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MPC 606 – Image-Based 3D Reconstruction of Utah Roadway Assets

Presented by:
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Our partners:

Mountain-Plains Consortium · Montana MDT Department of Transportation · North Dakota Transportation · South Dakota DOT · Wyoming Department of Transportation · NDSU Upper Great Plains Transportation Institute Transportation Learning Network

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Image-Based 3D Reconstruction of Utah Roadway Assets

MPC Presentation

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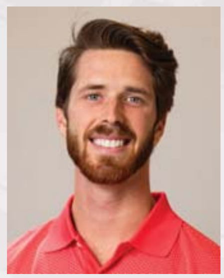

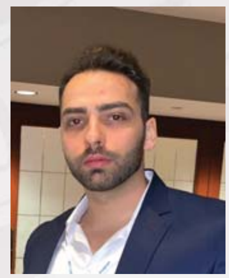

MPC
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Outline

1. Why was this project necessary?
2. Data acquisition technologies
   - LiDAR
   - Photogrammetry
3. Software testing
4. Data collections
   - Highway asset management
   - UAS highway asset management
   - Pedestrian access ramp inspections
   - Pavement distress & bridge inspection
5. Data evaluations
   - For case studies mentioned above
6. Limitations and challenges
7. Recommendations
8. Cost & Time Analysis
9. Summary
10. Conclusion
11. Acknowledgements

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Why was this project necessary?

- Utah's transportation system is one of it's most valuable assets
  - Valued at more than $45 billion
- Various tiers of assets within UDOT based on value and financial impact
  - Tier 1
  - Tier 2 – Main focus of this research
  - Tier 3
- Asset management is of utmost importance to ensure an efficient and safe transportation system
- Asset managers must have access to up-to-date information regarding all assets and their conditions
- Requires a fast, efficient, and affordable data collection procedure
- Necessary to test whether photogrammetry can be considered an acceptable alternative to LiDAR within UDOT

Asset	Tier
Pavement	1
Bridges	1
ATMS/Signal Devices	1
Pipe Culverts	2
Signs	2
Walls	2
Rumble Strips	2
ADA Ramps	2
Barrier	2
Pavement Markings	2
Cattle Guards	3
Interstate Lighting	3
Fences	3
Rest Areas	3
Curb and Gutter	3
Trails	3
Bike Lanes	3
Surplus Land	3
At-grade Railroad Crossings	3

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Data Acquisition Technologies - LiDAR

VX15 mounted to a drone – Asset Management

Maptek I-Site 8820 Terrestrial LiDAR Scanner – Pedestrian Access Ramps & Pavement Distress

Mandli Communications Mobile LiDAR Vehicle - Asset Management

Data Acquisition Technologies - Photogrammetry

GoPro Hero 8+ - Asset Management & Pavement Distress

Fujifilm X-T30 – Pedestrian Access Ramps

DJI Mavic 2 Pro – Asset Management

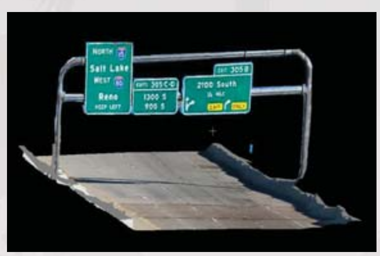
List of Case Studies for Asset Management

Main Case Studies

1. Highway Asset Management
   - Mobile LiDAR
   - Mobile photogrammetry
   - UAS LiDAR and photogrammetry
2. Pedestrian Access Ramp Inspections
   - Terrestrial LiDAR
   - Photogrammetry

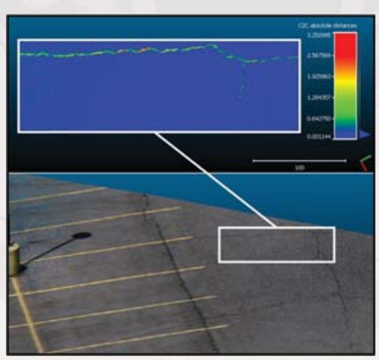
Supplemental Case Studies

1. Pavement Distress Analysis
   - Terrestrial LiDAR
   - Mobile photogrammetry
2. Bridge Inspection
   - Mobile LiDAR
   - Terrestrial LiDAR
   - Mobile photogrammetry



Highway Asset Management

Pedestrian Access Ramps



Pavement Distress Analysis

Bridge Inspection

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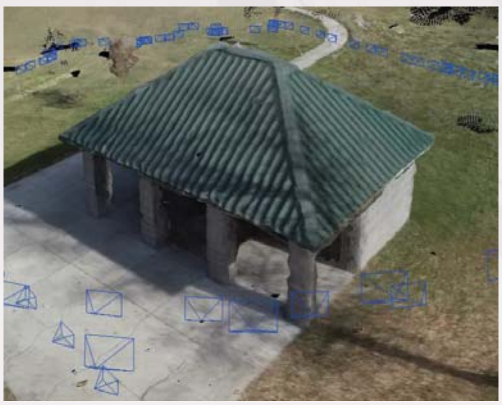
Software Testing

- Multitude of photogrammetry software on the market
- Imperative to decide which software provided the best overall point cloud
- Tested both data collection procedures
  - Traditional
  - Linear
- The same data was uploaded into each software for comparison
  - 163 images from a city street data collection



