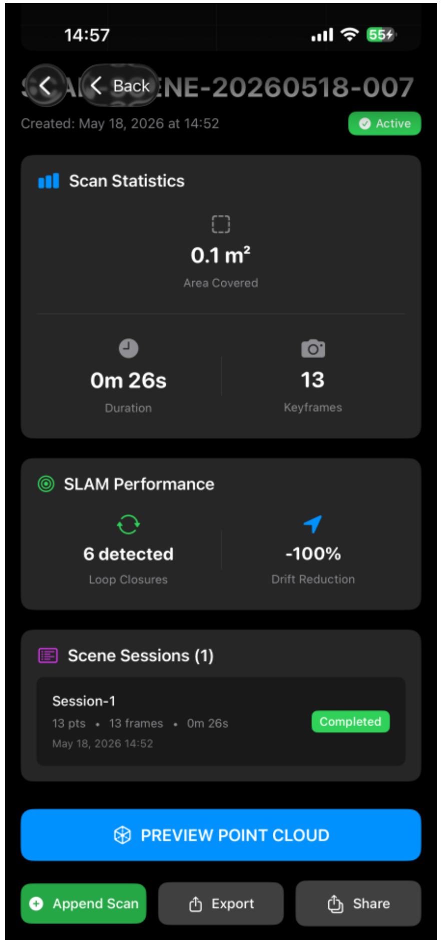
3D Scanner	Abound	DOT3D	KIRI	Pix4D
			*N/A*	
Polycam	**RTAB**	**Scaniverse**	**SiteScape**	**RealityScan**
				*N/A*

