Oregon State University

COLLEGE OF ENGINEERING | School of Civil and Construction Engineering

Lessons Learned from OSU PacTrans & ODOT UAS Projects

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UAS in Transportation Workshop

July 30-31, 2018

Oregon Department of Transportation

Pacific NW Transportation Consortium
PACTRANS
Region 10

3+ Years' of Research Projects

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1. PacTrans Small project: Cost-effective Bridge Safety Inspections Using Unmanned Aerial Vehicles (UAVs), 2015-2016
2. ODOT SPR 787: Eyes In The Sky: Bridge Inspections With Unmanned Aerial Vehicles, 2015-2017
3. FHWA project with Parsons Brinckerhoff (now WSP): Effective Use of Geospatial Tools in Highway Construction
4. PacTrans Multi-Institution Project: An Airborne Lidar Scanning and Deep Learning System for Real-time Event Extraction and Control Policies in Urban Transportation Networks (OSU & UI), 2016-2019

Specific Project Goals

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1. Evaluate the performance of UAS-based methods for inspecting bridges

1. Identify which ODOT inspection requirements can and cannot be satisfied with a UAV inspection

2. Provide a cost-benefit analysis of performing UAV inspections for communication towers and bridges

3. Develop procedures/guidelines for how to safely and effectively perform UAS inspections of bridges and communication towers

Test Bridge Inspections

Bridges Inspected

(1) Independence Bridge

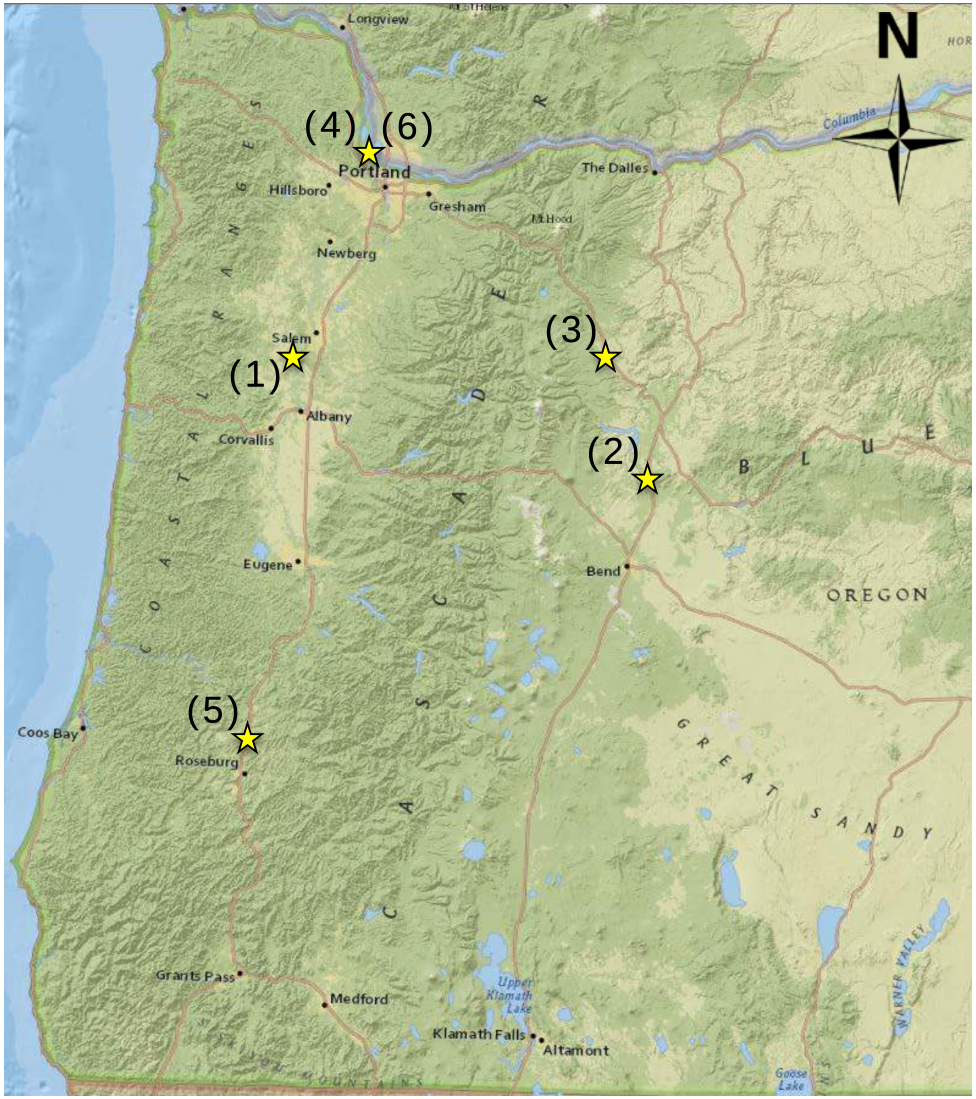
(2) Crooked River Bridge

(3) Mill Creek Bridge

(4) St. Johns Bridge
- Preliminary

(5) Winchester Bridge

(6) St. Johns Bridge
- Detailed



Test Bridge Inspections

Independence Bridge: Sept 2015

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Location:
- In Independence, OR

Airframe(s) used:
- DJI Phantom 3 Pro

Flight Objective:
- Familiarize with bridge inspection workflow
- Capture high quality imagery/video for inspection purposes

Details:
- Large deck plate girder bridge
- 675.4 m long
  - Longest span: 46.3 m
- Classified as Fracture Critical

Independence Bridge

Captured Imagery

Independence Bridge

Captured Imagery

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Test Bridge Inspections

Oregon State University College of Engineering

Crooked River Bridge: July 2016

Location:
- 8 km north of Terrebonne, OR

Airframe(s) used:
- senseFly Albris

Flight Objective:
- Capture high quality imagery for inspection purposes
    - targeting specific areas difficult to inspect using traditional methods
- Create 3D model using SfM

Details:
- Steel Arch Bridge
- 141 m long
    - Longest span: 100 m
- Pedestrian Only

Crooked River Bridge

Captured Imagery

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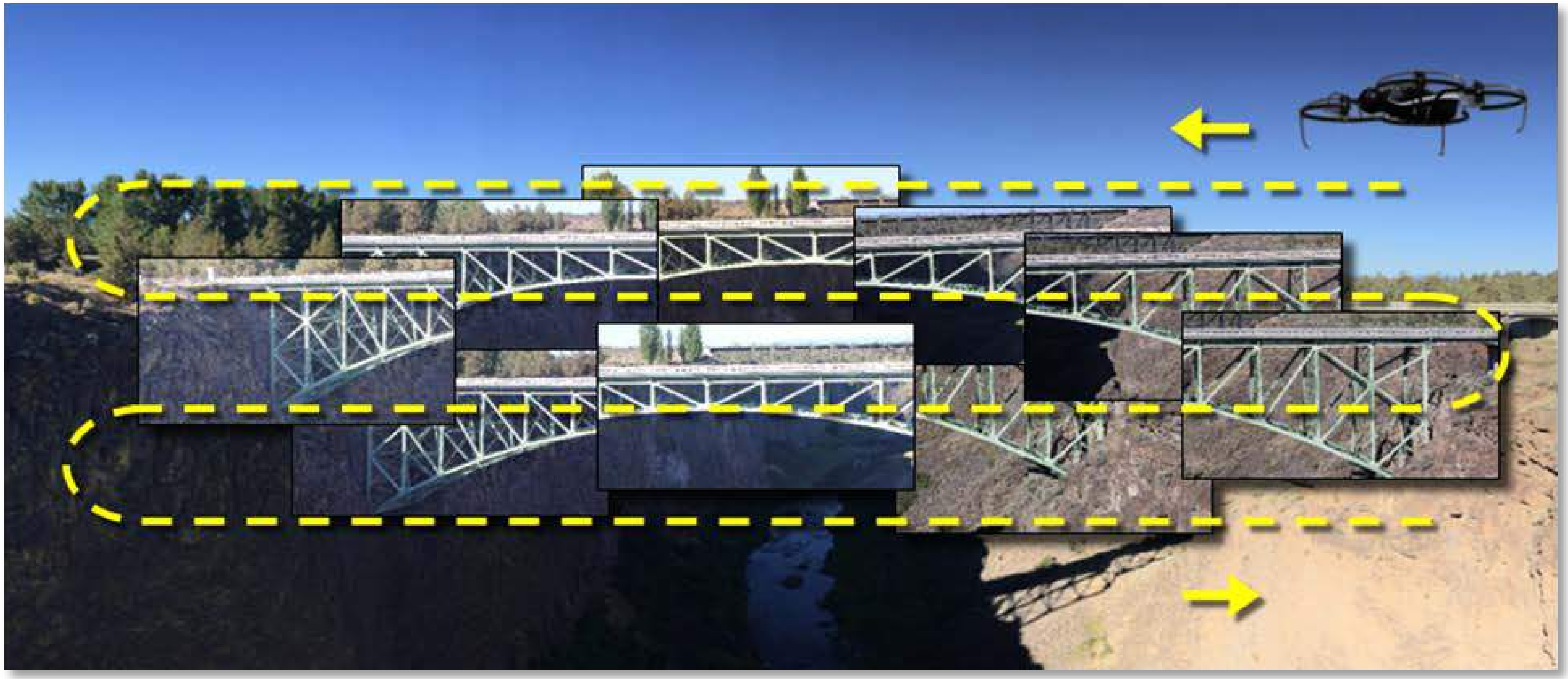
Crooked River Bridge