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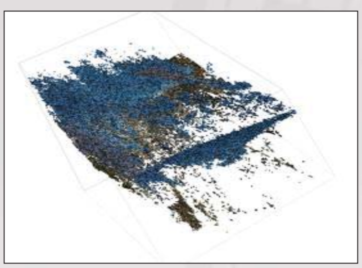
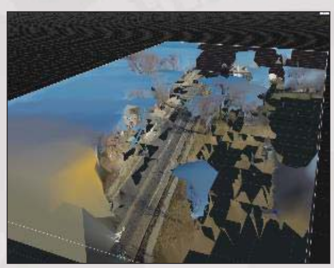
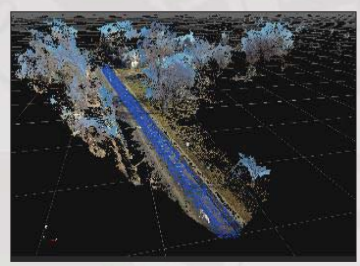
Software Testing



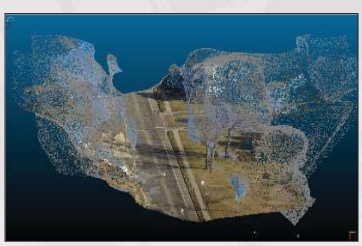
Agisoft



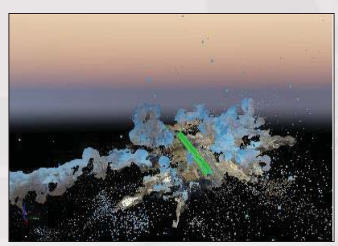
Reality Capture



3DF Zephyr



Context Capture



Pix 4D

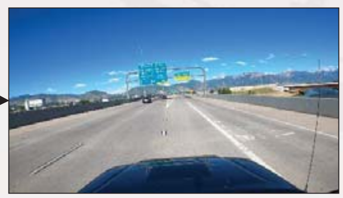
Software Package	Number of Registered Images (Out of 163)	Processing Time (hrs)	Number of Generated Points	Point Cloud Quality
Agisoft	89	3.5	21,145,499	Unacceptable
Reality Capture	161	3	12,000,000	Unacceptable
3DF Zephyr	163	2	2,102,289	Average
Context Capture	163	1.75	55,104,235	Above Average
Pix 4D	163	4	1,452,751	Unacceptable

Data Collection – Highway Asset Management

- Tested different cameras
  - Started with GoPro Hero 3+
    - Limited to: 4K @ 15 FPS, 2.7K @ 30 FPS, 1080 @ 60 FPS
    - No stabilization
  - Upgraded to the GoPro Hero 8+
    - 4K @ 60 FPS, 2.7K @ 120 FPS, 1080 @ 240 FPS
    - Great video stabilization

•Hood mounted vs. roof mounted camera
  •Roof mounted captured the vehicle hood in frame which can cause processing problems
  •Hood mounted had a good unobstructed field of view

Roof mounted GoPro



Hood mounted GoPro

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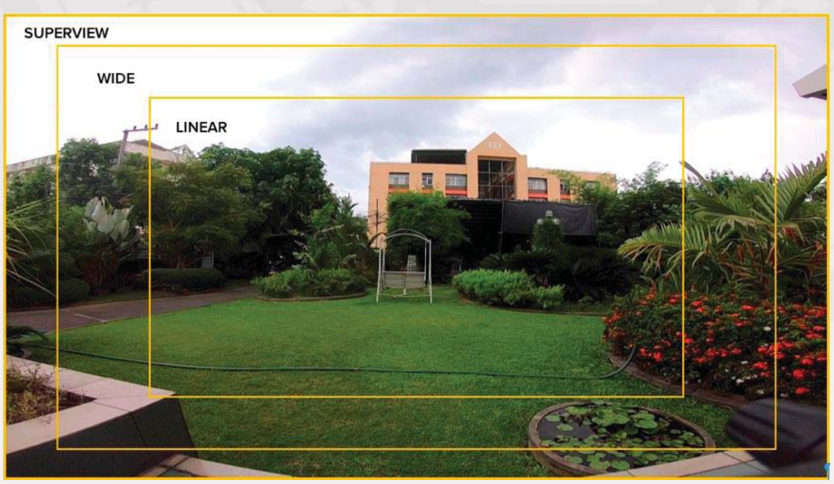
Data Collection – Highway Asset Management

•Field of View
  •Linear
  •Wide
  •Superview
•Viewing angles
  •Camera pointing straight forward works best
•Mobile LiDAR models were obtained through UDOT
  •Mandli Communication does all of UDOT's asset management data collection



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Data Collection – Highway Asset Management

Asset Management Data Collection Table

Model	Lighting Conditions	Acquisition Time	Traveling Speed (MPH)	Model Length (Miles)	Number of Registered Images (Aligned/Total)	Processing Time (Image-Based)	Number of Points
Model 1	Dense Clouds, Intermittent light	18 sec	50	0.25	999/999	2 hr 11 min	410 Million
Model 2	Sunny, perfect sign visibility, no reflections	20 sec	45	0.25	1195/1195	2 hr 48 min	430 Million
Model 3	Sunny, perfect sign visibility, no reflections	18 sec	20 (Exit)	0.1	1026/1026	2 hr 58 min	771 Million
Model 4	Bright sunlight, many reflections	40 sec	45	0.5	850/850	2 hr 5 min	776 Million
Model 5	Indirect sunlight, low light on signs	20 sec	45	0.25	850/850	2 hr 41 min	706 Million
Model 6	Sunny, good sign visibility	18 sec	40	0.2	1107/1301	3 hr 42 min	1.3 Billion

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Data Collection – UAS Asset Management

- Also used Unmanned Aerial Systems (UAS) for asset management data collections
- Two drones
  - DJI M600 w/ a mounted VX15 LiDAR scanner
  - DJI Mavic 2 Pro
- Flew drones with UDOT personnel to gather data regarding a previously-constructed highway model
- Drones were flown 250ft above roadway
- LiDAR scanner only emits laser pulses straight down
  - 100,000 points per second
- Mavic 2 Pro has an adjustable camera angle
  - Angle was set to 60 degrees below the horizon

