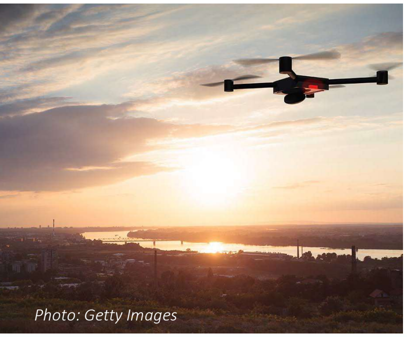
U.S. Department of Transportation
Federal Highway Administration

OKLAHOMA Transportation

LOCAL TECHNICAL ASSISTANCE PROGRAM
College of Engineering, Architecture and Technology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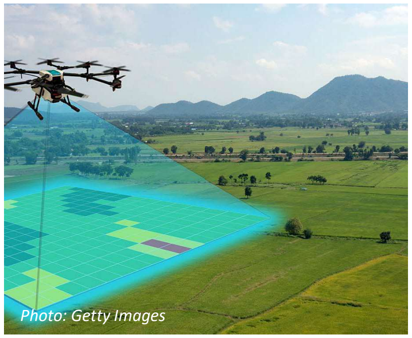
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Use of UAS in Bridge Inspection

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Oregon State University

FHWA – EDC-5

Oregon State University

Outline

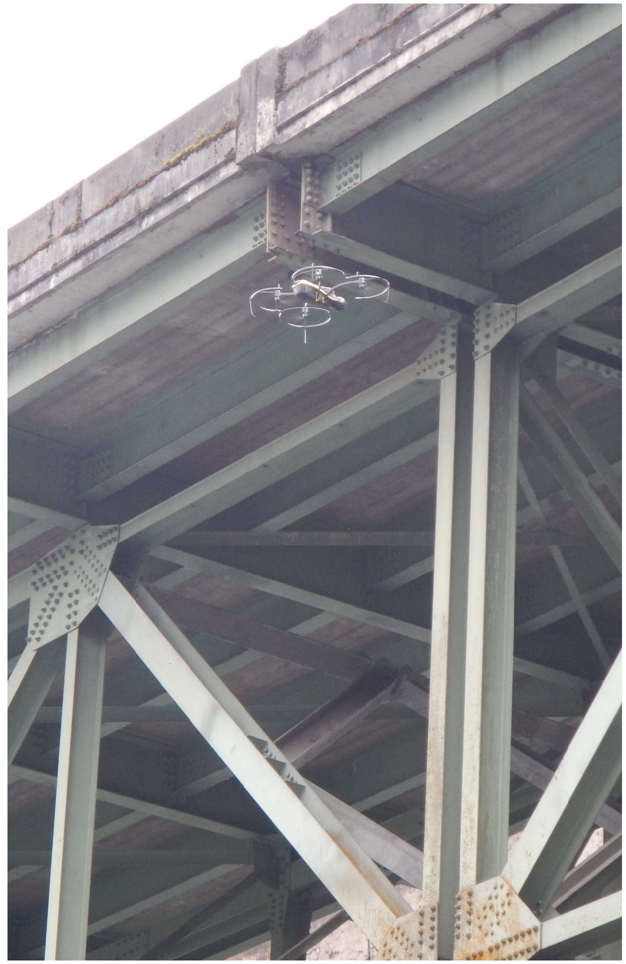
- Projects conducted to date
- Motivation for use of UAS in bridge inspection
- Operations
  - » Aircraft and sensor selection
  - » Workflow
  - » Safety plan
- Results of bridge inspections
- Cost-benefit analysis
- Key findings

Projects

- OSU UAS Bridge Inspection Projects:
  - » PacTrans (2015): Cost-Effective Bridge Safety Inspection using Unmanned Aerial Vehicles
  - » Oregon DOT (2015-2018): SPR 787 - Eyes in the Sky: Bridge Inspections with Unmanned Aerial Vehicles
- Related projects
  - » FHWA (2015-2017): Effective Use of Geospatial Tools in Highway Construction (with WSP)
  - » PacTrans (2018): UAS in Transportation Expo
  - » PacTrans (2017-2019): An Airborne Lidar Scanning and Deep Learning System for Real-time Event Extraction and Control Policies in Urban Transportation Networks
  - » PacTrans (2020): Unmanned Aircraft Systems in Transportation: Research-to-Operation (R2O) Peer Exchange

Motivation

- UAS
  - » Simply one tool--but a potentially powerful one--for bridge inspection
    - – Provides new method of remotely viewing bridge elements at high-resolution, while keeping both feet on the ground
    - – Can reduce lane closures, use of bucket trucks, and climbing for some percentage of bridges to be inspected annually
      - ✓ *Enhance safety and reduce costs for some percentage of inspections*



Specific Project Goals (SPR 787)

- Evaluate performance of UAS for bridge inspection
- Identify inspection requirements that can and cannot be satisfied with UAS
- Provide cost-benefit analysis
- Develop SOPs
- Develop safety plan
- (Also extend analysis to inspection of communication towers)

Aircraft and Sensor Analysis

- Main categories of remote aircraft:

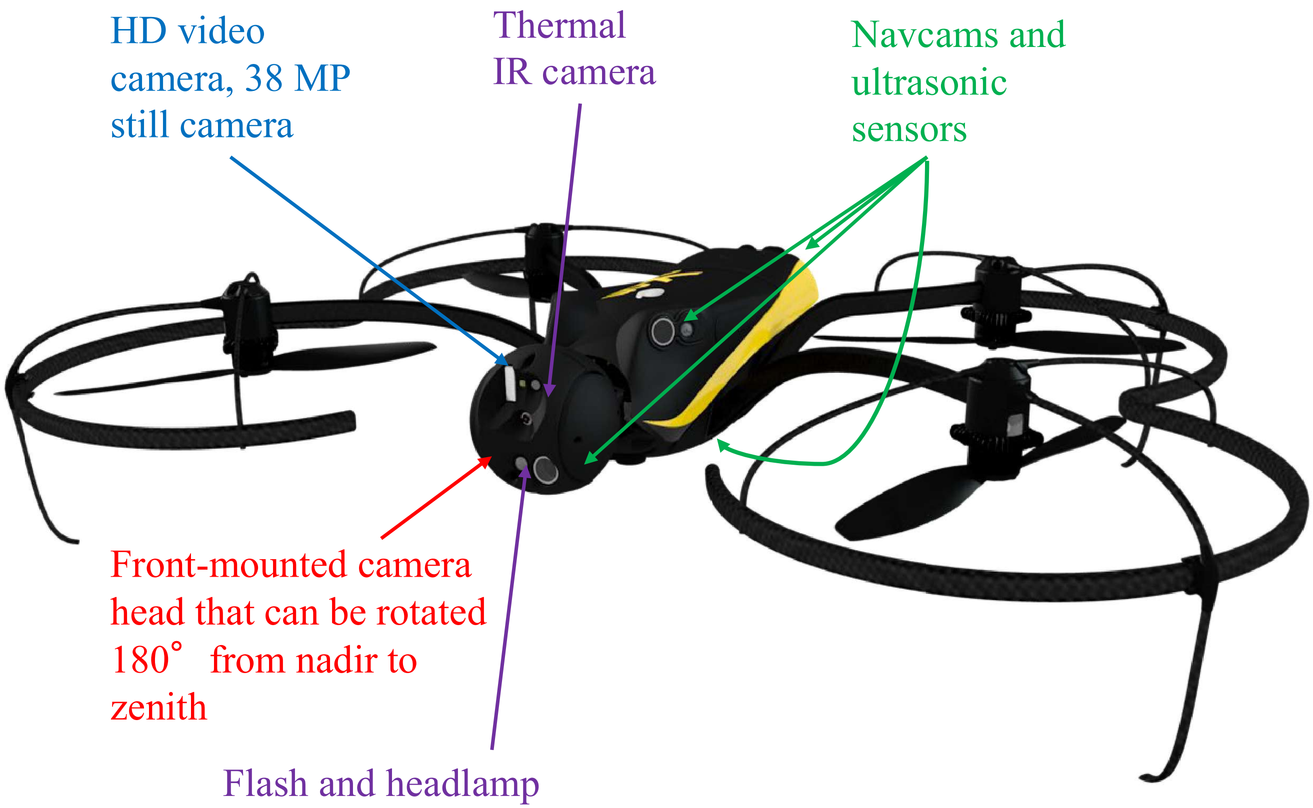
Best option for structural inspections

Helicopters

Fixed-wing

Multi-rotor

Components of a UAS Designed for Structural Inspections



Flight planning software designed to facilitate inspection projects

Importance of Rotating Sensor Head

A) Camera optical axis pointing down (nadir)