Flight Methods



Schematic representation of overlapping images taken from a UAS and the flight path using manual flight mode with sensor assistance (from Javadnejad et al. 2017, with permission)

Crooked River Bridge

Captured Imagery

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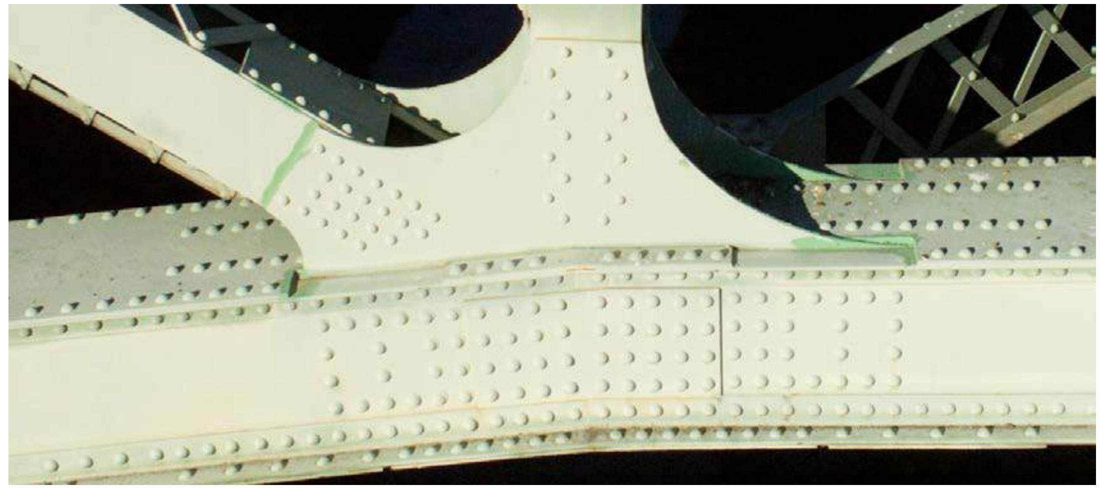
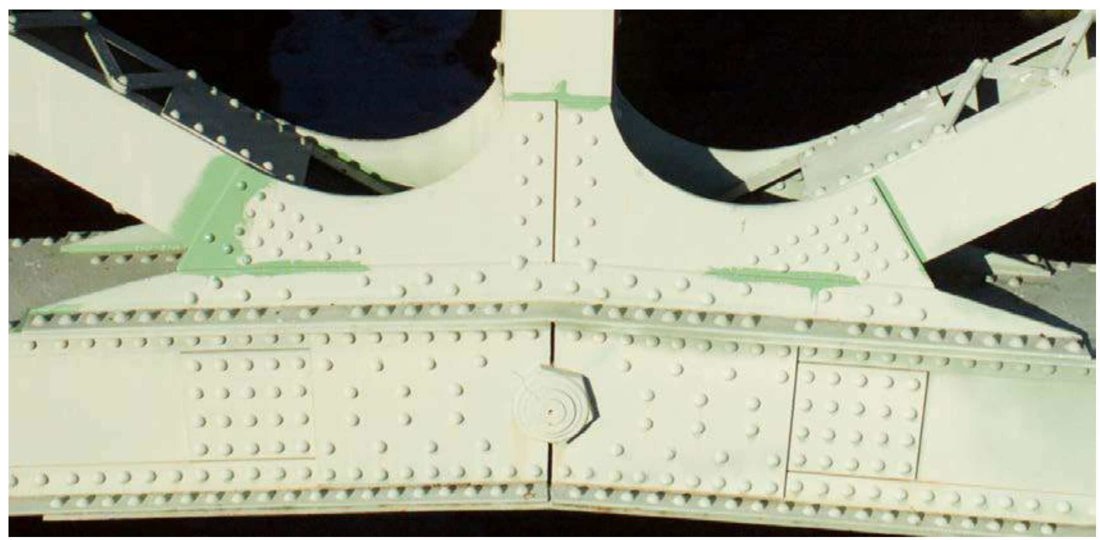
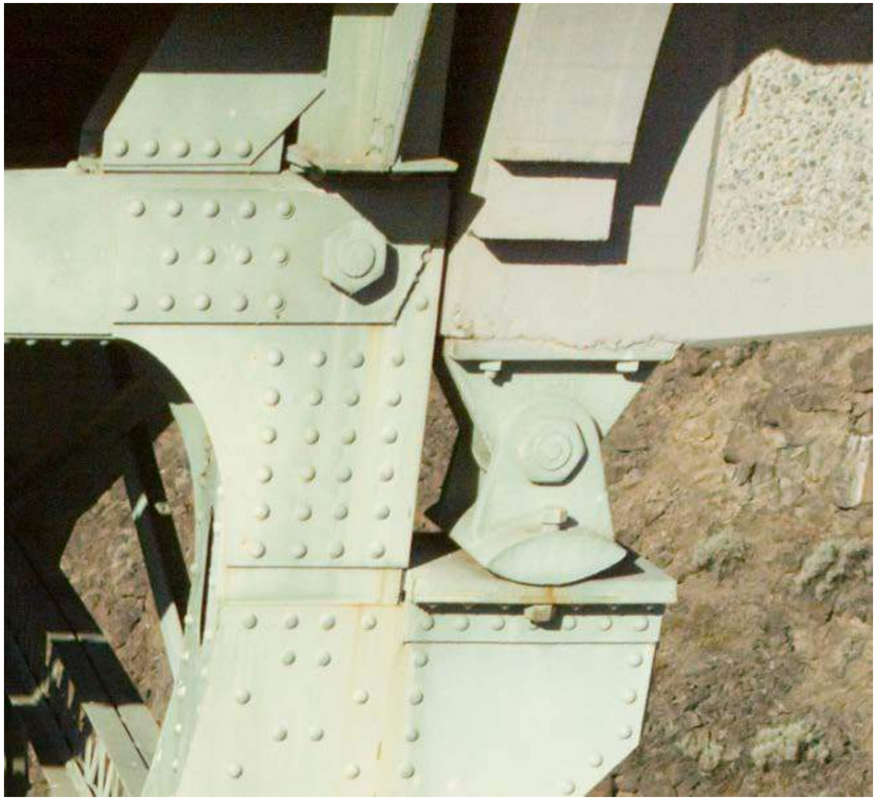