DJI M600 Drone

VX15 LiDAR Scanner

DJI Mavic 2 Pro

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Data Collection – Pedestrian Access Ramp Inspections

- Met with UDOT pedestrian ramp experts to discuss pedestrian ramp elements and inspection protocol
  - Red: Pedestrian Access Route
  - Dark Blue: Turning Space
  - Yellow: Ramp
  - Purple: Ramp Flares
  - Green: Detectable Warning Surface
  - Light Blue: Clear Space
  - Orange: Crosswalk
- UDOT C-170 Pedestrian Access Ramp Evaluation Form
  - SmartTool Smart Level
  - Tape Measurer
- Photogrammetry
  - Fujifilm X-T30 digital camera
  - 25-30 pictures per ramp
- LiDAR
  - Maptek I-Site 8820 Terrestrial LiDAR scanner
  - 1 stationary scan

Pedestrian access ramp elements

Maptek I-Site 8820

Fujifilm X-T30

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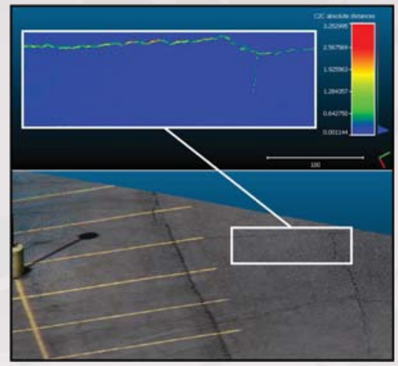
Data Collection – Pedestrian Access Ramp Inspections

Pedestrian Access Ramp Data Collection Table

Method	Model	In-Field Data Acquisition Time (Minutes)	Number of images/scans (Aligned/Total)	Processing Time	Number of Points in Point Cloud	File Size
Image-based Reconstruction	Ramp 1	< 5 min	31/31	47 min 2 sec	258,651,814	6.72 GB
	Ramp 2	< 5 min	37/37	52 min 22 sec	429,797,343	11.17 GB
	Ramp 3	< 5 min	27/29	52 min 26 sec	313,767,481	8.16 GB
	Ramp 4	< 5 min	31/31	47 min 8 sec	263,338,208	6.87 GB
	Ramp 5	< 5 min	27/29	51 min 23 sec	436,552,997	11.35 GB
	Ramp 6	< 5 min	24/25	49 min 20 sec	247,958,617	6.45 GB
LiDAR-Based Reconstruction	Ramp 1	16 m 30 s	1 scan	No Processing	12,182,400	768 MB
	Ramp 2	17 min	1 scan	No Processing	11,955,200	745 MB
	Ramp 3	12 m 9 s	1 scan	No Processing	3,498,634	222 MB
	Ramp 4	13 m 45 s	1 scan	No Processing	6,506,448	407 MB
	Ramp 5	13 m 9 s	1 scan	No Processing	2,999,779	102 MB
	Ramp 6	13 m 32 s	1 scan	No Processing	2,398,708	83 MB

Data Collection – Pavement Distress & Bridge Inspection

- Pavement Distress Analysis
  - Compared how accurately mobile photogrammetry could map pavement distress compared to a stationary LiDAR scan
  - LiDAR
    - Maptek I-Site 8820
  - Photogrammetry
    - GoPro Hero 8+
    - Modified asset management collection procedure



Pavement Distress Registration

- Bridge Inspection
  - Compared
    - Mobile LiDAR point cloud
    - Terrestrial LiDAR point cloud
    - Mobile photogrammetry point cloud
  - Asset management collection procedure
  - Evaluated the width of each diaphragm (11 locations) to the length of the total span
    - Photogrammetry unable to capture data under the bridge

Data Evaluation – Highway Asset Management

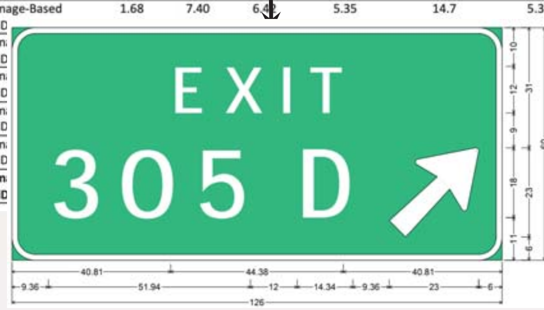
- Calculated reconstructed sign ratio error
  - Actual sign ratio to reconstructed sign ratio (Width/Length)
- Calculated Sign Densities (points/in^2)
  - Standard Deviation (SD): How far each measurement deviates from the average of the group
  - Coefficient of Variation (CV): The measure of variability within a group of measurements

- Photogrammetry Averages
  - Error – 4.33%
  - Sign Density – 14.6 points/in^2
  - SD – 14.6
  - CV – 0.49

- LiDAR Averages
  - Error – 3.48%
  - Sign Density – 0.96 points/in^2
  - SD – 0.41
  - CV – 0.42

Asset [illegible] *nt Table*

Model	Sensing Technology	Sma[illegible]	[illegible]	[illegible]	[illegible] Error (%)	Average Sign Density (Points/in^2)	Standard Deviation of Sign Density	Coefficient of Variation of Sign Density (CV)
Model 1	Image-Based	2.11	6.89	4.7[illegible]	5.09	35.3	18.4	0.52
	LiDAR	4.39	5.40	1.5[illegible]	3.93	0.74	0.32	0.44
Model 2	Image-Based	1.68	7.40	6.4[illegible]	5.35	14.7	5.38	0.37
	LiD[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.42
Model 3	Im[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.37
	LiD[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.42
Model 4	Im[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.56
	LiD[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.33
Model 5	Im[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.64
	LiD[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.52
Model 6	Im[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.49
	LiD[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.41
Averages	**Im[illegible]**	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	**0.49**
	LiD[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	**0.42**