» Typical mapping configuration

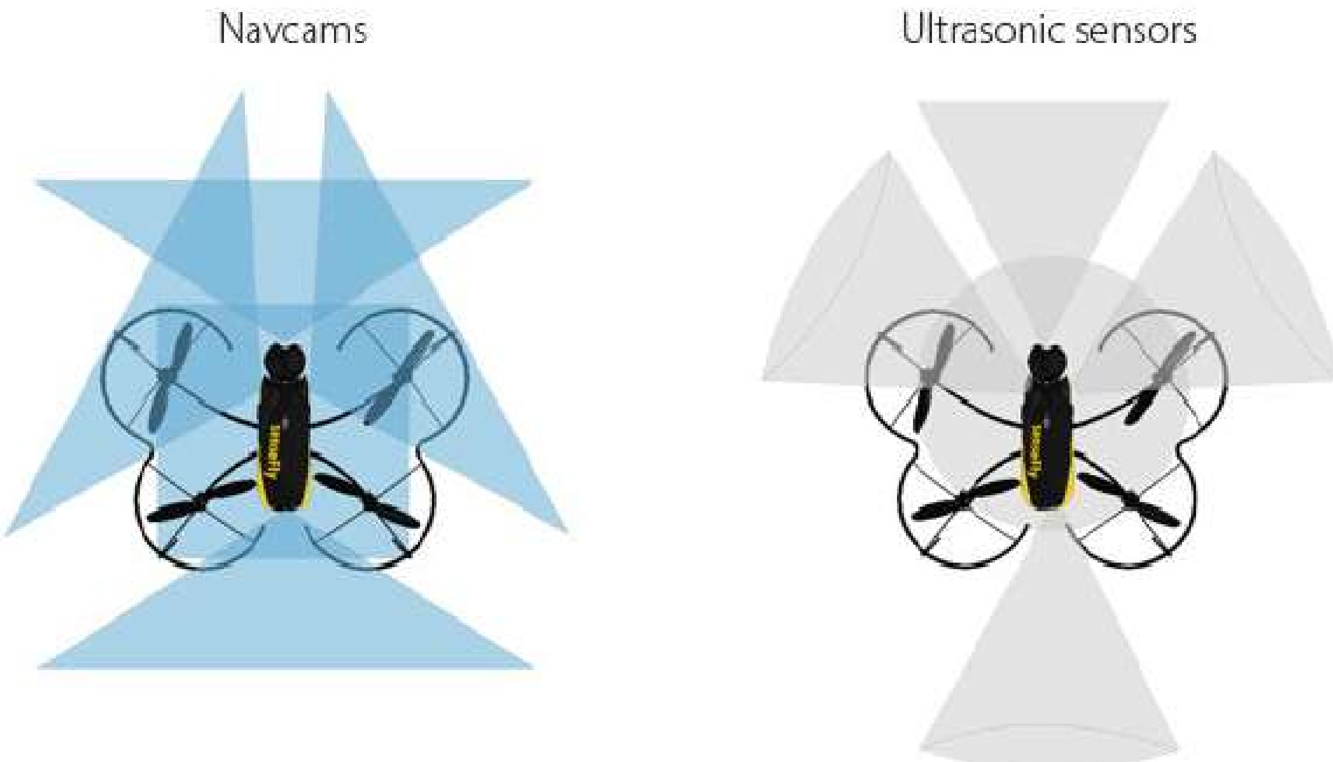
B) Camera optical axis pointing horizontal