Crooked River Bridge

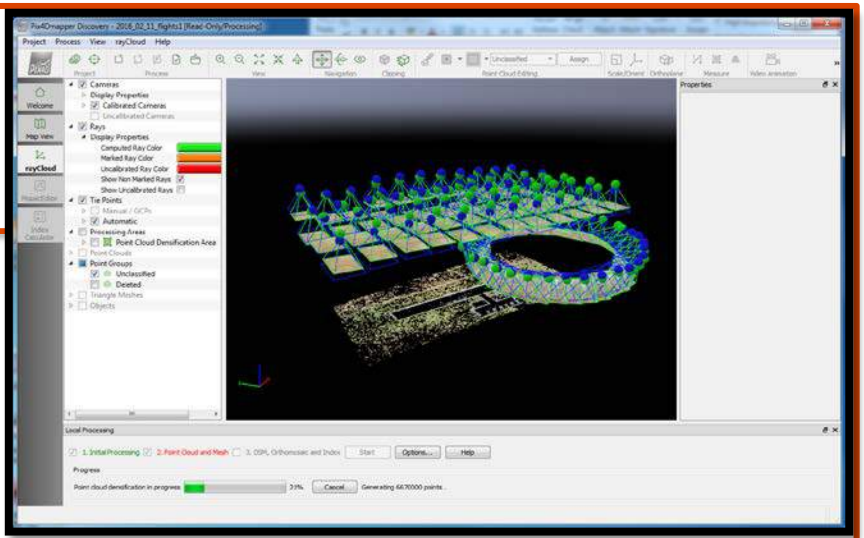
Captured Imagery



Post-Processing

Structure From Motion

- Relatively new photogrammetric approach
  - Leverages advanced image matching algorithms from the field of computer vision
- Many requirements are relaxed, as compared with conventional photogrammetry:
  - Can work with a wide range of viewing geometries and consumer-grade cameras
  - Well suited to UAS imagery!
  - Highly automated, easy to use software



Additional Survey Equipment

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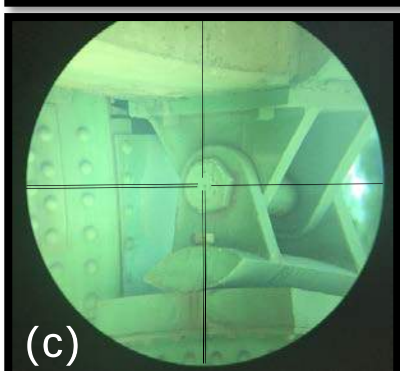
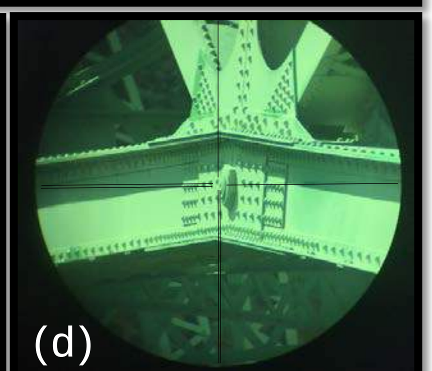
Ground Control Survey Equipment



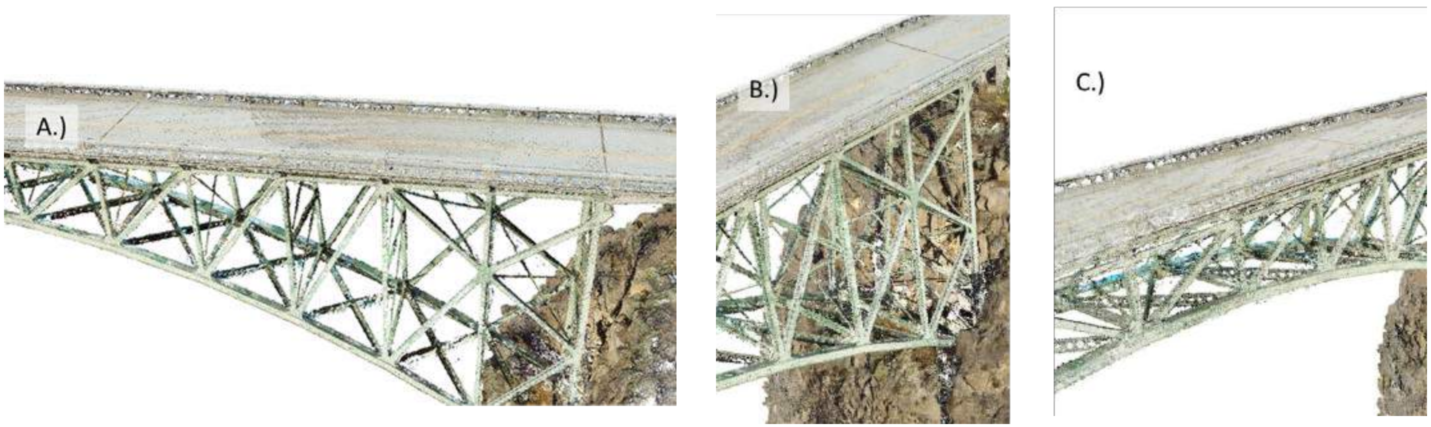


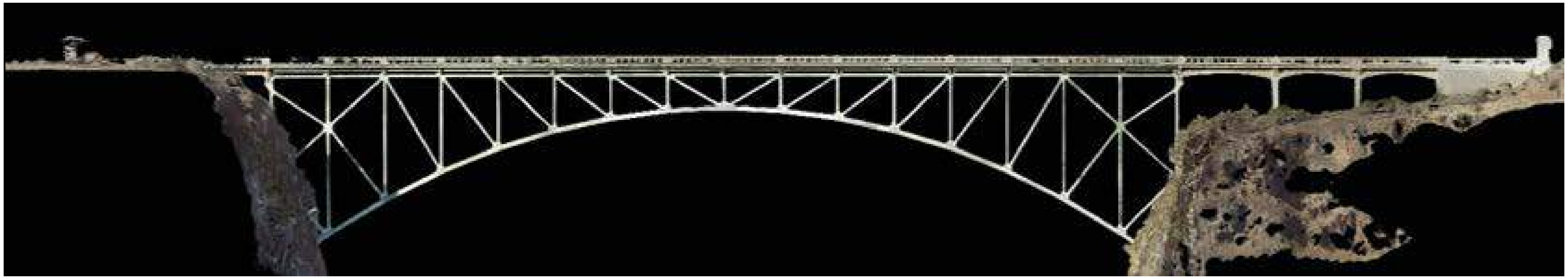
(a) Total station used to position photo identifiable features on bridge Example (c) & (d)

(a) GNSS Antenna occupying an aerial ground control target

Crooked River Bridge

Post-Processing Results – Pointcloud & Orthomosaic





An orthophoto of the profile of the Crooked River Bridge produced from processing the images using SfM. (from Javadnejad et al. 2017, with permission)

Test Bridge Inspections

Mill Creek Bridge, July 2016

Location:
- 17 km NW of Warm Springs, OR

Airframe(s) used:
- senseFly Albris

Flight Objective:
- Capture high quality imagery for inspection purposes
  - targeting specific areas difficult to inspect using traditional methods

Details:
- Cantilevered Warren deck truss bridge
- 163 m long
  - Longest span: 50 m