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Data Evaluation – Highway Asset Management

- Overall point cloud density
  - Number of neighbors algorithm
    - Circles of a user defined radius (1 cm) are superimposed throughout the entire model
    - Program counts the number of points within each circle
    - Data output in the form of a histogram
- Photogrammetry point clouds were much more dense than LiDAR point clouds
  - Mandli Communications most likely uses smart technology to limit data gathered
    - Data is gathered at a faster rate at highway speeds than when slowing down or at a stop
    - Limits the amount of redundant data gathered

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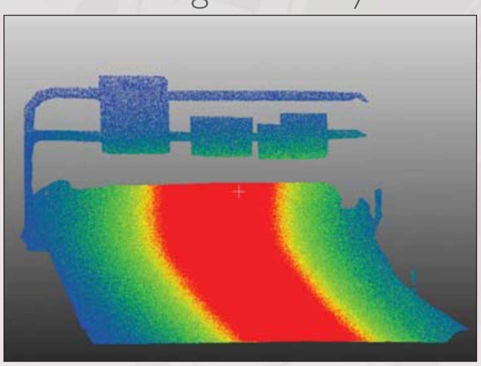
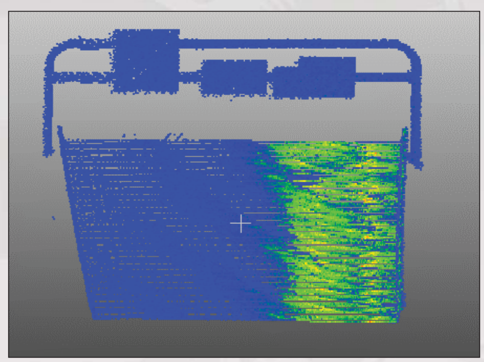
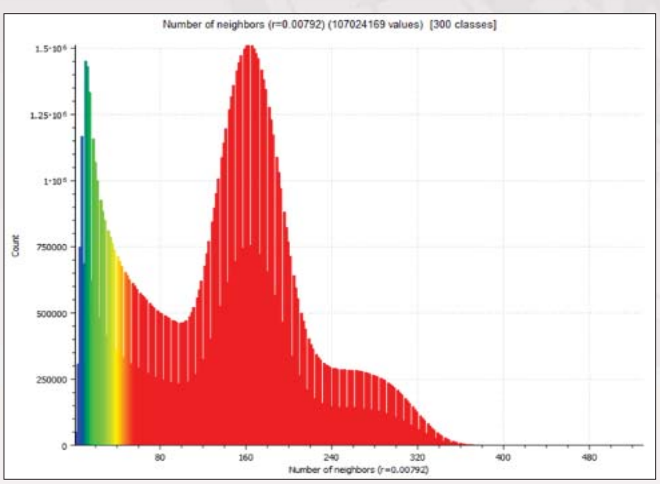
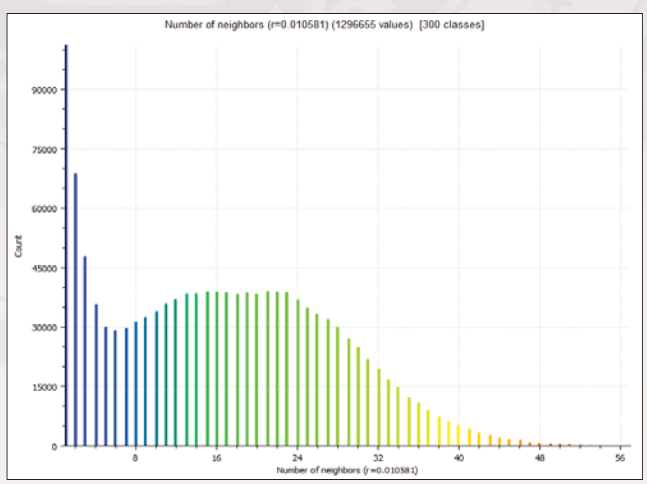
Photogrammetry



LiDAR

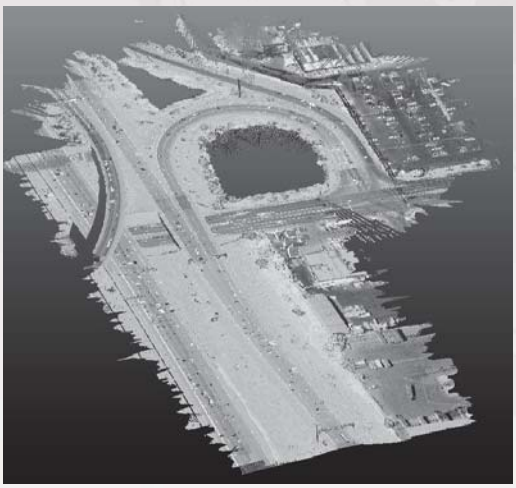






Data Evaluation – UAS Asset Management

- LiDAR unable to capture any signs due to limited scanner angle
- Photogrammetry could provide accurate sign locations
  - Sign surfaces not generated well enough to extract measurements
  - Each signs location was captured
- Both technologies accurately mapped surrounding terrains
- Could possibly be used for bridge structural inspections
  - More thorough data review needed