» Common in inspection work

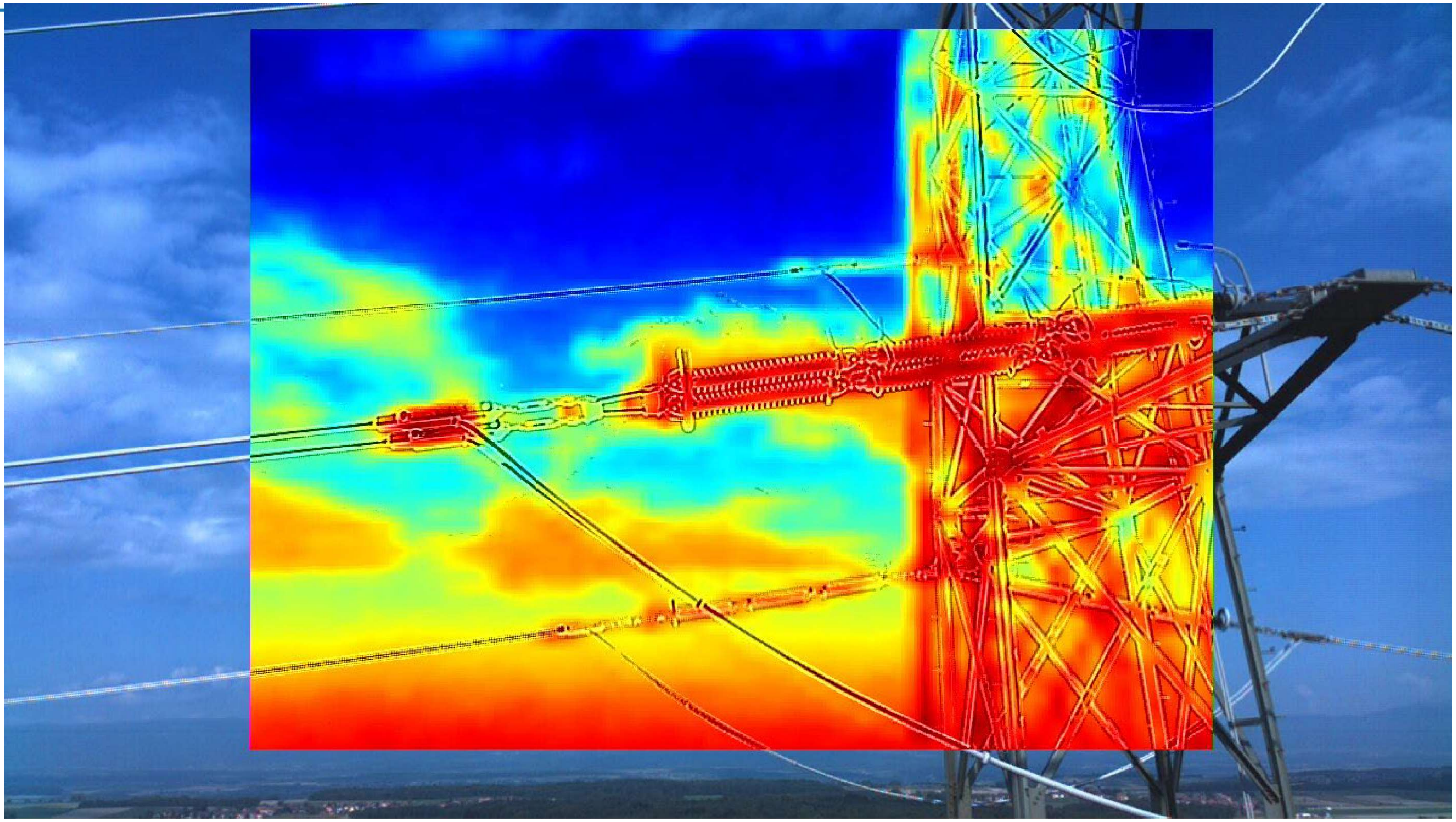
C) Camera optical axis tilted up

» Common in inspection work

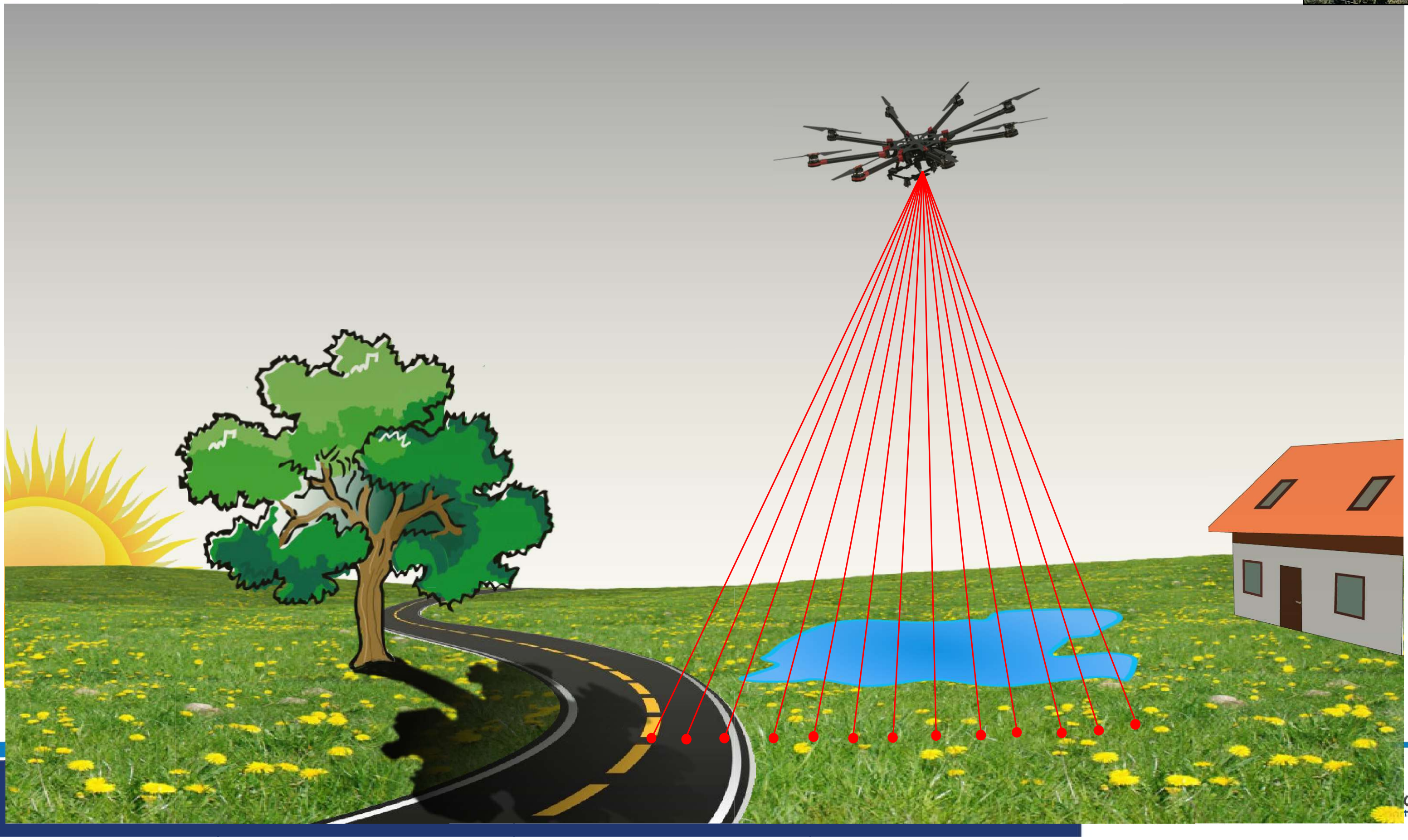
Importance of NavCams & Obstacle Avoidance



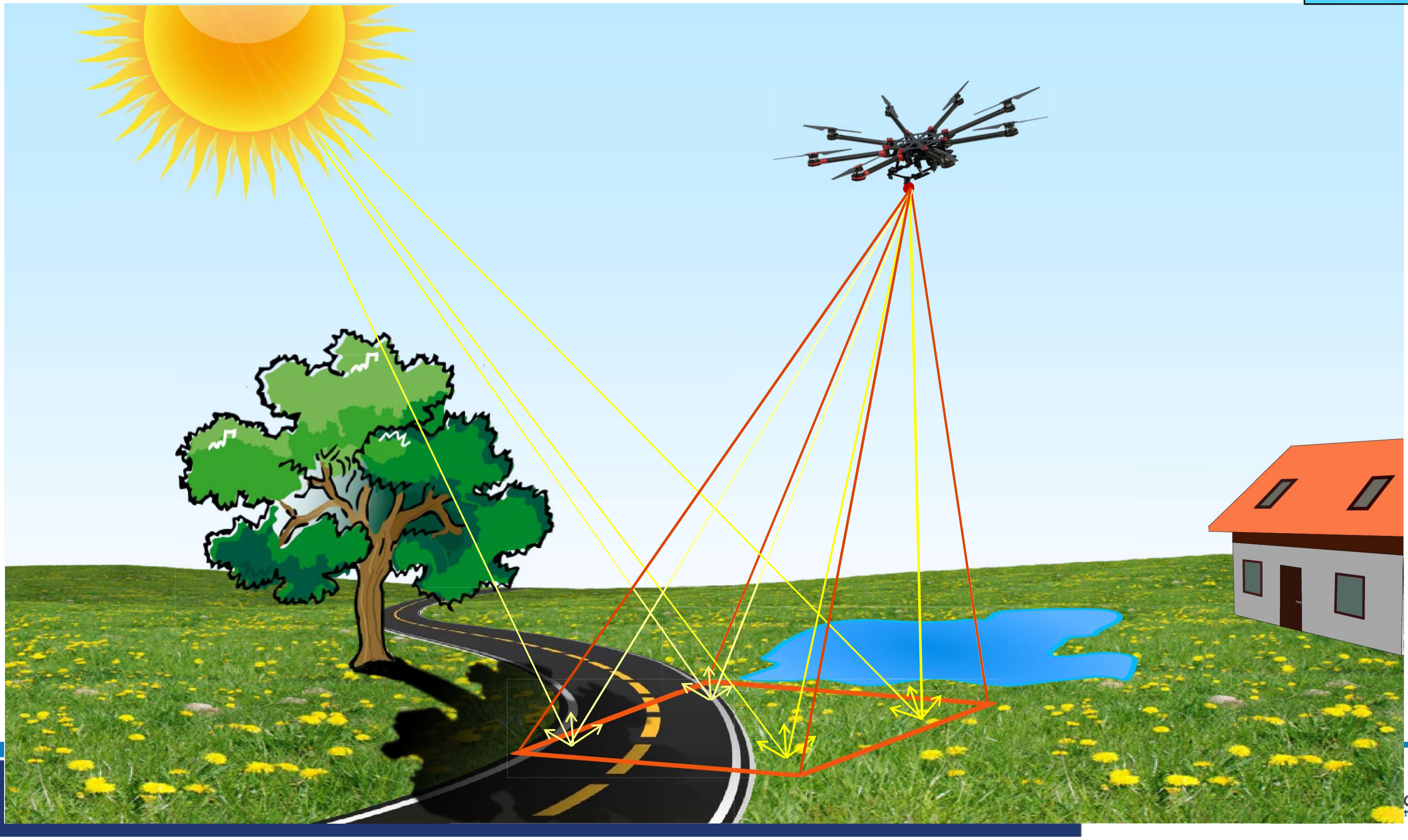
Thermal Camera



Sensor Types: Lidar



Sensor Types: Cameras



Ground Control Station

Laptop/Computer

Datalink Antenna

Sun-Shade

Various Trays

Portable Music Stand

Marine Battery

- Takeoff and landing zone
  - » Large, clear, flat area
  - » Away from people
  - » Access permissions (!)