Mill Creek Bridge

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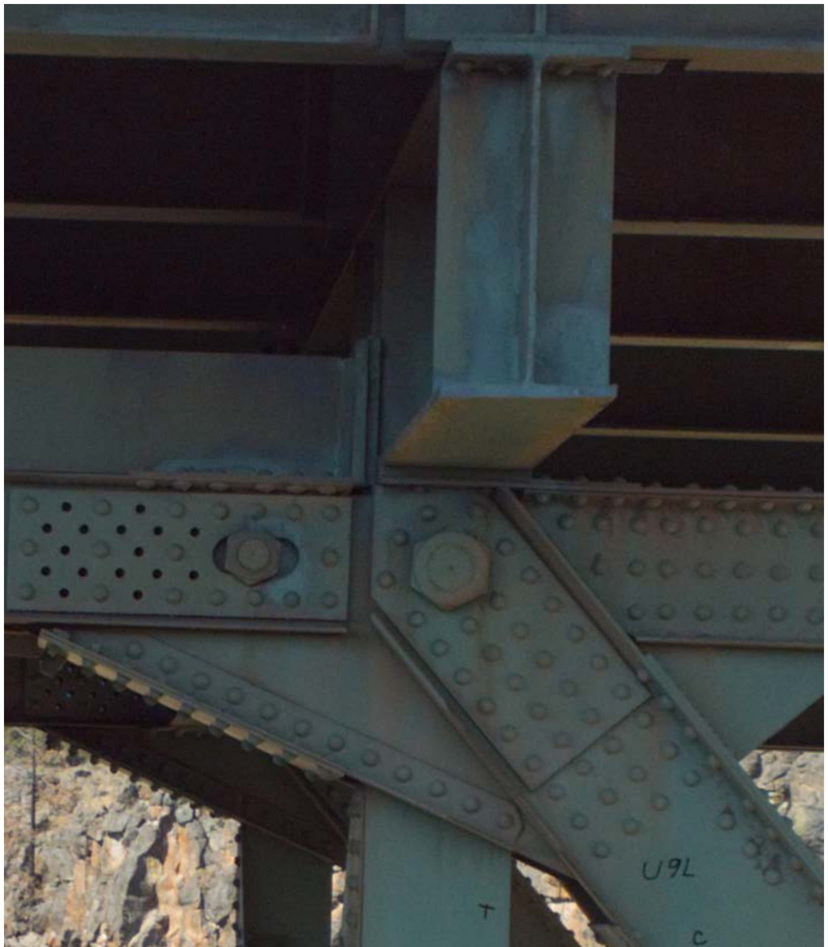
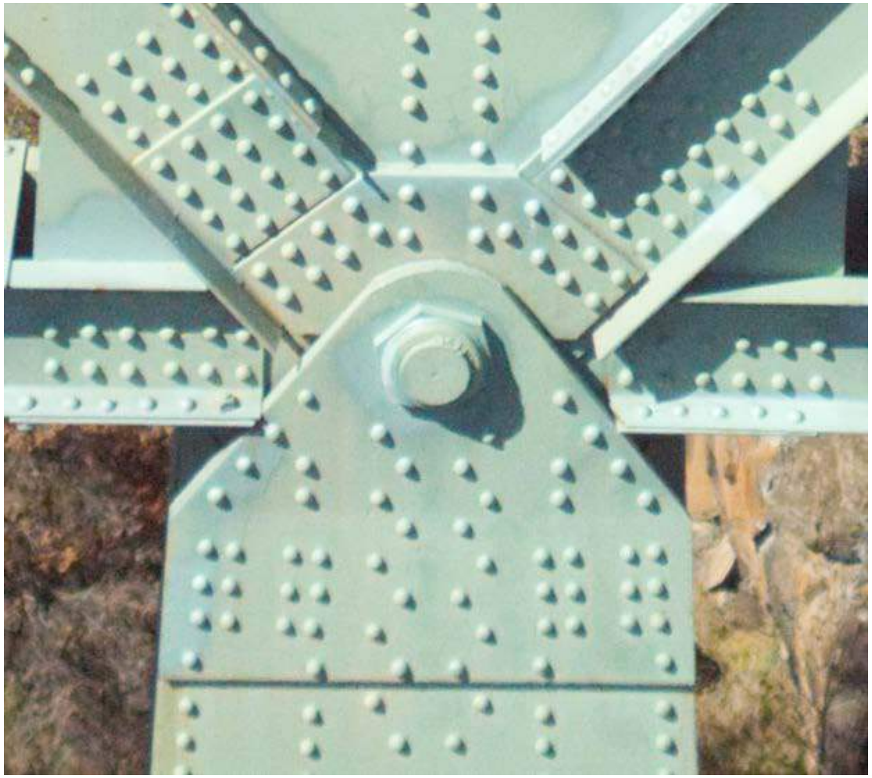
Captured Imagery



Mill Creek Bridge

Captured Imagery



Test Bridge Inspections

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St. Johns Bridge (Prelim Test), Sept 2016

Location:
- St. Johns Portland, OR

Airframe(s) used:
- senseFly Albris
- DJI S900 w/ Sony WX500 (30x optical zoom)

Flight Objective:
- Test use of optical zoom camera
- Capture high quality imagery for inspection purposes
  - targeting specific areas difficult to inspect using traditional methods

Details:
- Metal Riveted Warren deck truss
- Wire Cable Suspension
- 1100 m long
  - Longest span: 368 m

St. Johns Bridge (Preliminary Test)

Captured Imagery

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St. Johns Bridge (Preliminary Test)

Captured Imagery

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St. Johns Bridge (Preliminary Test)

Captured Imagery

Test Bridge Inspections

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Winchester Bridge, March 2017

Location:
- Winchester, OR

Airframe(s) used:
- senseFly Albris

Flight Objective:
- Capture high quality imagery for inspection purposes
  - While receiving real-time input from onsite inspectors

Details:
- Warren deck truss bridge
- Southbound bridge of I-5
- 500 m long
  - Longest span: 42 m

Winchester Bridge

Captured Imagery

Winchester Bridge

Captured Imagery

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Winchester Bridge

Captured Imagery

Test Bridge Inspections

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St. Johns Bridge (Detailed Test), April 2017

Location:
- St. Johns Portland, OR

Airframe(s) used:
- senseFly Albris

Flight Objective:
- Capture high quality imagery for inspection purposes
- Week long in-depth inspection
- Test inspecting directly under deck

Details:
- Metal Riveted Warren deck truss
- Wire Cable Suspension
- 1100 m long
  - Longest span: 368 m
- Flight limited to eastern 550 m from center of main span

St. Johns Bridge (Detailed Test)

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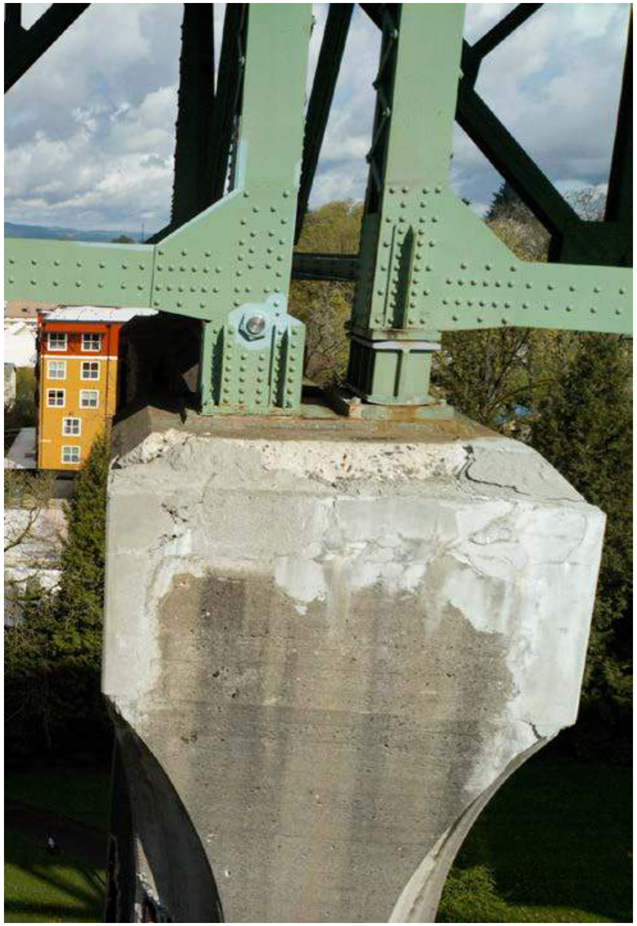
Captured Imagery



St. Johns Bridge (Detailed Test)

Captured Imagery

St. Johns Bridge (Detailed Test)

Captured Imagery

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St. Johns Bridge (Detailed Test)

Captured Imagery

St. Johns Bridge (Detailed Test)

Captured Imagery

St. Johns Bridge (Detailed Test)