LiDAR model using UAS

Photogrammetry model using UAS

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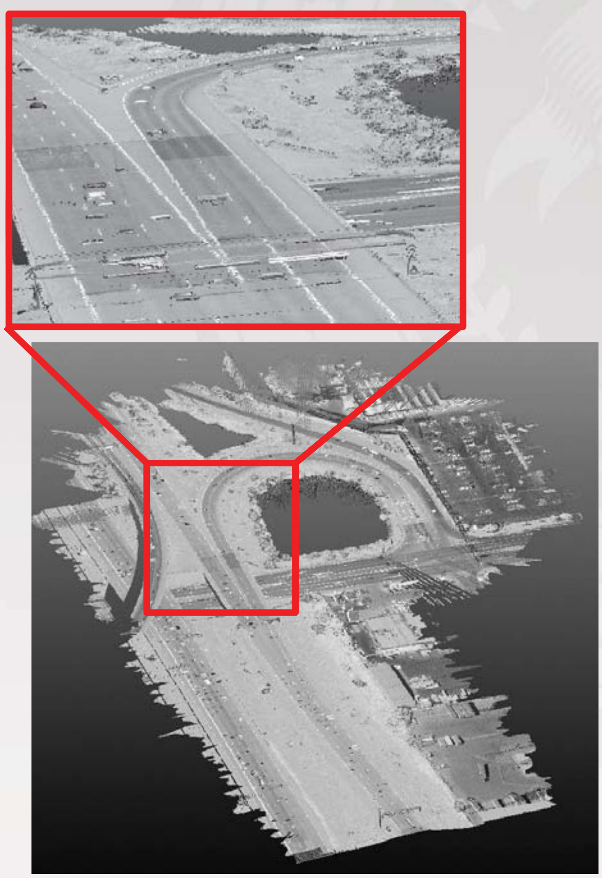

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Data Evaluation – Pedestrian Access Ramp Inspections

- Computed errors for how much each model deviated from the in-field measurements
  - LiDAR
  - Photogrammetry
- Consistency of the results
  - Standard Deviation (SD)
  - Coefficient of Variation (CV)

- Photogrammetry
  - Error - 0.32%
  - SD – 0.15
  - CV – 0.48

- LiDAR
  - Error - 0.19%
  - SD - 0.04
  - CV - 0.24

Pedestrian access ramp slope error table

Pedestrian Access Ramp Model	Technology	Slope Error (%)
Ramp 1	Photogrammetry	0.60
	LiDAR	0.27
Ramp 2	Photogrammetry	0.28
	LiDAR	0.19
Ramp 3	Photogrammetry	0.28
	LiDAR	0.16
Ramp 4	Photogrammetry	0.35
	LiDAR	0.19
Ramp 5	Photogrammetry	0.24
	LiDAR	0.18
Ramp 6	Photogrammetry	0.16
	LiDAR	0.14
Average Error	**Photogrammetry**	**0.32**
	LiDAR	**0.19**
Standard Deviation	**Photogrammetry**	**0.15**
	LiDAR	**0.04**
Coefficient of Variation	**Photogrammetry**	**0.48**
	LiDAR	**0.24**

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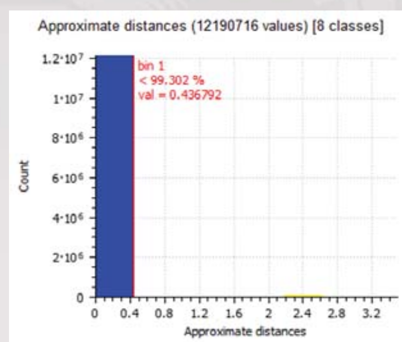
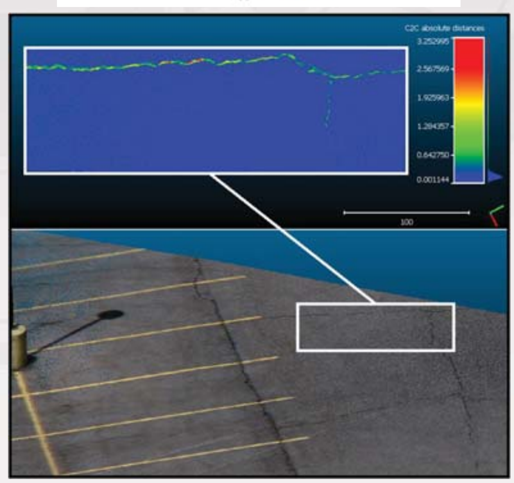
Data Evaluation – Pavement Distress



- LiDAR point cloud used as the ground truth model
- Models were registered using ground control points
- On-site measurements indicate the widths of the target pavement crack are in the range of 2-4 cm (0.79-1.57 in)
- Point cloud registration
  - 99.302% of equivalent point pairs have a distance of less than 0.436 cm (0.17 in)
- Histogram index shows a max deviation of 3.25 cm (1.28 in)
  - Red areas
- Majority of crack is color coded with green
  - Image-based point cloud deviates roughly 1cm (0.39 in) from ground truth model



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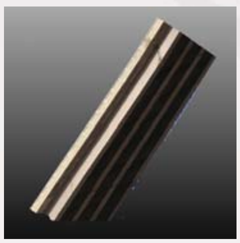
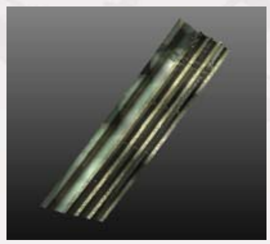
Data Evaluation – Bridge Inspections

- Photogrammetry unable to capture data on the underside of the bridge due to the cameras field of view
  - Side facing the camera showed details very well
- Mobile & terrestrial LiDAR gathered data regarding the underside and backside of the bridge
  - Calculated the percent error of diaphragm width to span length between the two LiDAR methods
    - 1.29% average deviation of mobile LiDAR to terrestrial LiDAR