Test Bridge Inspections

(1) Independence Bridge

(2) Crooked River Bridge

(3) Mill Creek Bridge

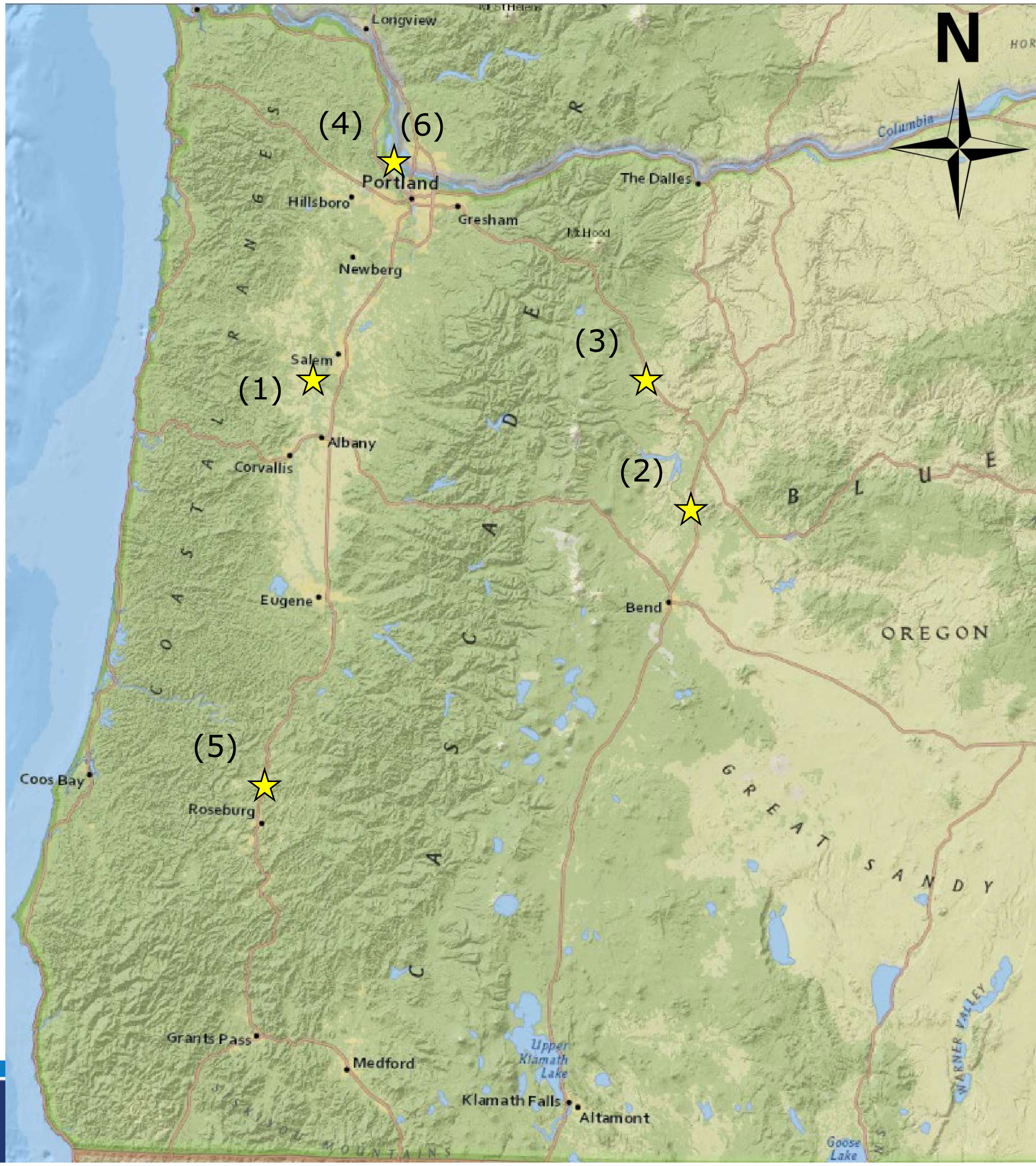
(4) St. Johns Bridge

» Preliminary

(5) Winchester Bridge

(6) St. Johns Bridge

» Detailed



Test Bridge Inspection: Independence Bridge, Sept 2015

- Location: Independence, OR
- Airframe: Phantom 3 Pro
- Flight objective
  - » Test bridge inspection workflow
  - » Capture still and video imagery
- Details
  - » Large deck plate girder bridge
    - – 675.4 m long
    - – Longest span: 46.3 m
  - » Classified as Fracture Critical

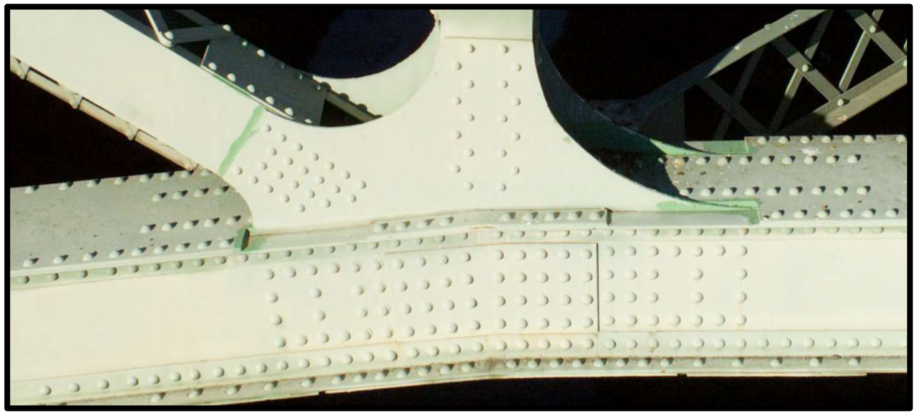
Independence Bridge: Imagery Examples

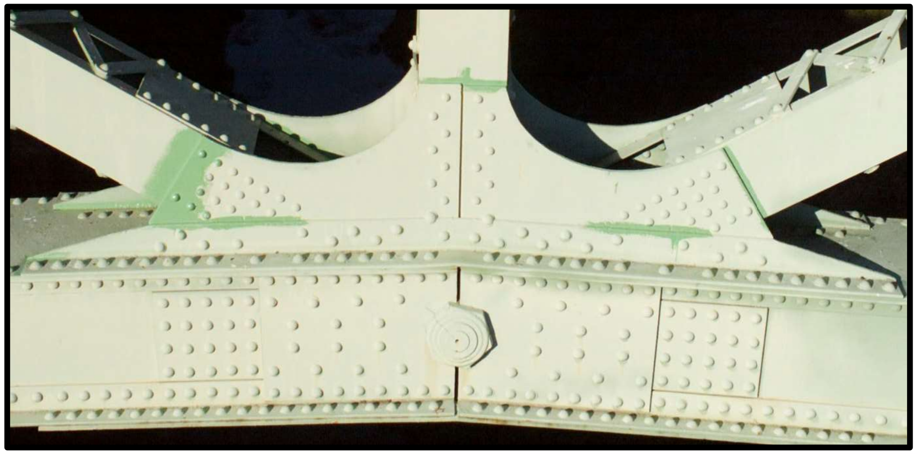
Independence Bridge: Imagery Examples

Test Bridge Inspection: Crooked River Bridge, July 2016

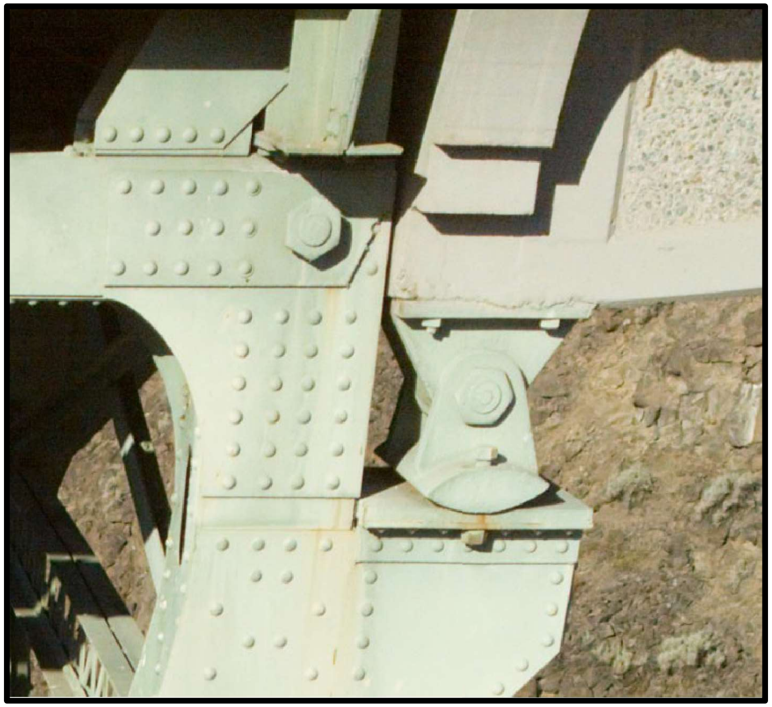
- Location: 8 km north of Terrebonne, OR
- Airframe: senseFly Albris
- Flight objective
  - » Capture high-quality imagery for inspection purposes
  - » Targeting specific areas that are difficult to inspect using traditional methods
  - » Create 3D model via SfM
- Details
  - » Steel Arch Bridge
  - » 141 m long
    - – Longest span: 100 m
  - » Pedestrian only