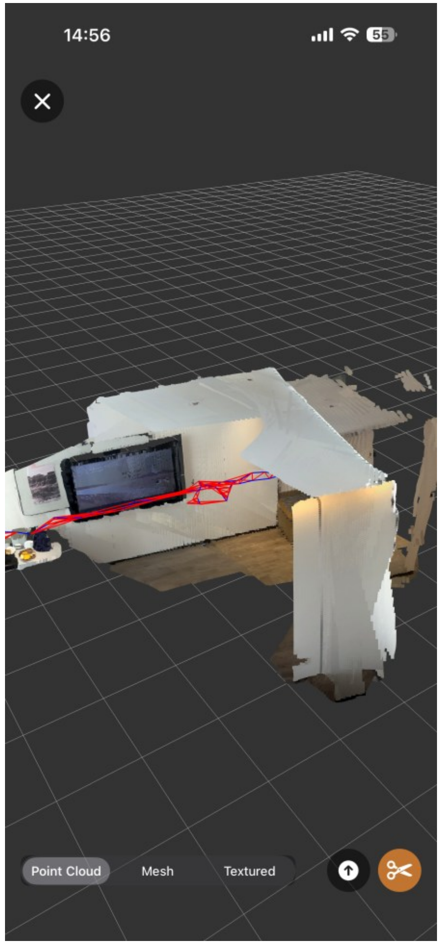
Resolution and Accuracy

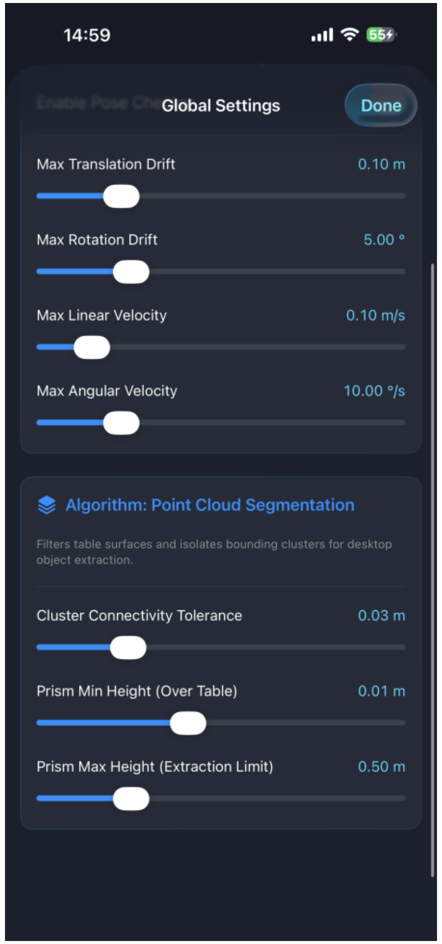
App	Lidar Scan (Point Count, RMSE)				Photo Scan (Point Count, RMSE)			
	Point Cloud		Mesh		Point Cloud		Mesh	
3D Scanner	7,855	9.5 mm	1,931	8.7 mm	3,935	Failed	1,994	Failed
Abound	4,542	8.2 mm	355	8.6 mm	3,928	19.4 mm	3,006	19.6 mm
DOT3D	142,300	15.0 mm	N/A	N/A	N/A	N/A	N/A	N/A
KIRI	N/A	N/A	657	22.9 mm	N/A	N/A	5,682	Failed
Pix4D	22,553	26.7 mm	3,968	18.4 mm	138,700	7.9 mm	13,395	8.1 mm
Polycam	7,705	11.2 mm	348	12.8 mm	N/A	N/A	N/A	N/A
RTAB	962	12.7 mm	1,295	52.0 mm	N/A	N/A	N/A	N/A
Scaniverse	19,097	10.4 mm	4,320	15.7 mm	N/A	N/A	N/A	N/A
SiteScape	514,799	14.7 mm	518,998	14.9 mm	N/A	N/A	N/A	N/A
RealityScan	N/A	N/A	N/A	N/A	N/A	N/A	12,365	Failed

API Testing

- Gain insights of multiple APIs
  - ARKit
  - RealityKit
  - RoomPlan
- Explore API capabilities
  - E.g., in-field computations/analysis
- Develop prototype script
- Identify benefits and limitations