Location	Mobile LiDAR			Terrestrial LiDAR			Percent Error (%)
	Span Length	Span Width	Ratio (W/L)	Span Length	Span Width	Ratio (W/L)	
1	54.84	6.72	0.1225	55.24	6.89	0.1247	1.76
2	54.84	6.76	0.1233	55.24	6.79	0.1229	0.28
3	54.84	6.70	0.1222	55.24	6.78	0.1227	0.46
4	54.84	6.72	0.1225	55.24	6.72	0.1217	0.73
5	54.84	6.69	0.1220	55.24	6.90	0.1249	2.34
6	54.84	6.90	0.1258	55.24	6.72	0.1217	3.43
7	54.84	6.78	0.1236	55.24	6.80	0.1231	0.43
8	54.84	6.79	0.1238	55.24	6.82	0.1235	0.29
9	54.84	6.86	0.1251	55.24	6.74	0.1220	2.52
10	54.84	6.85	0.1249	55.24	6.83	0.1236	1.02
11	54.84	6.77	0.1235	55.24	6.88	0.1245	0.88
						Average	1.29


Mobile LiDAR


Terrestrial LiDAR


Mobile Photogrammetry

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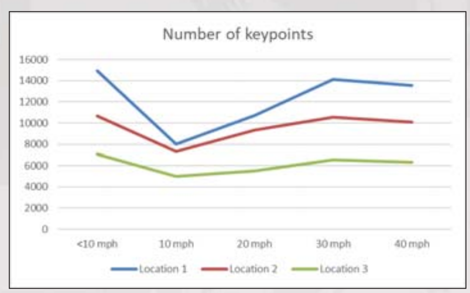
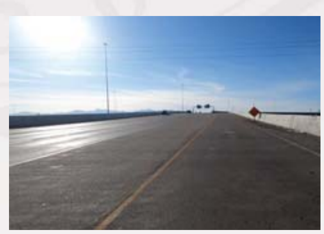
Limitations & Challenges

- Largest factor that directly affects point cloud quality is speed
  - Unable to create a good model over 50 MPH
  - Keypoint matching is used to align consecutive photos
  - Keypoint matches begin to decrease after 30 MPH
- Poor lighting conditions are also a challenge
  - Light shining into the sensor can cause poor lighting in frames
  - Light reflecting off of roadway surfaces or signs can cause model errors
- Vehicular obstructions can cause problems
- Photogrammetry point clouds are very large files
  - Downsampling can help manage storage problems




Good Lighting


Poor Lighting

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Limitations & Challenges - Downsampling

- Original photogrammetry point clouds can be very large
  - Some as large as 30+ GB
- Downsampled each model to see how much quality was lost
  - 100%
  - 75%
  - 50%
  - 25%
- Point cloud visibility is categorized by:
  - Great, Good, Fair, Poor
  - Visibility includes sign visibility as well as pavement and other assets
- Very beneficial to downsample models
  - Retains data accuracy
  - Allows for easier file transfer
  - Reduces the amount of storage needed in office

Examples of visibility

Great Good Fair Poor

Effects of Downsampling on File Size and Sign Visibility					
Model		Downsampling Percentage			
		100%	75%	50%	25%
Model 1	# of Points	351,960,833	263,970,625	175,980,417	87,990,208
	File Size	11.1 GB	8.84 GB	5.89 GB	2.94 GB
	Visibility	Great	Great	Good	Good
Model 2	# of Points	318,014,773	238,511,080	159,007,387	79,503,693
	File Size	10 GB	7.99 GB	5.33 GB	2.66 GB
	Visibility	Great	Great	Good	Good
Model 3	# of Points	770,930,961	578,198,221	385,465,481	192,732,740
	File Size	24.4 GB	19.3	12.9 GB	6.46 GB
	Visibility	Great	Good	Good	Fair
Model 4	# of Points	714,905,162	536,178,872	357,452,581	178,726,291
	File Size	22.6 GB	17.9 GB	11.9 GB	5.99 GB
	Visibility	Good	Good	Fair	Fair
Model 5	# of Points	570,359,305	427,769,479	285,179,653	142,589,826
	File Size	19.1 GB	14.3 GB	9.56 GB	4.78 GB
	Visibility	Good	Good	Fair	Poor
Model 6	# of Points	500,000,000	375,000,000	250,000,000	125,000,000
	File Size	16.7 GB	12.5 GB	8.38 GB	4.19 GB
	Visibility	Great	Good	Good	Fair

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Recommendations

- Asset Management
  - Pay close attention to speed
    - Drive as slow as traffic allows (best to keep it under 50 MPH)
  - Choose the optimal time of day for lighting conditions
    - Early (AM) – Drive West or North
    - Later (PM) – Drive East or South
  - Record in a high number of frames per second
    - May not use all frames for processing
  - Downsampling models can play a large factor in easing data storage and data transfer
  - Using a powerful processor can help streamline point cloud processing
    - HP Zbook 17, Intel Core I7-7700 HQ, 64 GB of RAM

- Pedestrian Access Ramps
  - Ensure every point in the scene is captured by 3 different views
  - Ensure photos have good overlap with previous and following frames
  - Laser scanner must be perfectly level before scanning
    - Unlevel scanner can cause measurement errors

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Cost & Time Analysis

- Photogrammetry is much more cost effective than LiDAR
  - Photogrammetry
    - GoPro Hero 8+ - $400
    - FujiFilm XT-30 - $1,300
    - DJI Mavic 2 Pro - $1,600
  - LiDAR
    - 2 Velodyne HDL-32s - $49,000
    - VX15 Scanner - $140,000
    - Maptek I-Site 8820 - $30,000 (Used)
  - Photogrammetry requires slightly less time for in-field labor
- Photogrammetry requires less storage in the field
  - It requires more storage in the office
  - Downsampling can help with in-office storage