Crooked River Bridge: Imagery Examples

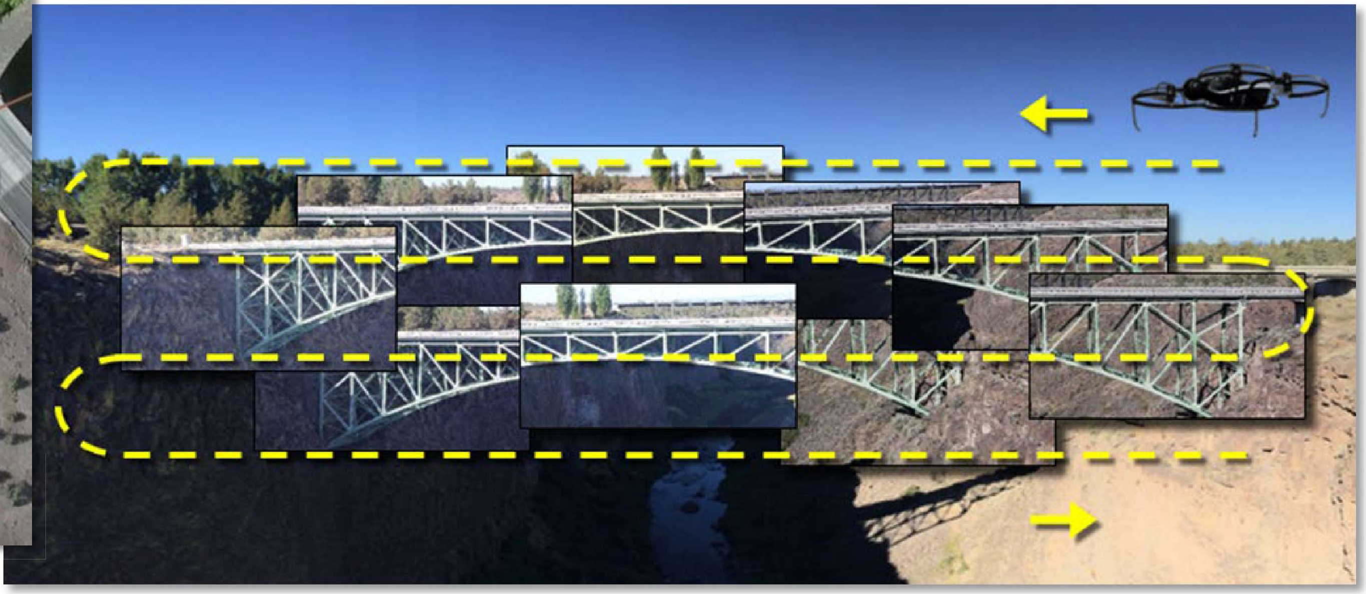




Crooked River Bridge: Imagery Examples

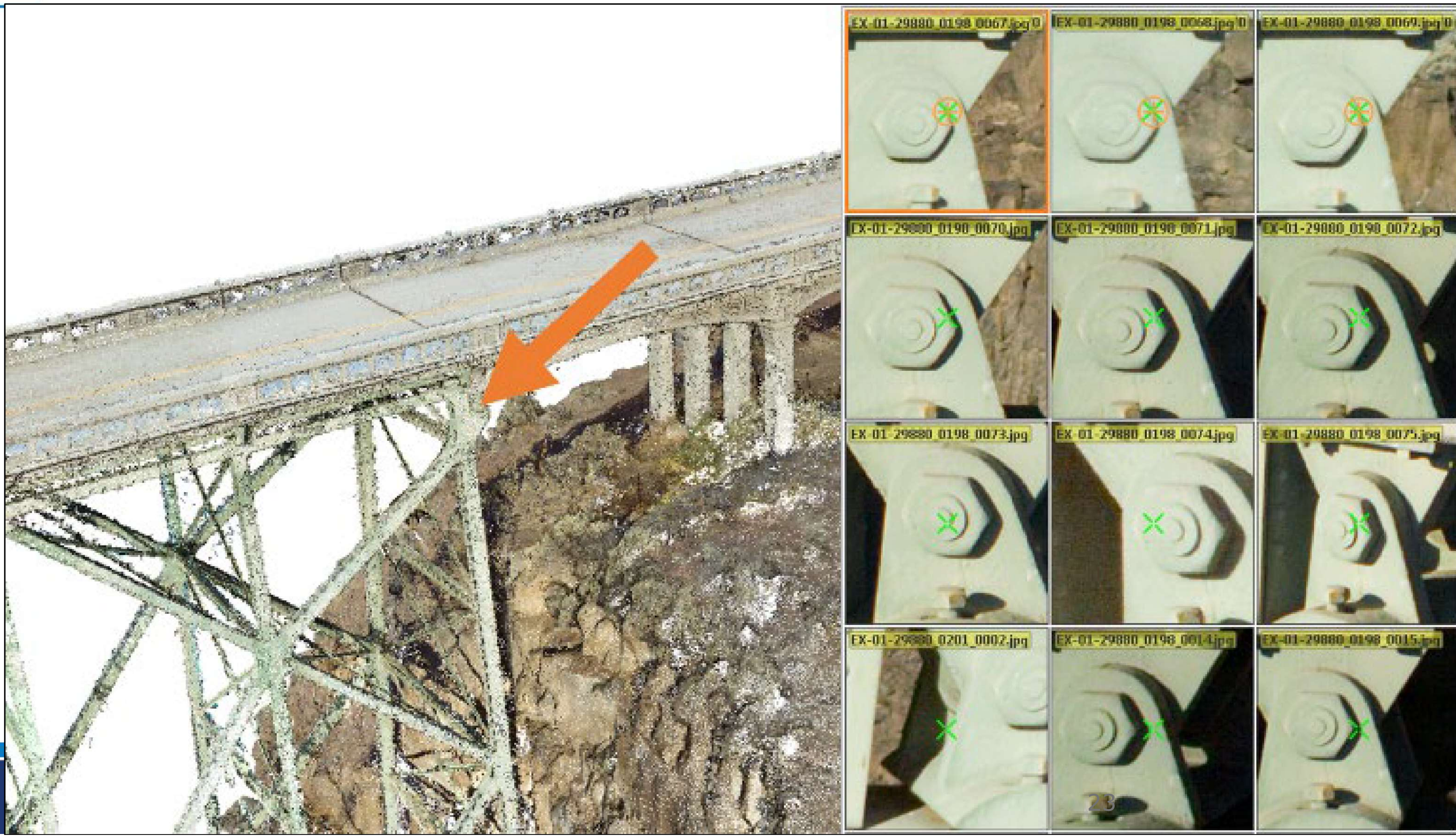


Crooked River Bridge: Mapping Flights



Crooked River Bridge: Point Cloud

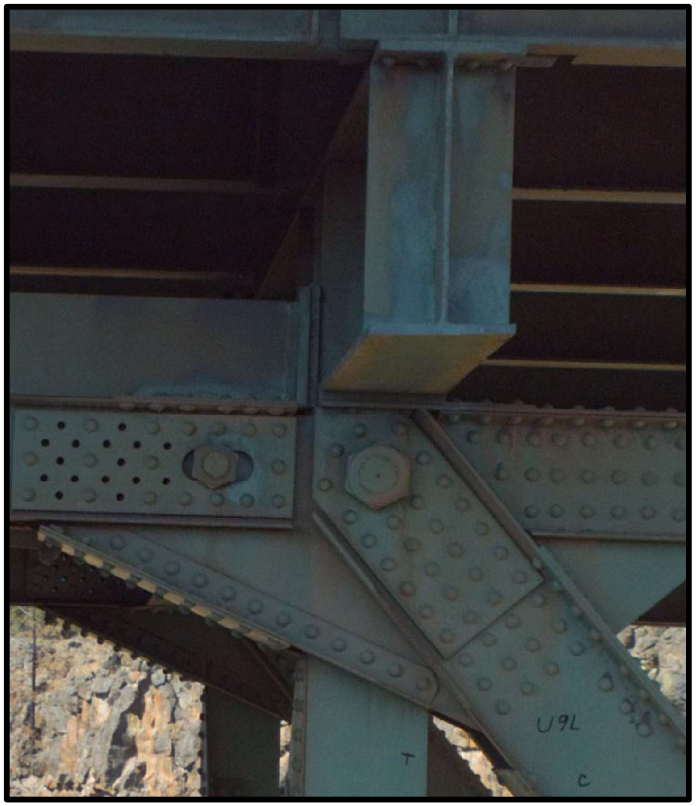
Point Cloud ↔ Raw Imagery



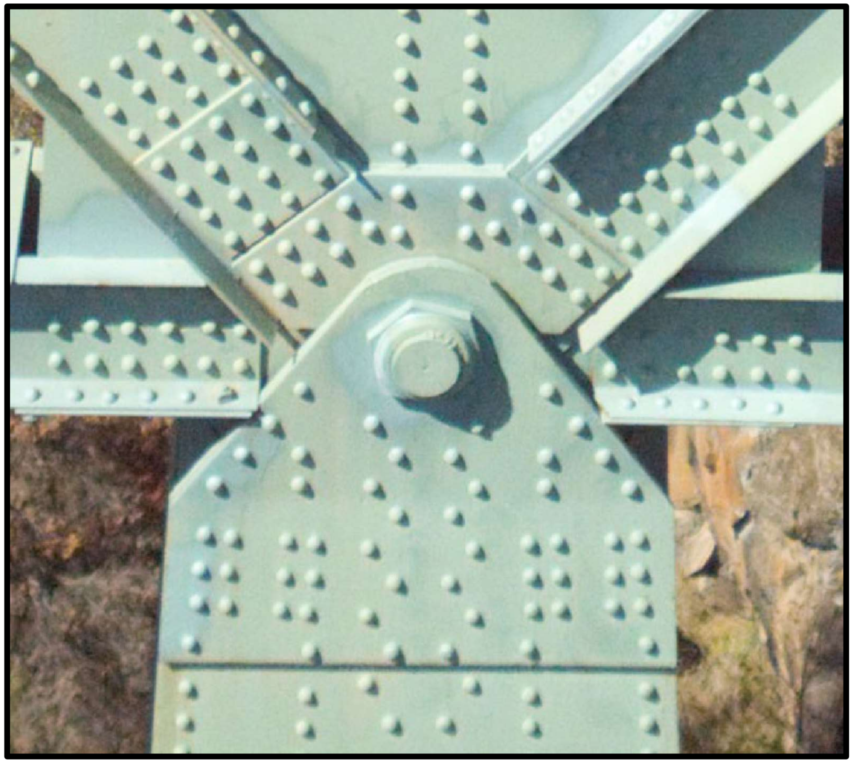
Test Bridge Inspection: Mill Creek Bridge, July 2016

- Location: 17 km NW of Warm Springs, OR
- Airframe: senseFly Albris
- Flight objective
  - » Capture high-quality imagery for inspection purposes
  - » Targeting specific areas that are difficult to inspect using traditional methods
- Details
  - » Cantilevered Warren deck truss bridge
  - » 163 m long
    - – Longest span: 50 m

Mill Creek Bridge: Imagery Examples



Mill Creek Bridge: Imagery Examples



Test Bridge Inspection: St. Johns Bridge (Prelim Test), Sept 2016

- Location: Portland, OR
- Airframes: senseFly Albris, s900 with Sony WX500 (30x optical zoom)
- Flight objective
  - » Test of optical zoom camera
  - » Capture high-quality imagery
- Details
  - » Metal Riveted Warren deck truss
  - » Wire Cable Suspension
  - » 1100 m long
    - – Longest span: 368 m

St. Johns Bridge: Imagery Examples

St. Johns Bridge: Imagery Examples

St. Johns Bridge: Imagery Examples

Test Bridge Inspection: Winchester Bridge, March 2017