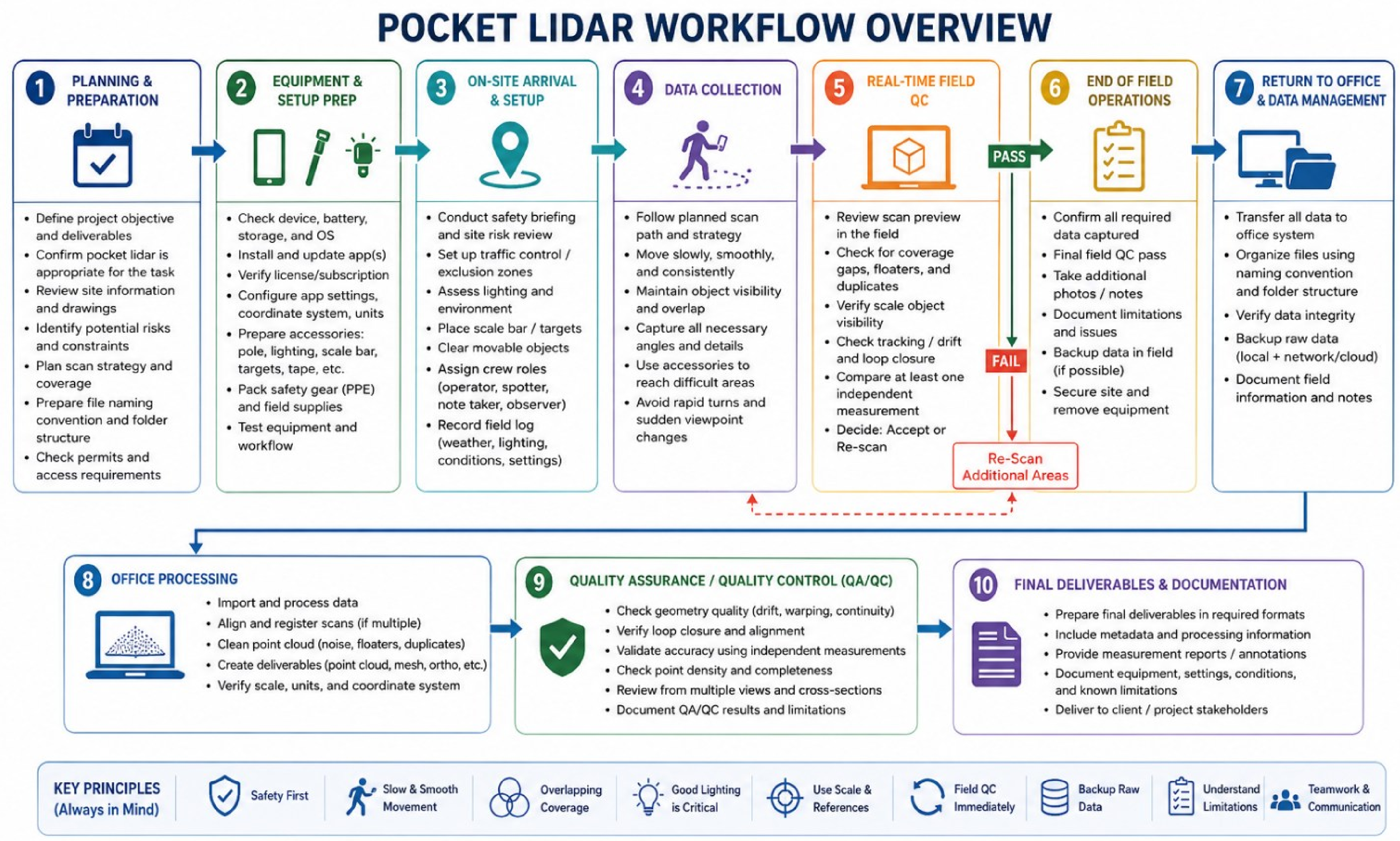




Field Protocol Development

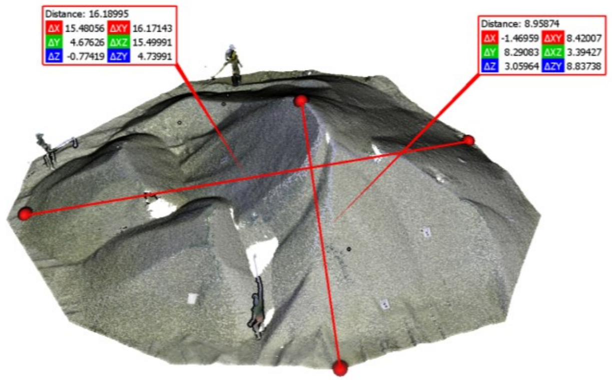
- Provide general guidelines to operate pocket lidar device:
- Scope and intended use
- Introduction
- App selection and settings
- Equipment and accessories
- Pilot testing procedures
- Safety considerations
- General field data collection protocol
- Field data QC checks
- Post-processing procedures