Case Study	Technology	Equipment	Cost of Equipment	Software	Cost of Software	In-Field Labor	In-Field Data Storage Requirements	Office Data Storage Requirements
Vehicular Systems for Asset Management	Photogrammetry	GoPro Hero 8 Black Edition	$400	Context Capture	$9,100 (First year) +$1100 (yearly)	5 min equipment setup + 0.04 Man-hr/mi	~0.5 GB/Mi (2.7K @ 120 FPS)	~15 GB/Mi
				3DF Zephyr	$149 (Lite) $3,200 (Pro) $4,200 (Aerial) (Perpetual)			
	LiDAR	2 * Velodyne HDL-32 (x2)	$49,000 (for two)	Roadview Workstation	Comes with Mandli Communication services	1 hr equipment setup + 0.036 Man-hr/mi	~3 Gb/Mi	~3 Gb/Mi
Unmanned Aerial Systems for Asset Management	Photogrammetry	DJI Mavic 2 Pro	$1600	Pix4D	$4,990 (Perpetual)	0.5 hr equipment setup + 0.4 Man-hr/Mi	~0.5 GB/Mi	~2.7 GB/Mi
	LiDAR	DJI M600 with VX15 LiDAR Scanner	$6000 (Drone) $140,000 (VX15)	Pix4D	$4,990 (Perpetual)	0.5 hr equipment setup + 0.53 Man-hr/Mi	~1 GB/Mi	~1 GB/Mi
Pedestrian Access Ramp	Photogrammetry	Fujifilm XT-30 (18-55mm lens)	$1300	Context Capture	See above	0.08 Man-hr/Ramp	300 Mb/Ramp (30 images, 6240x4160)	7.5 GB/Ramp
				3DF Zephyr	See above			
	LiDAR	Maptek I-Site 8820	$30,000 (Used)	Maptek PointStudio	Included with the purchase of the scanner	0.25 Man-hr/Ramp	545 Mb/Ramp	545 MB/Ramp

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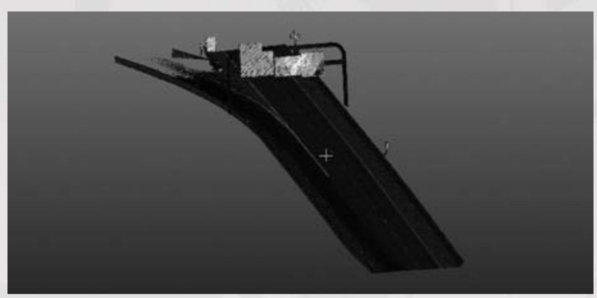
Summary – Asset Management

- LiDAR
  - Error: 3.48%
  - CV: 0.42
- Photogrammetry
  - Error: 4.33%
  - CV: 0.49
- UAS LiDAR
  - Unable to accurately reconstruct sign surfaces
  - Accurately mapped surrounding road terrains
- UAS Photogrammetry
  - Captured accurate sign locations
  - Accurately mapped surrounding road terrains
- 0.85% difference between measured error for both technologies
- LiDAR had a slightly more uniform distribution of points
- Image-based models were much more dense before downsampling
- Photogrammetry is much more cost effective



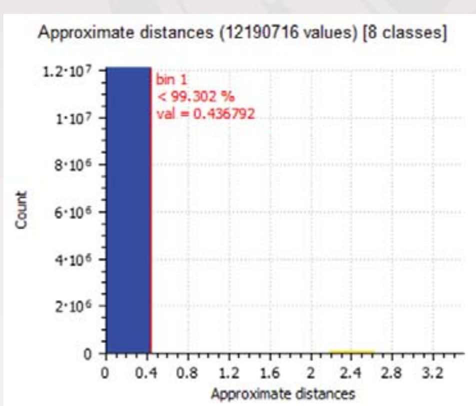
Summary – Pedestrian Access Ramp Inspections

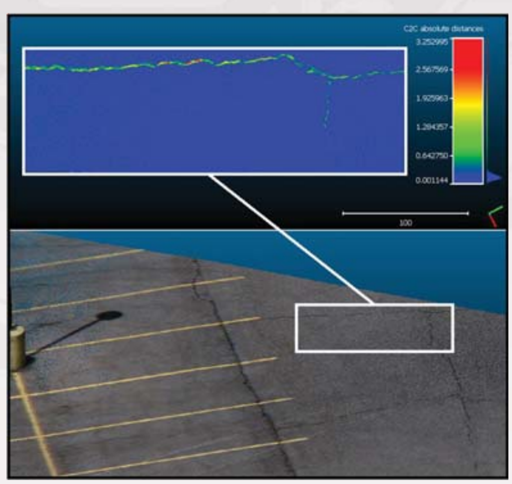
- LiDAR
  - Error: 0.19%
  - CV: 0.24
- Photogrammetry
  - Error: 0.32%
  - CV: 0.48

- 0.13% difference between computed errors
- LiDAR had less deviation in its measurements
- Photogrammetry took less time to gather data on each ramp
  - Could possibly use drones to capture multiple rams