- Location: Winchester, OR
- Airframes: senseFly Albris
- Flight objective
  - » Capture imagery while receiving real-time input from inspectors
- Details
  - » Warren deck truss bridge
  - » Southbound bridge of I-5
  - » 500 m long
    - – Longest span: 42 m

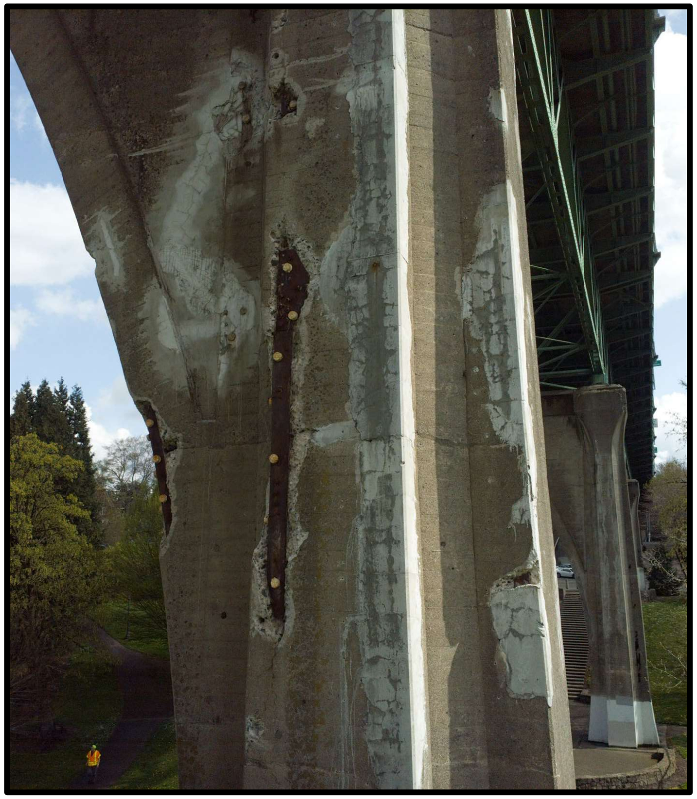
Winchester Bridge: Imagery Examples

Winchester Bridge: Imagery Examples

Test Bridge Inspection: St. Johns Bridge (Detailed Test), April 2017

- Location: Portland, OR
- Airframes: senseFly Albris
- Flight objective
  - » 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: Imagery Examples



St. Johns Bridge: Imagery Examples

St. Johns Bridge: Imagery Examples

St. Johns Bridge: Imagery Examples

St. Johns Bridge: Imagery Examples

St. Johns Bridge: Imagery Examples

Cost-Benefit Analysis Procedures

1. Establish baseline costs for bridge inspections conducted *without* the use of UAS by compiling existing data from Oregon DOT
   » 33 bridge inspection project budget spreadsheets
2. Determine the percentage of bridges that Oregon DOT 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 Procedures (cont'd)

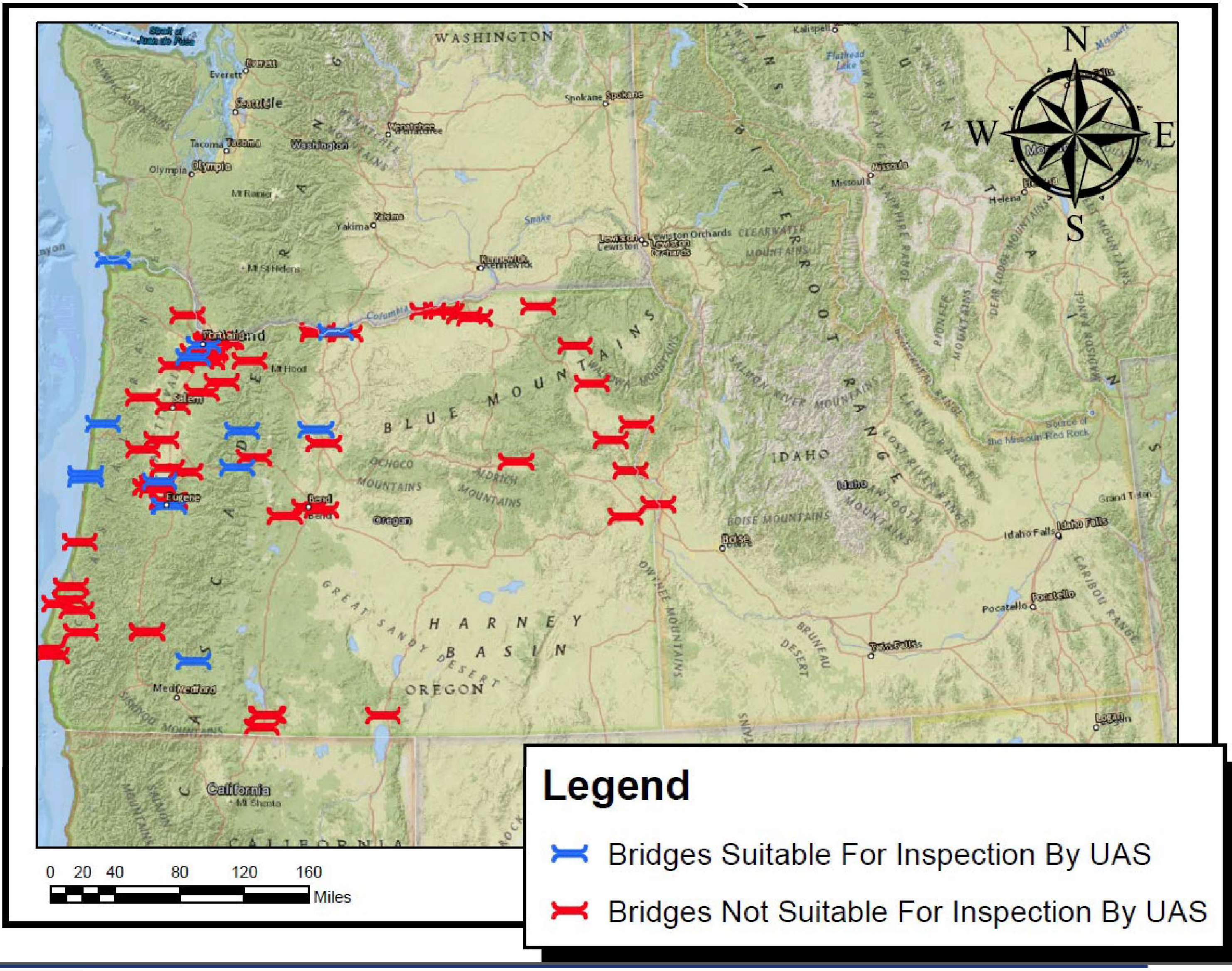
4. Estimated annual cost savings = (average cost savings per suitable bridge) × (# of bridges/yr inspected by ODOT) × (percentage of bridges suitable for UAS inspection)