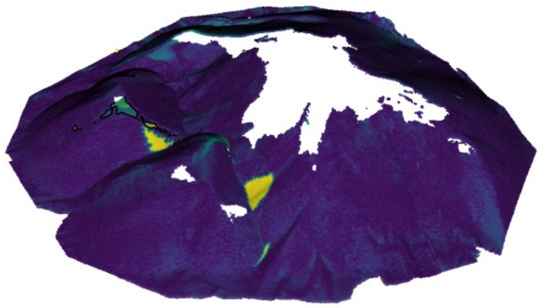
Data Collection Protocols

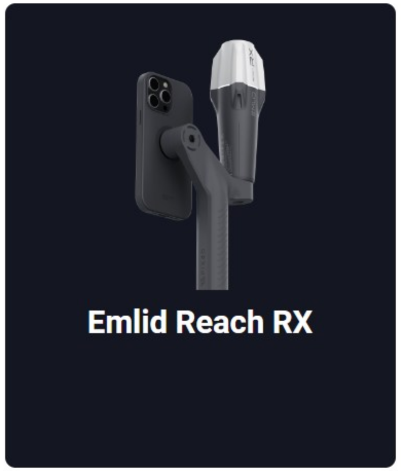


More Case Studies

- Extend from prior project
  - Use latest model and different apps
  - Tackle tasks that the older model and apps were limited in
- Assess hardware enhancements
  - Reach out to manufacturers about the new models
  - Custom parts if needed
  - Evaluate the improvements
- Explore new use cases
  - Reach out to federal and state transportation agencies