Captured Imagery

Test Tower Inspections

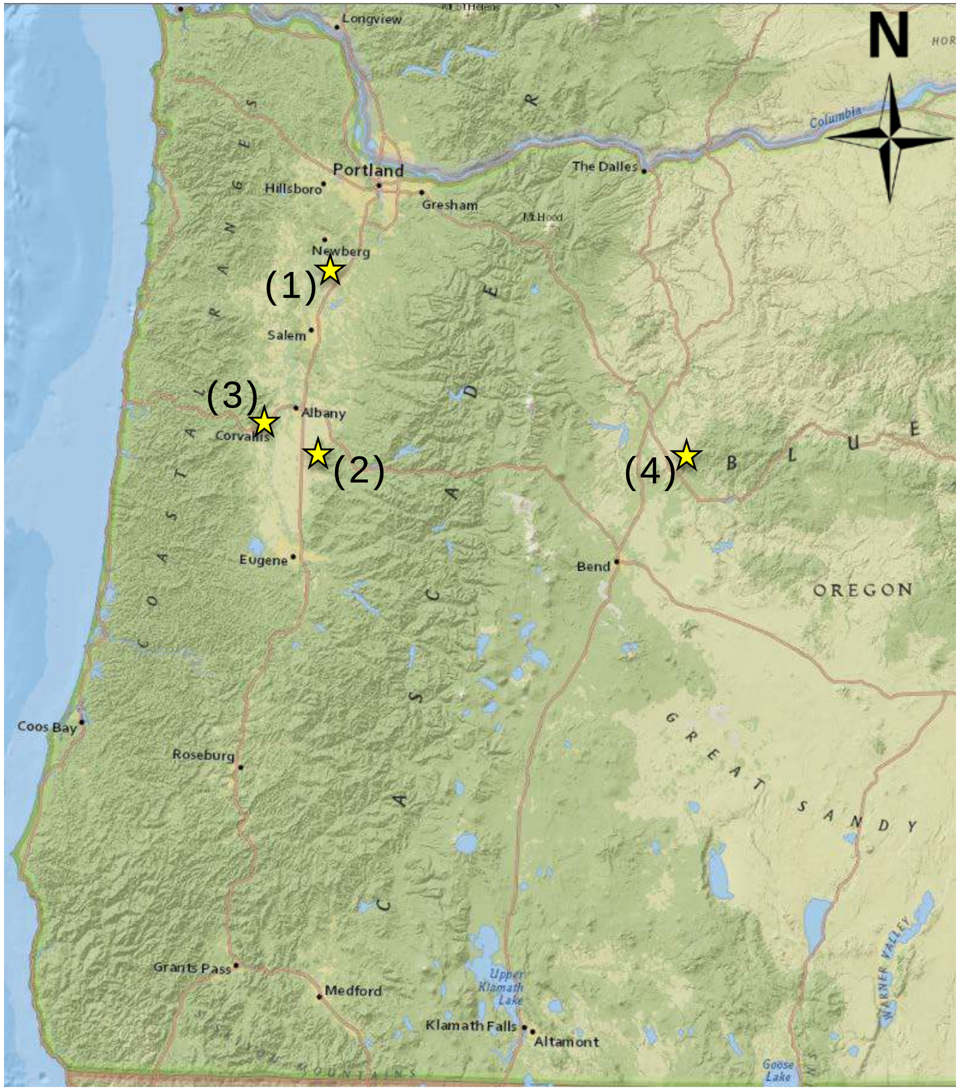
Towers Inspected

(1) Woodburn Tower

(2) Washburn Butte Tower

(3) Corvallis Maintenance Tower

(4) Grizzly Mountain Tower



Washburn Butte Tower

Flight Planning

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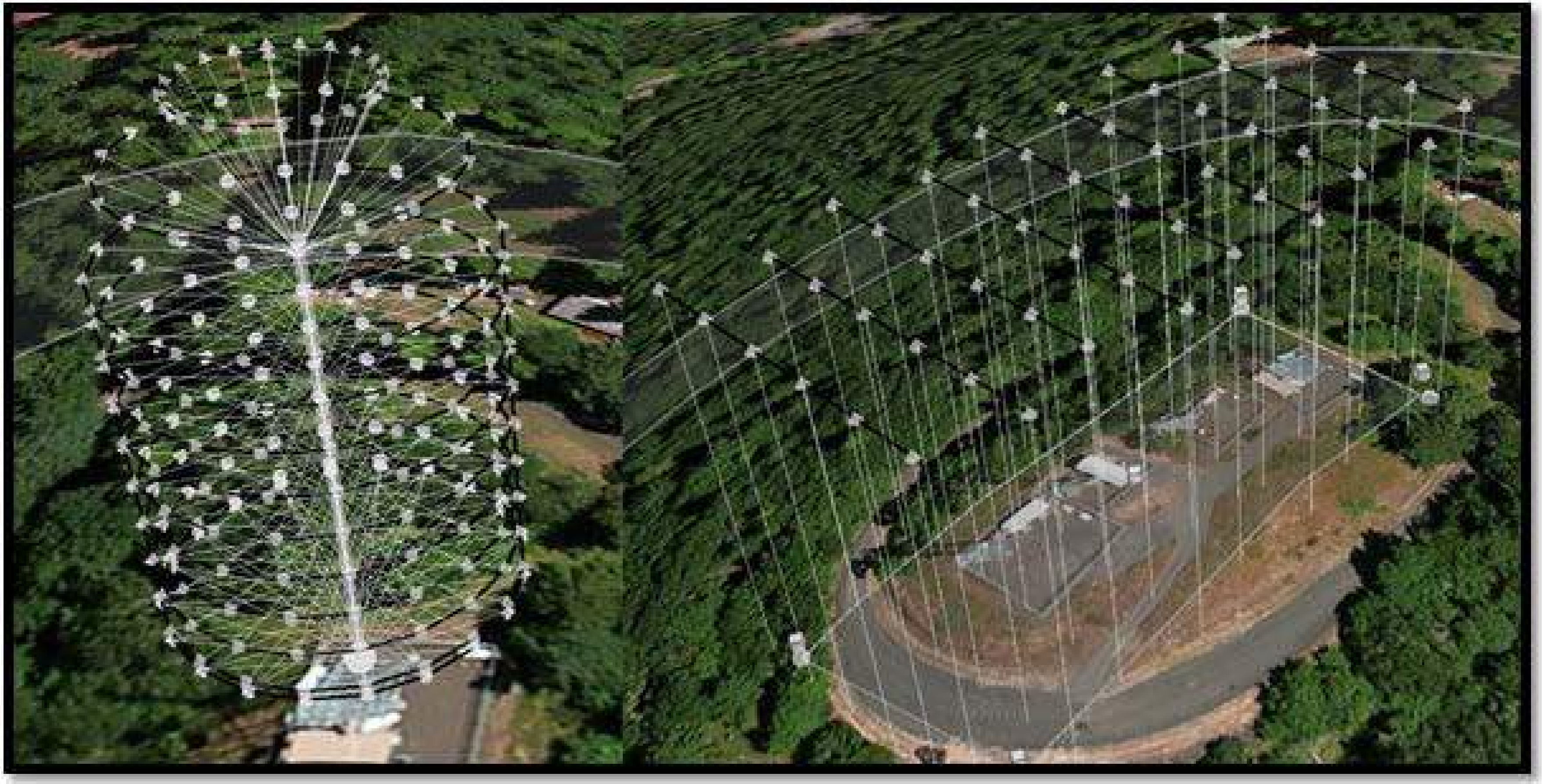

Test Tower Inspections

Woodburn Tower, April 2016

Location:
- 3 km NNW of Woodburn, OR

Flight Objective:
- Familiarize with tower inspection workflow
- Capture high quality imagery for inspection purposes
- Create orthomosaic of site
- Create 3D model using SfM

Details:
- Owned by Marion County
- A-Frame tower with triangle base
- 5 installed antennas
- 53 m tall

Woodburn Tower

Captured Imagery

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Woodburn Tower

Captured Imagery

Woodburn Tower

Point cloud generated using PhotoScan

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Test Tower Inspections

Washburn Butte Tower, April 2016

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Location:
- 6km north of Brownsville, OR

Flight Objective:
- Capture high quality imagery for inspection purposes
- Create orthomosaic of site
- Create 3D model using SfM