5. Estimate costs:
   - Cost of purchasing 3 UAS
   - Annual maintenance cost
   - Data storage

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

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

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



- Reasons bridges were deemed "not suitable"
  - Low height, low clearance bridges, where it wouldn't be worthwhile to use UAS
  - Airspace
  - Access issues
  - Vegetation poses risks to UAS
  - Lack of suitable takeoff/landing site

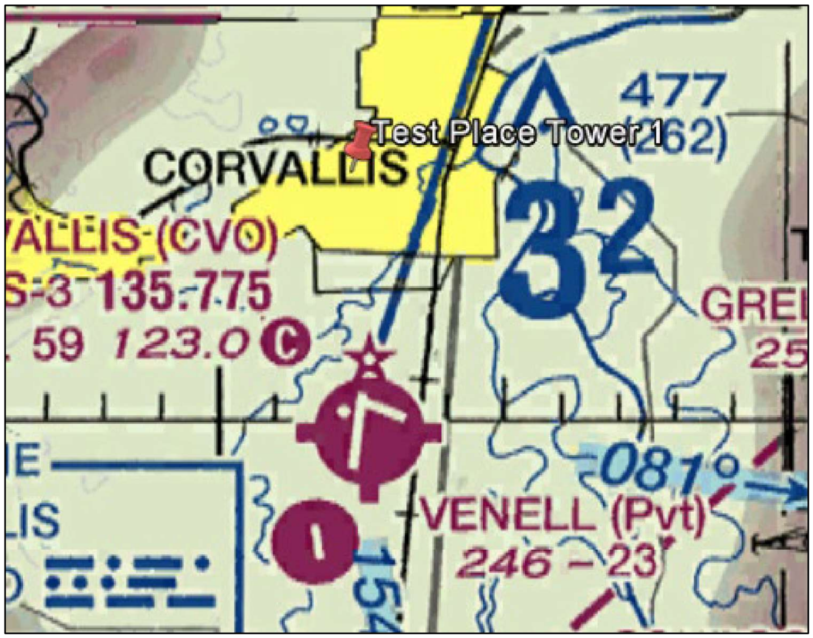
Key Project Findings

- 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
  - Potential for >$1M in savings/year from use of UAS in structural inspections in large bridge inspection program
  - Should be refined as more data becomes available

Practical Recommendations/Lessons-Learned

- Remote aircraft requirements
  - » Variable tilt (0-180°) camera
  - » Zoom lens
  - » Obstacle avoidance capabilities
  - » Establish max wind speeds for structural inspections (aircraft dependent)
- Personnel requirements
  - » UAS bridge inspection flight crews should have at least a basic level of expertise in photography
    - – ISO, aperture, shutter speed
  - » Frequent practice (proficiency flights) *specifically for structural inspection*
    - – Simulate: loss of GPS, wind gusts, operating near large structure

Safety Plan

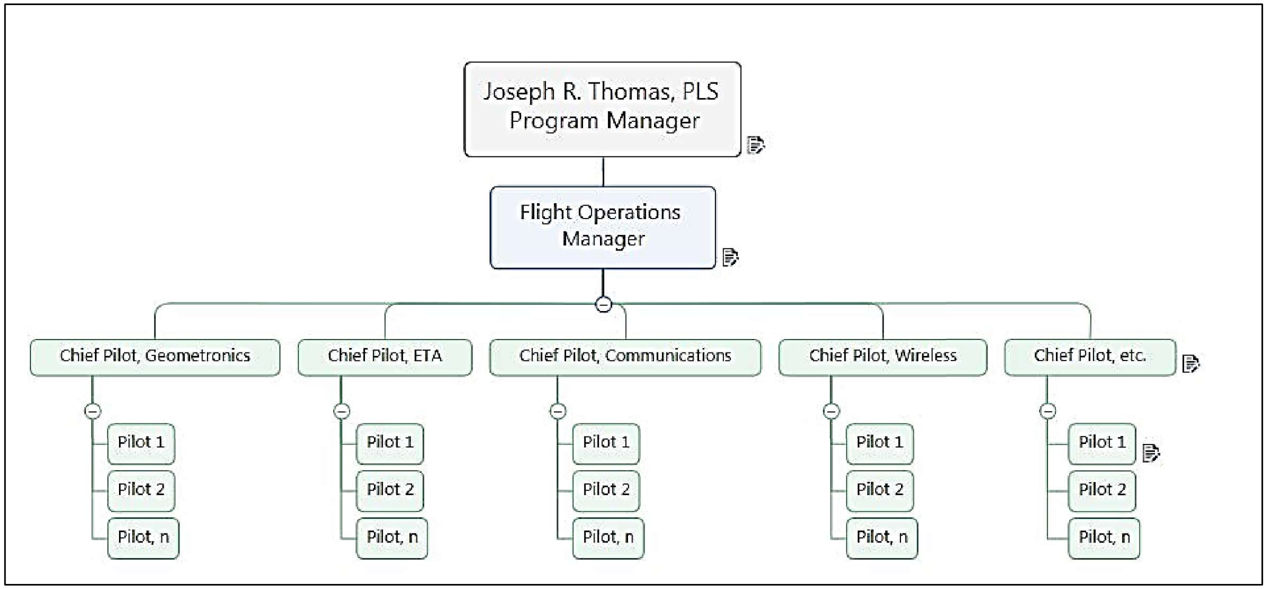


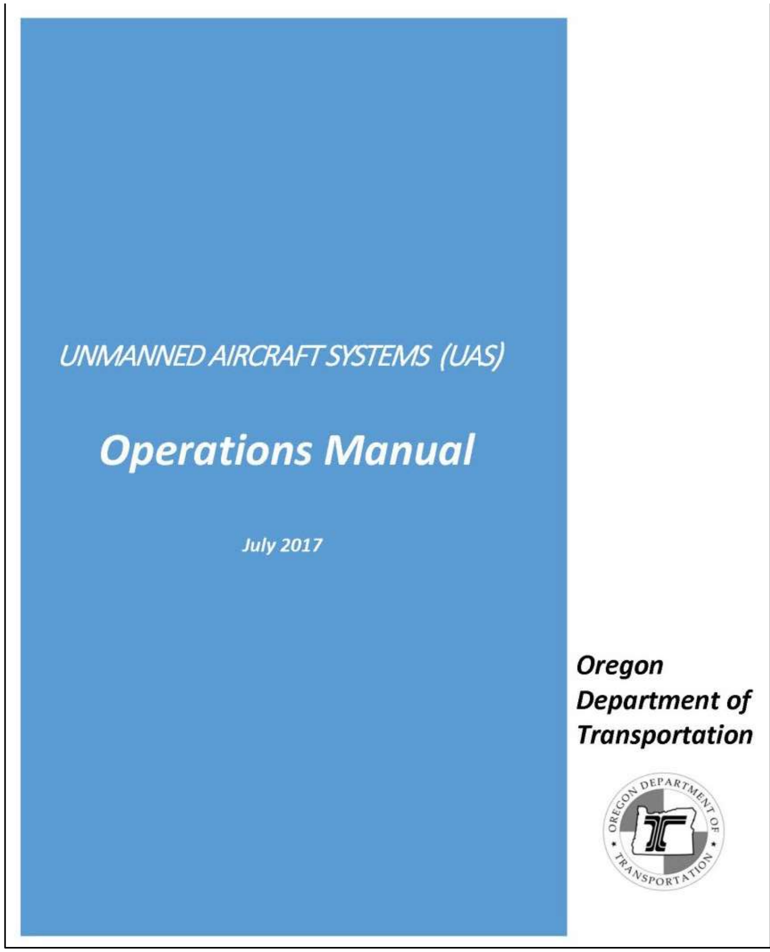
Date of Assessment:	04/25/2016	Personnel:	Pilot in Command:	Tom Normandy
Structure Type:	Communication Tower		Primary Observer:	Matt Gillins
Location of Structure:	44°26'10.8" N 122°59'07.1" W		Other Spotters:	Farid Javadnejad Dan Gillins Chris Parrish
Owner of Structure:	ODOT			
Owner's Contact info:	555 13th St NE Salem, OR 97301-6867 Phone (503) 986-2700		COA Number:	2015-AHQ-105-COA-TS
			Team 's Emergency Contact Number:	(818)-497-8576
Airport within 5 nm?	Yes: X	No:	Airport Manager:	Jacob Kropf
If Yes Which:	J & J airport		Manger Contact info:	(541)-766-6783
Distance from Airport:	3.2 nm		Radio Frequency Air Traffic Controller:	N/A UNICOM 123.0