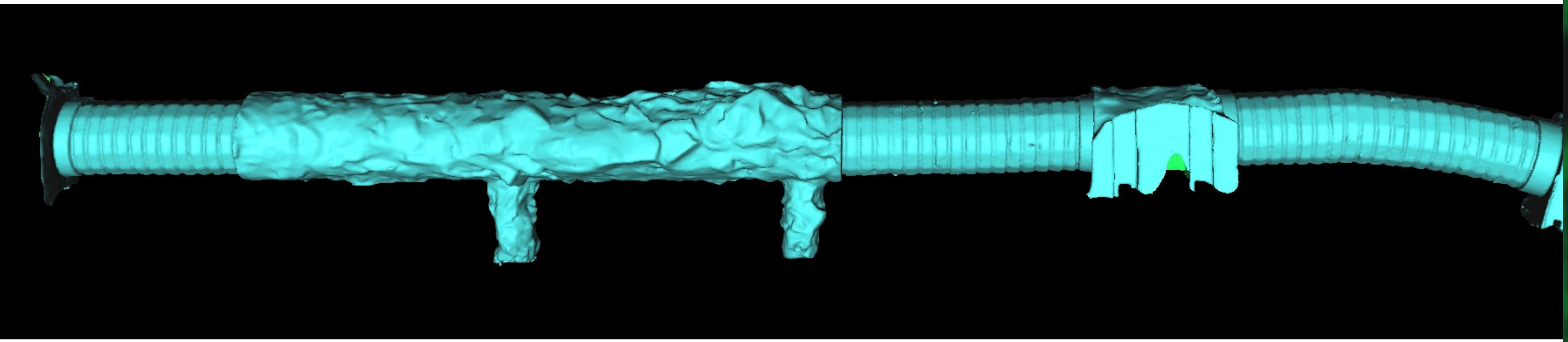






https://www.pix4d.com/blog/PIX4Dcatch-2-0/

Tunnel Inspections- OR DOT

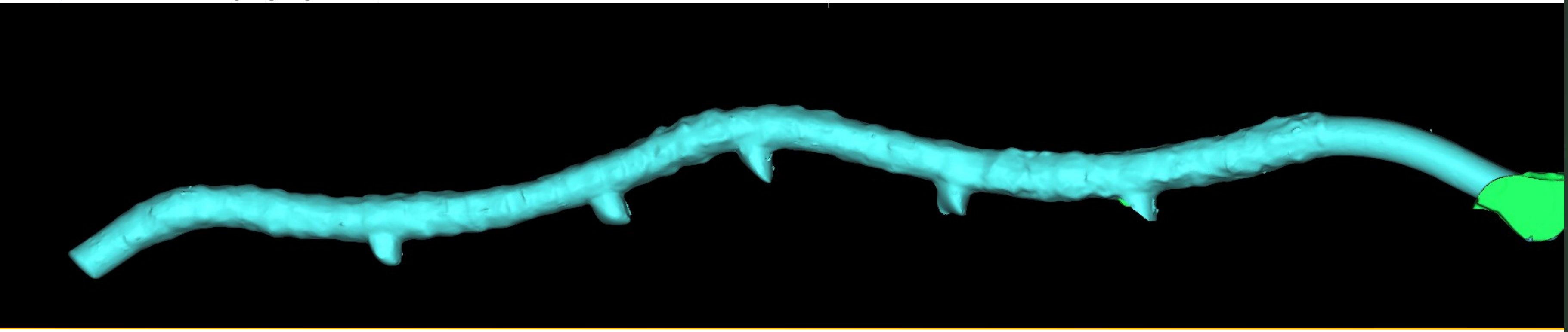


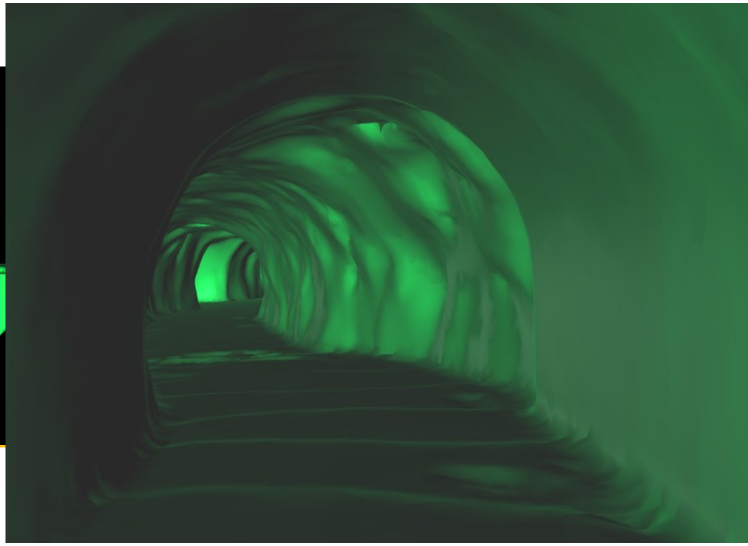
Mosier Twin Tunnels

-West: 81 ft, East: 288 ft + 700 ft rockfall structure

Mitchell Point Tunnel

- -655 ft





In Fall: Vista Ridge Tunnel

As-builts: CT DOT

- Evaluate the effectiveness of pocket lidar for:
  - Generating improved as-built documentation
  - Supporting construction quality control (QC)
  - Capturing geometric and contextual site conditions
  - Capturing utilities and “covered” objects
  - Developing reporting workflows

Project	Town	Active for late July / early August?	Why it ranks here	
0301-0130 Car & Diesel Shop Rehab	New Haven	Yes (~6.5%, to 2030)	Largest, most feature-rich site - two historic shop buildings, full interior/exterior rehab, $208M; active for years.	
0301-0509 Stamford MOE Rail Facility	Stamford	Yes (~7%, to 2028)	Dense multi-area rail facility (buildings, two storage yards, Track 44 extension, fencing, drainage), $155M.	X
0118-0171 D1 HQ & Materials Testing Lab	Rocky Hill	Yes (~10%, to 2028)	New ~135,000 SF multi-story building + demolition + site remediation; new-build ideal for progressive as-built.	
0403-0017 Stamford Electric Bus Garage	Stamford	Yes (~48%, to 10/2026)	New ~12,000 SF building, charging/electrical-dense (11 pantograph chargers + cabinets); high as-built value. Mid/later-build (~48% now, ~60-65% by late July / early August) - still active in late July / early August, but not early-stage.	X
0304-0029 Naugatuck Railroad Station	Naugatuck	Yes (~14%, to 2027)	New station - 350-ft high-level platform + canopy, parking lot, site work; compact discrete site.	
0158-0223 New Maintenance Facility	Westport	Yes (~26%)	New 18,000 SF facility + 2,200 SF truck wash + storage conversion. Curator note: “recommended by D3 Survey.”	X
0301-0521 Catenary Maint. Vehicle Shed	Bridgeport	Yes (~2%, to 2026)	Bridgeport Rail Yard - new shed, track removal/replacement, foundation, electrical relocation; very early stage.	X