Details:
- A-Frame tower with square base
- 8 installed antennas
- 48.8 m tall

Washburn Butte Tower

Collected Imagery

Washburn Butte Tower

Collected Imagery

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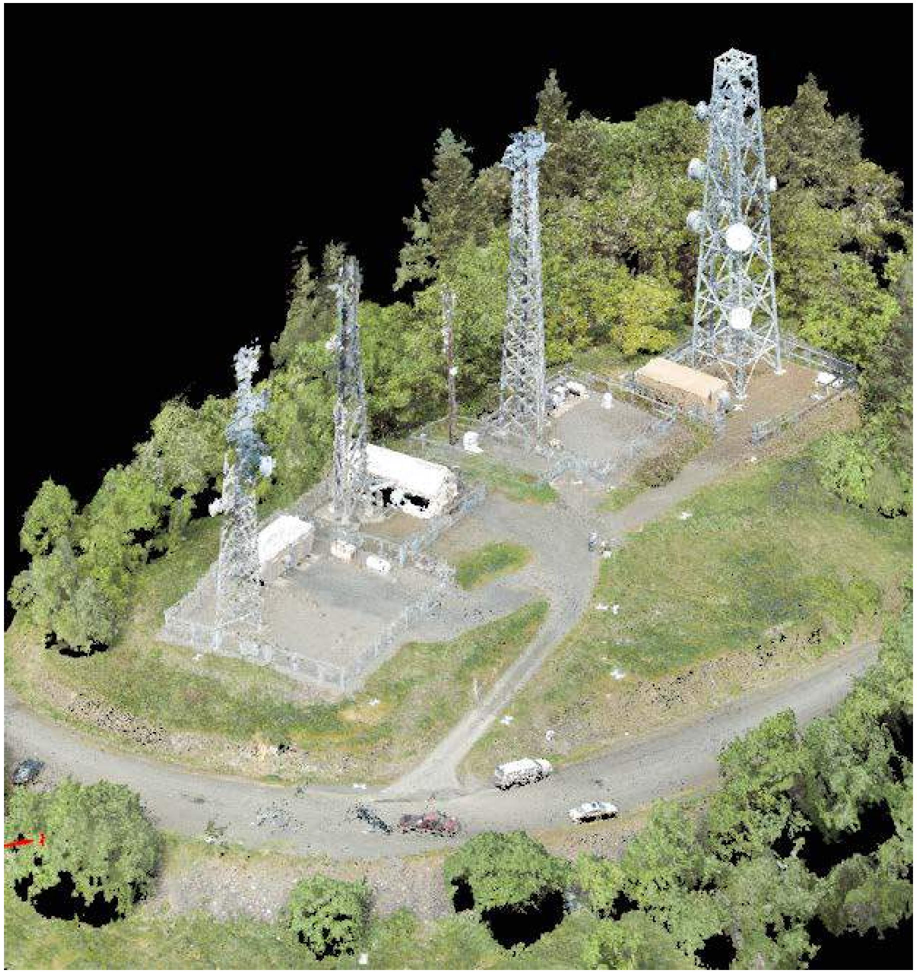
Washburn Butte Tower

3D Modeling Results



Washburn Butte Tower

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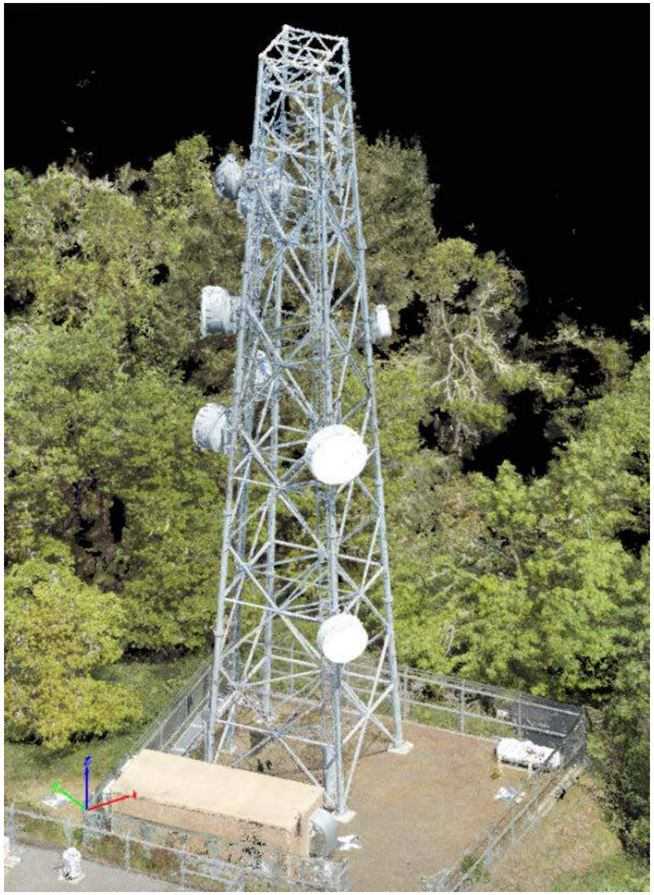
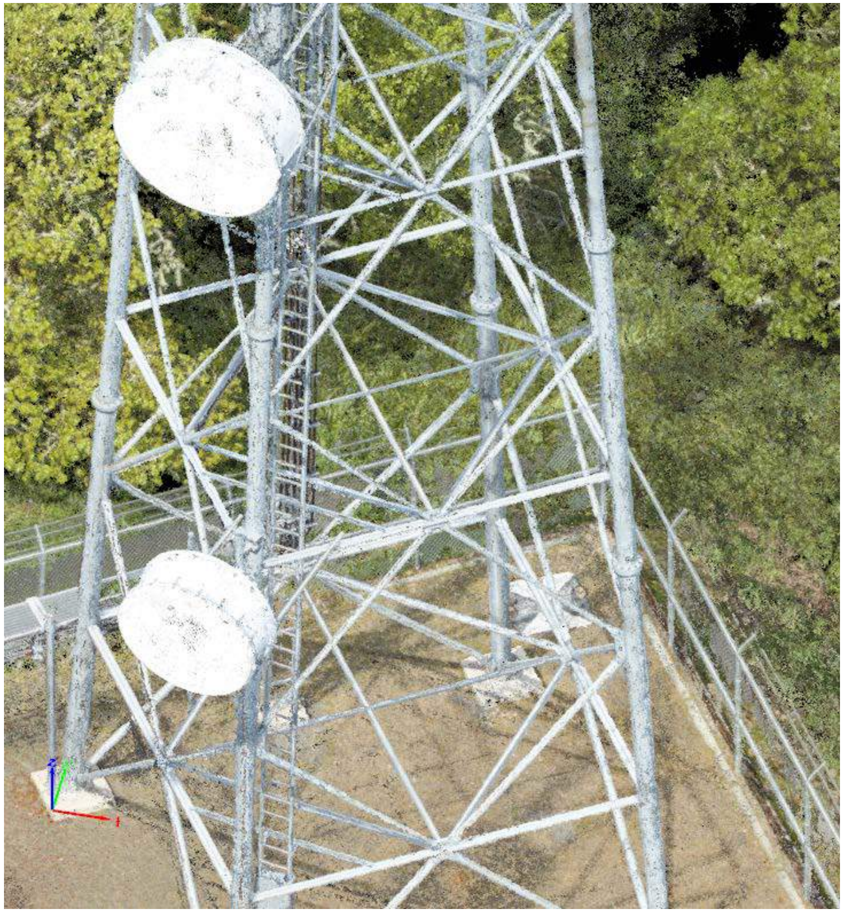
3D Modeling Results