Safety Inventory: Mark yes or no if any of the following hazards are potential for work site.

YES	NO	Equipment Hazards	YES	NO	Personal Hazards	YES	NO	Environmental Hazards
X		Nearby Vehicular Traffic		X	Twisting/Bending/Awkward Positions/ Heavy Lifting		X	Falling Debris
	X	Nearby Heavy Equipment Operations		X	Working Over water		X	Confined Space
	X	Transport/Launch of Boat/ATV/Etc.		X	Loose unstable footing	X		Weather Related
	X	Boat/Watercraft Operations	X		Slip/Trip/Fall Hazard	X		Live Stock/Wildlife
	X	ATV Operations		X	Ladders/Elevated Platforms	X		Transients
X		Other		X	Other		X	Other

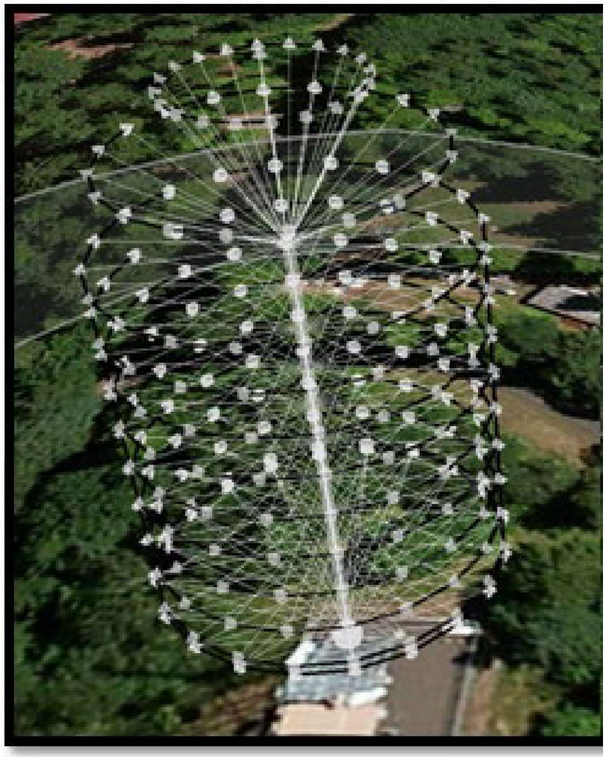
Oregon DOT UAS Program



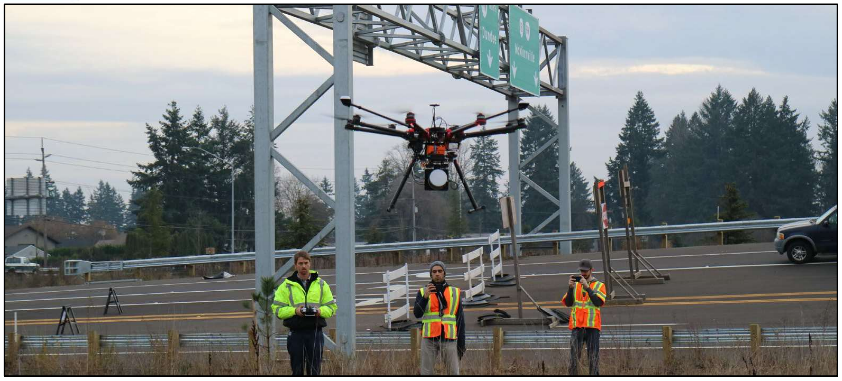


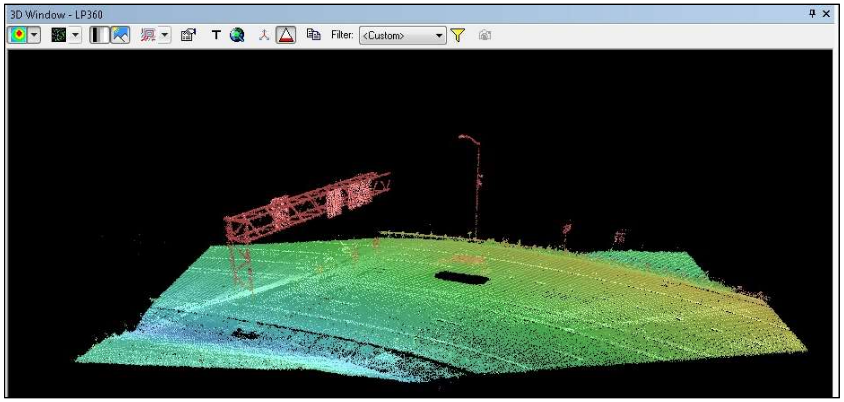
Courtesy of Chris Glantz, PLS, Oregon Department of Transportation

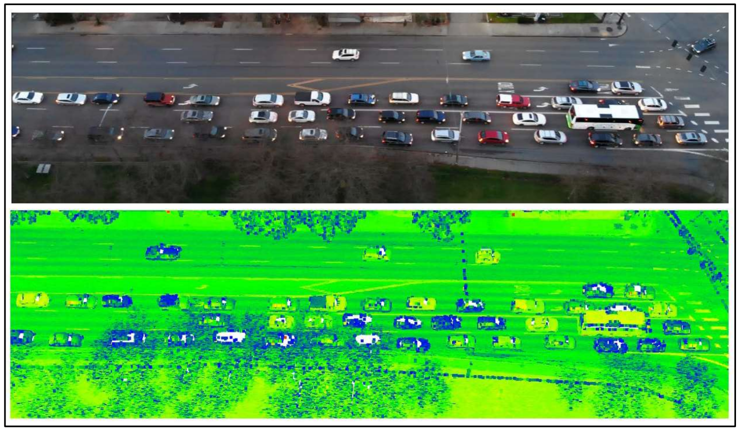
Related Work: Communication Tower Inspections



Related Work: UAS Traffic Network Monitoring (PacTrans)







References

Gillins, D.T., C.E. Parrish, and M.N. Gillins, 2018. *Eyes in the Sky: Bridge Inspections with Unmanned Aerial Vehicles, SPR 787 Final Report*. Oregon Department of Transportation: https://www.oregon.gov/ODOT/Programs/ResearchDocuments/SPR787_Eyes_in_the_Sky.pdf

Gillins, M.N., D.T. Gillins, and C. Parrish, 2016. Cost-Effective Bridge Safety Inspection using Unmanned Aircraft Systems (UAS). GEO Structures Congress 2016 14-17 Feb, Phoenix, Arizona.

Parrish, C.E., D. Hurwitz, C. Simpson, S. Sorour, and A. Abdel-Rahim, 2019. *An Airborne Lidar Scanning And Machine Learning System For Real-time Event Extraction And Control Policies In Urban Transportation Networks*. PacTrans Final Project Report (in review).

Parrish, C., R. Slocum, and C. Simpson, 2018. UAS in Transportation Expo Final Report, online: http://depts.washington.edu/pactrans/wp-content/uploads/2018/11/UAS-in-Transportation-Report.pdf

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