Test RTK GNSS attachments

Rebar Placement – Caltrans Specifications

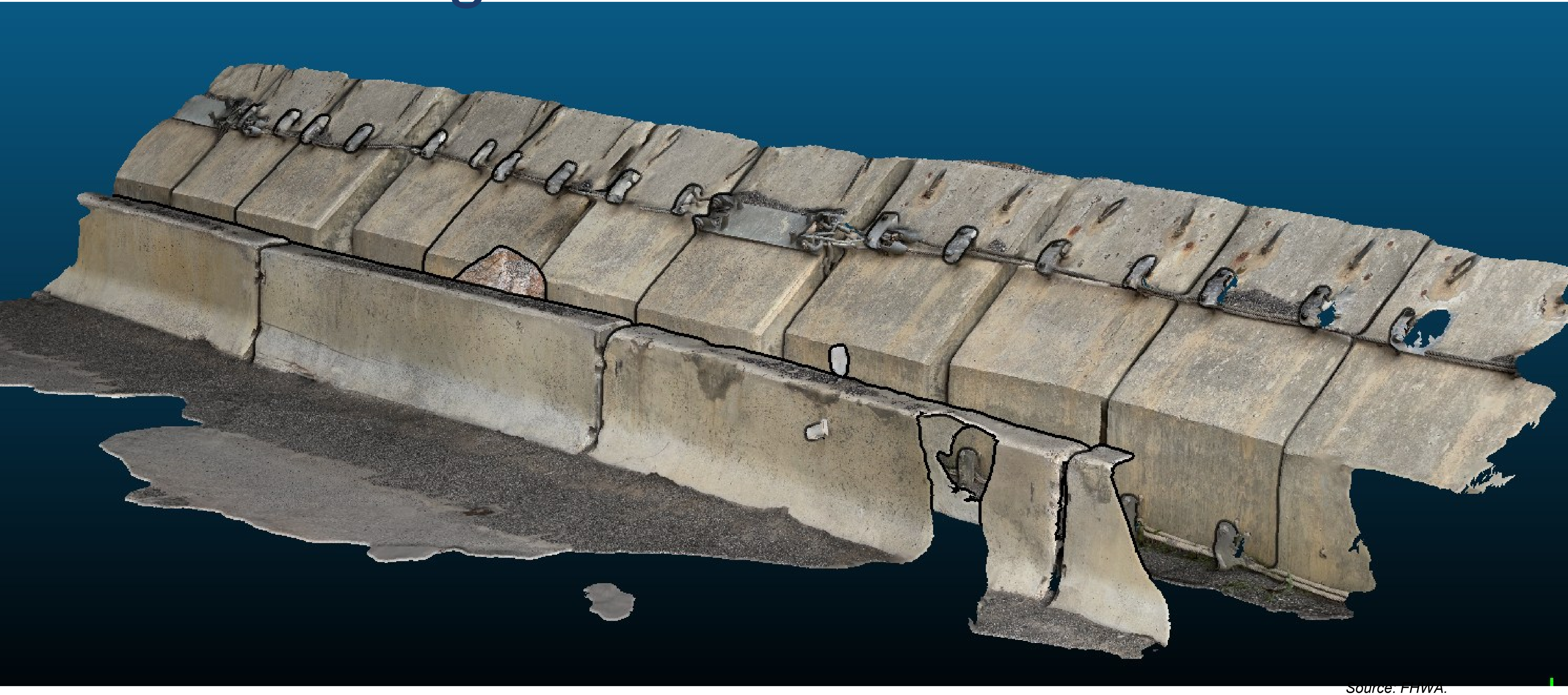
- Placement
- Backfill volume
- Spacing
- Pipe location documentation



Bridges- FHWA WFL

- Support survey planning
- Comparisons to handheld lidar and multi-station
- Test new long range lidar attachments (30 m)

Acknowledgements and Questions



Source: FHWA.

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