Washburn Butte Tower

3D Modeling Results



Washburn Butte Tower

3D Modeling Results - Organization

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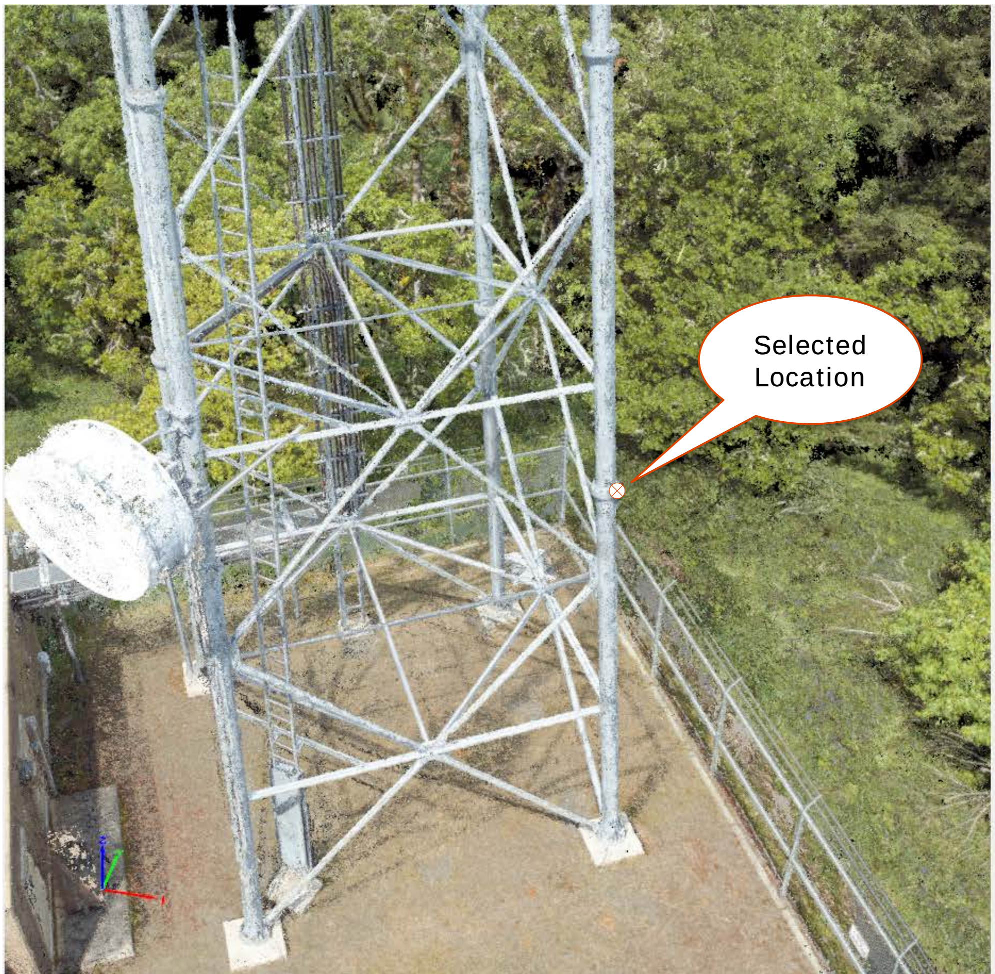

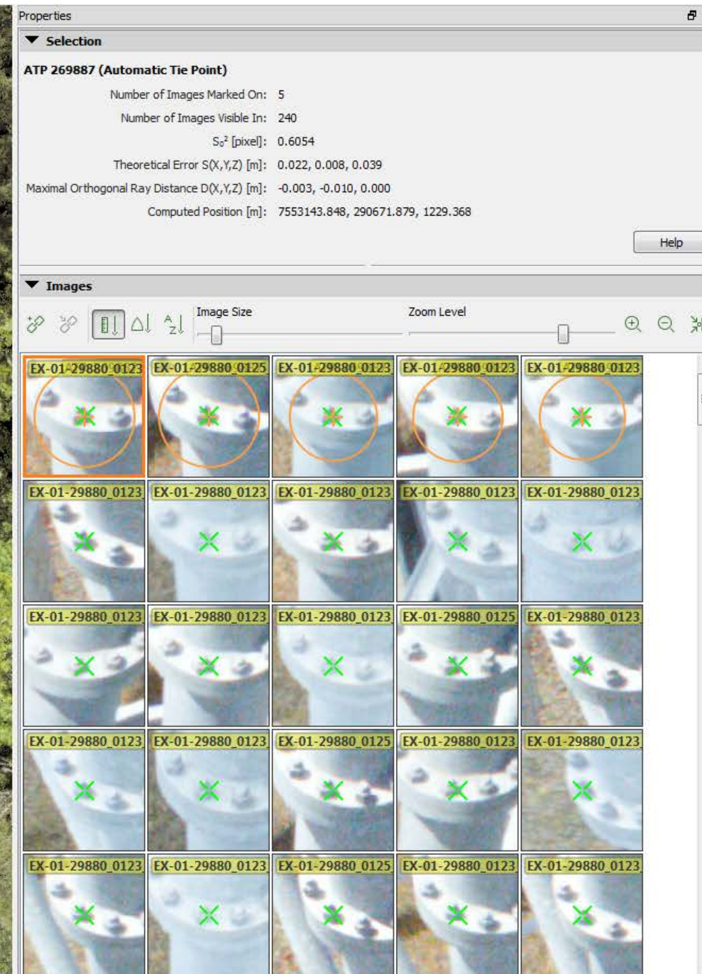

Washburn Butte Tower

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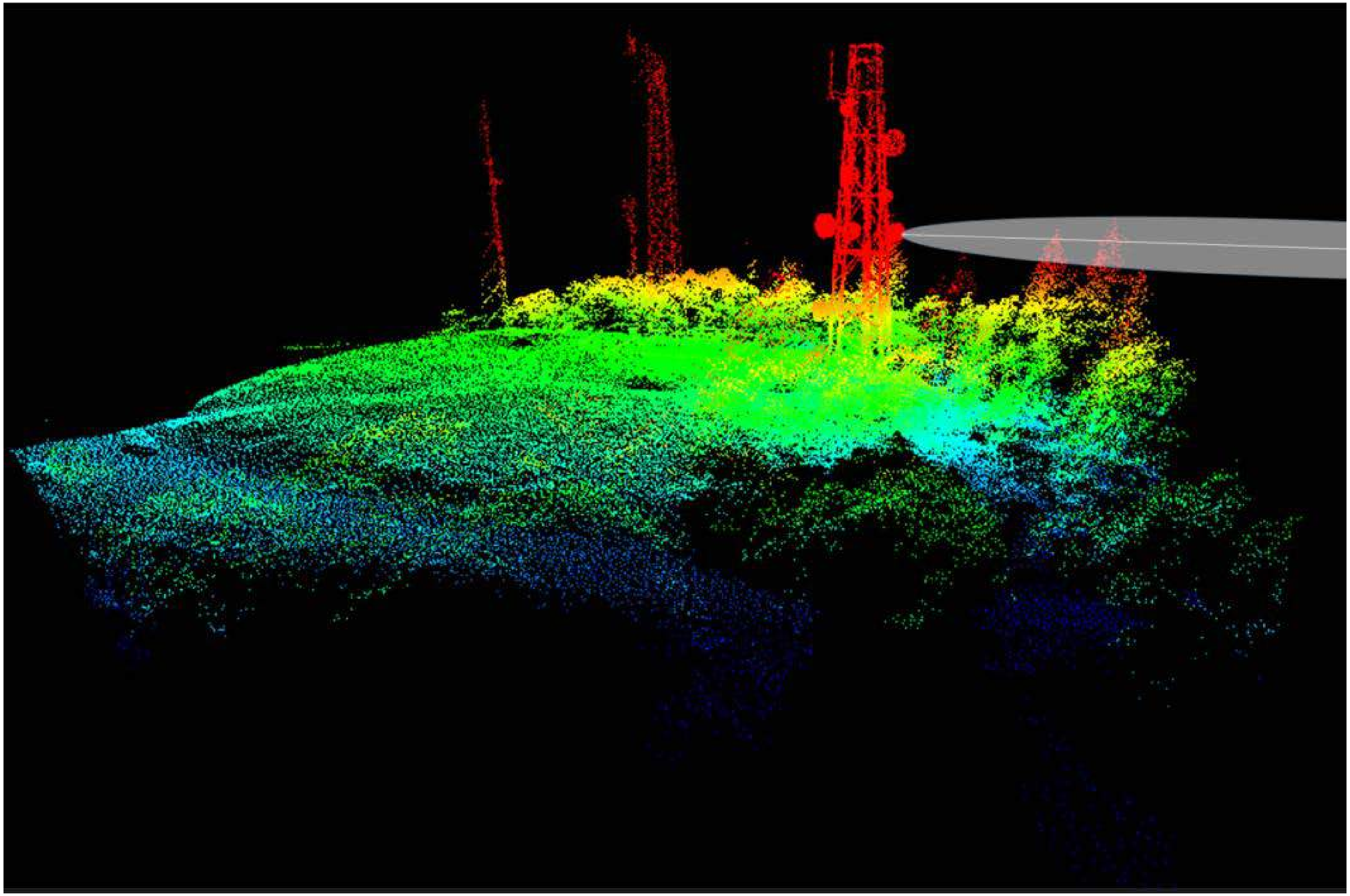
3D Modeling Results - Obstructions



Test Tower Inspections

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Corvallis Maintenance Site Tower, April 2016