Summary – Pavement Distress Analysis

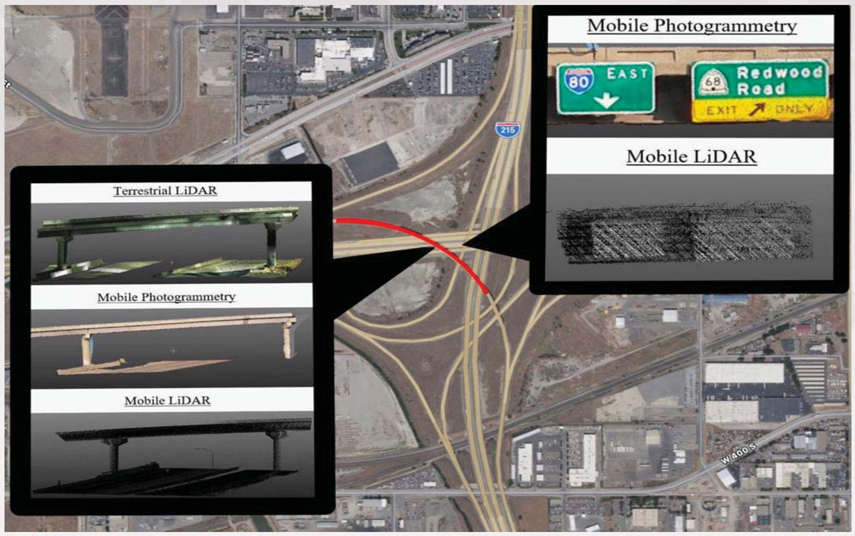
- 99.302% of points have a distance of less than 0.436 cm (0.17 in)
  - Very accurate alignment
- Maximum deviation of 3.25 cm (1.28 in)
- Photogrammetry model deviates an average of ~1 cm from LiDAR model
- Supplementary case study
  - More research needed for in-depth analysis





Summary – Bridge Inspections

- Photogrammetry unable to capture data regarding the underside or backside of bridge
- Mobile LiDAR and terrestrial LiDAR captured data regarding under/backside
- 1.29% deviation of mobile LiDAR from terrestrial LiDAR
- Mobile LiDAR & Photogrammetry could be used for asset inventory of bridges, but not bridge inspections



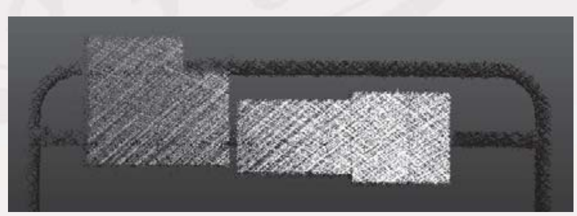
Summary – Pros & Cons

Photogrammetry

- Pros
  - Easy to use
  - Cost Effective
    - $400 for GoPro Hero 8+
    - $1,300 for Fujifilm XT-30
    - $1,600 for DJI Mavic 2 Pro
  - Good accuracy
    - Less than 1% difference from LiDAR
  - Very dense point clouds
  - Visual, colored representation of assets
    - Images are engrained in the models
- Cons
  - Limited speed of travel
    - Less than 50 MPH
  - Slightly less accurate than LiDAR
  - Model sizes can be hard to process on some systems

LiDAR

- Pros
  - Very high accuracy
  - Can gather data at higher speeds
    - Mandli can travel up to 65 MPH
  - Amount of data collected can be controlled
  - Point cloud is generated as the scanner gathers points
- Cons
  - Very expensive
    - Dual Velodyne HDL-32 - $49,000
    - Maptek I-Site 8820 - $30,000 (used)
    - VX15 - $140,000
  - Steep learning curve (required training)
  - Must physically mail large amounts of data to processing office



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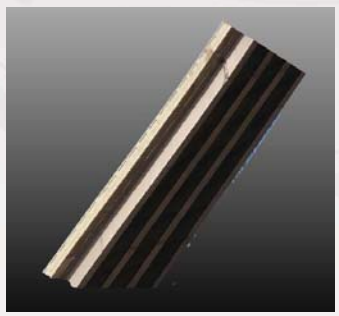
Conclusion

- Imperative for transportation managers to have up-to-date knowledge of the current state of all assets
  - Requires a quick, efficient, and affordable data collection procedure
- LiDAR is the traditional data acquisition technology
  - High accuracy
  - Very high initial cost
  - Requires technical knowledge of the scanner and software
- Image-based reconstruction is emerging as a more affordable alternative to LiDAR
  - Slightly lower accuracy than LiDAR (Still very good)
  - Low up-front cost
  - Can be done with a smart phone or digital camera

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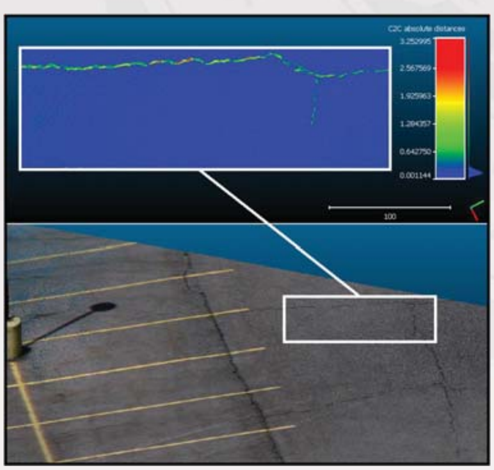
Conclusion

- Photogrammetry performed nearly as well as LiDAR in both case studies
  - 0.85% difference for Asset Management
  - 0.13% difference for Pedestrian Access Ramp Inspections
- Photogrammetry can be used as an affordable solution to lapses in model generations
  - Mandli collects data regarding state routes every 2 years
- The low cost, ease-of-use, and good accuracy of image-based reconstruction cameras and software makes photogrammetry a very capable technology that may soon be considered as an acceptable alternative to LiDAR
- Where to go from here?

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TRANSPORTATION LEARNING NETWORK

A partnership with MDT•NDDOT•SDDOT•WYDOT and the Mountain-Plains Consortium Universities

Thank you for participating!

Please take a moment to complete the evaluation included in the reminder email.

We appreciate your feedback.

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