Location:
- Corvallis, OR
- ODOTS District 4 maintenance yard

Flight Objective:
- Capture high quality imagery for inspection purposes

Details:
- Rectangular tower with square base
- 2 installed antennas
- 27.4 m tall

Corvallis Maintenance Site Tower

Collected Imagery

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Corvallis Maintenance Site Tower

Collected Imagery

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Corvallis Maintenance Site Tower

Collected Imagery

Test Tower Inspections

Grizzly Mountain Tower, July 2016

Location:
- 23 km NW of Prineville, OR

Flight Objective:
- Capture high quality imagery
- Create 3D model using SfM

Details:
- A-Frame tower with square base
- 9 installed antennas

Grizzly Mountain Tower

Findings

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- Over 10 towers near mountain summit
- Detected significant frequency interference using a spectrum analyzer
  - 2.4 and 5.0 GHz frequencies
- Interference from nearby Wireless Internet Service Provider (WISP) towers
- Unable to perform any flights
  - Tried all possible radio frequencies available

Cost Benefit Analysis

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Procedures

1. Establish baseline costs for bridge inspections conducted *without* the use of UAS by compiling existing data from ODOT
   – 33 bridge inspection project budget spreadsheets
2. Determine the percentage of bridges that ODOT inspects that are suitable for UAS inspection
   – Airspace, proximity to populated areas, vegetation, size of bridge, etc.
3. Establish which project cost categories could be reduced (not eliminated) through use of UAS:
   – Personnel time (field and office)
   – Equipment rental/usage (e.g., snooper trucks)
   – Traffic control
   – Travel (including lodging, meals and incidentals)

Cost Benefit Analysis

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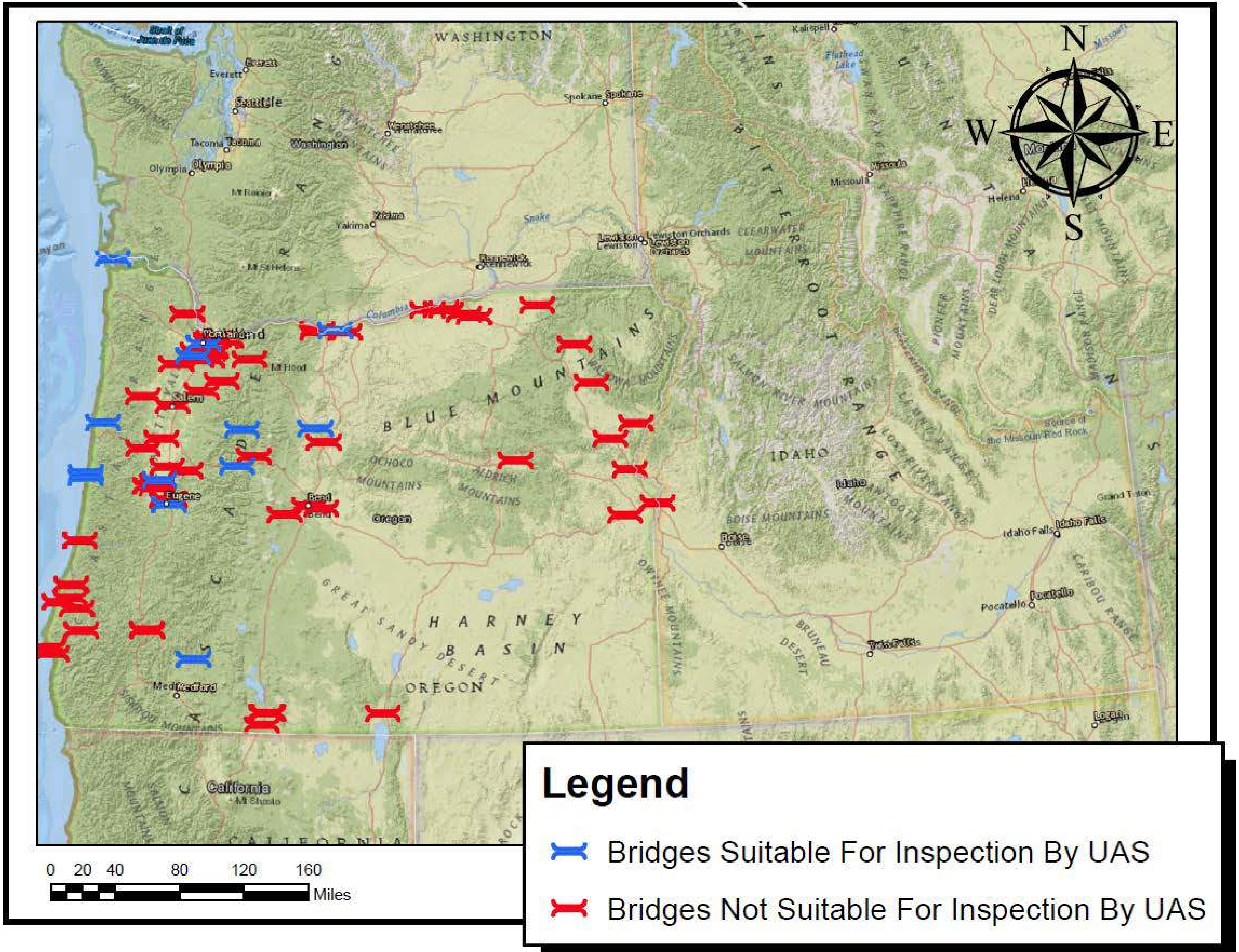
Procedures (cont'd)

4. Estimated annual cost savings = (average cost savings per suitable bridge) × (# of bridges/yr inspected by ODOT) × (percentage of bridges suitable for UAS inspection)
5. Estimate costs:
   - Cost of purchasing 3 UAS
   - Annual maintenance cost
   - Data storage

$$B = \$10{,}200(730 \times 0.16) = \$1{,}191{,}360$$

$$\sum C = \$117{,}237 + \$4{,}500 + \$5{,}700 = \$127{,}437$$

$$\boldsymbol{BCR = \frac{\$1{,}191{,}360}{\$127{,}437} \approx 9}$$


WASHINGTON
OREGON
IDAHO
BLUE MOUNTAINS
HARNEY BASIN
N
S
W
E
Legend
Bridges Suitable For Inspection By UAS
Bridges Not Suitable For Inspection By UAS
0
20
40
80
120
160
Miles

Project Key Findings

Operational Considerations

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- Sensor-assisted and waypoint-assisted flight modes are most useful flight modes for bridge inspection
  - But, unmanned aircraft pilots must be proficient in entirely manual flight, due to the possibility of losing GPS
- UAS with front-mounted, variable-tilt cameras are advantageous for bridge inspection
- Wind condition is the most important environmental variable in UAS bridge inspection
  - Illumination conditions and camera settings (ISO, f-stop and focal length) are critical to obtaining high-quality imagery
    - UAS bridge inspection flight crews should have at least a basic level of expertise in photography

Project Key Findings

Overarching conclusions

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- UAS can assist to varying degrees in many required elements of a bridge inspection
  - Very well suited for initial and routine inspections and for satisfying report requirements related to geometry and structural evaluation
- Cracks, pack rust, connections, hardware and bearing locations were all determined to be readily-identifiable in the imagery collected in this project, with the recommended flight procedures
- Cost-benefit analysis provides strong indication of positive ROI for implementing UAS in ODOT's bridge inspection program
  - Should be refined as more data becomes available
- UAS are likely to be an increasingly valuable tool to Sate DOTs in bridge inspection

Acknowledgements

- ODOT and PacTrans
- Dr. Joe Li, ODOT Research Coordinator
- Erick Cain, ODOT Bridge Inventory Coordinator
- ODOT TAC:
  - Paul Panzica, ODOT Wireless Network Infrastructure Manager
  - Michael Goff, ODOT Bridge Inspector
  - Mitch Swecker, OR State Aviation
  - Tim Rogers, FHWA
  - Jeff Swanson, ODOT Bridge Section
  - Joe Thomas, ODOT Geometronics Manager / Chief of Surveys
  - Ron Singh, ODOT Chief of Surveys/Geometronics Manager (recently retired)
- OSU graduate students: Kory Kellum, Farid Javadnejad, and Richie Slocum