Unmanned Aircraft Systems (UAS) for Bridge Inspection

Oregon State University, CCE Geomatics

Chase Simpson, Christopher Parrish, Dan Gillins, Matt Gillins

Oregon Department of Transportation

Erick Cain, Christopher Glantz

Oregon GPS User Group

06/15/2018

Why we Inspect Bridges

- 1967 – Silver Bridge collapse (fracture of an eyebar at a pin connection)
- 1968 – National bridge inspection (NBI) program initiated (requiring regular and periodic inspections)
- 1971 – National bridge inspection standards (NBIS) adopted (prescribe how, with what frequency, and by whom bridge inspections must be completed)
- 1987 – Schoharie Creek collapse (scour)
- 2007 – Minnesota I-35W collapse (undersized gusset plate design)

23 CFR Part 650, Subpart C - National Bridge Inspection Standards

- Structures must carry vehicular traffic open to public.
- Greater than 20 feet in length
- Owned by the public. *(State, County, City, Housing Association, Port, etc.)*

Oregon NBI Bridge Count

- ODOT Owned = 2742
- County Owned = 3432
- City Owned = 623
- Other State Agencies = 57
- Railroad Owned = 6
- Local Toll Owned = 2

____

Total NBI Bridges = 6862

Types of Inspections and Frequency

- **NBI Inspection** *(2 Year Max)*
- **Element Level Inspection** *(2 Year Max)*
- **Fracture Critical Inspection** *(2 Year Max)*
- **Fatigue Prone Inspection** *(Not to exceed 10 years)*
- **Timber *Boring*** *(Not to exceed 8 years)*
- **Under Water** *(Not to exceed 5 years)*
- **Cross Channels** *(Not to exceed 10 years)*
- **Scour Inspections** *(As Needed)*
- Multiple Other Specialty Types of Inspections.

Reports

Oregon Department of Transportation
Bridge Inspection Report

District :	2B	**Structure :**	Hwy 1 NB over UPRR	**Bridge ID :**	N8588E
Fac Crossed :	UPRR	**Owner :**	State Highway Agency	**Fac Carried :**	I-5 (HWY 001) NB
Suff Rating :	43.1	**County :**	Multnomah	**Mile Point :**	301.70 mi
AC Depth :	0.00	**Record Type :**	1	**Insp Date :**	02/26/2017
Bridge Length :	2251.07 ft	**Insp Freq :**	24	**Inspector 1 :**	Kevin Shearmire (ODOT)
		Bridge Width :	33.73 ft	**Inspector 2 :**	ROBERT IWAI (267)

Signature: ______________________________

Element Condition States (New AASHTO report)

Element	Structure Unit	Environment	Quantity	Units	CS 1	CS 2	CS 3	CS 4	Temp
12-Re Concrete Deck	**1**	**3**	**93687**	**(SF)**	**91836**	**1824**	**27**	**0**	
1081-Soffit Spalls/Delams/Patches	1	3	3	(SF)	0	0	3	0	
1090-Exposed Rebar	1	3	24	(SF)	0	0	24	0	
1120-Efflorescence/Rust Staining	1	3	1824	(SF)	0	1824	0	0	
513-Rigid Wearing Surface	1	3	88297	(SF)	28249	40032	20016	0	
16-Re Conc Top Flange	**1**	**3**	**4202**	**(SF)**	**4178**	**24**	**0**	**0**	
1080-Delamination/Spall/Patched Area	1	3	8	(SF)	0	8	0	0	
1090-Exposed Rebar	1	3	1	(SF)	0	1	0	0	
1120-Efflorescence/Rust Staining	1	3	15	(SF)	0	15	0	0	
513-Rigid Wearing Surface	1	3	3964	(SF)	3961	3	0	0	
107-Steel Opn Girder/Beam	**1**	**3**	**11317**	**(LF)**	**3165**	**8152**	**0**	**0**	
1000-Corrosion	1	3	8151	(LF)	0	8151	0	0	
1020-Connection	1	3	1	(LF)	0	1	0	0	

Oregon Department of Transportation
Structure Inventory and Appraisal Report

Suff Rating: 43.1

Bridge NO: N8588E
Insp Date: 02/26/2017

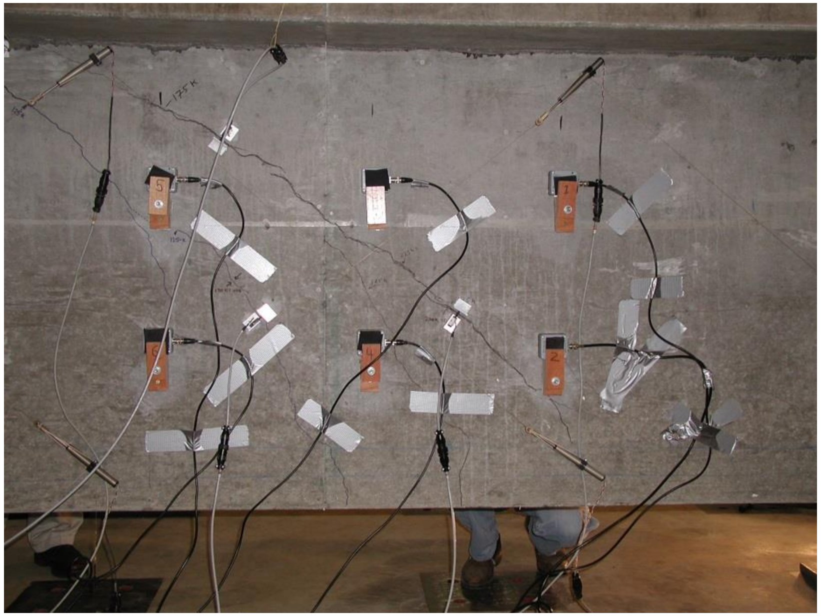
(2) Highway District	District 2B	(42A) Type Service On	1	(75) Type of Work	331
(3) County	Multnomah	(42B) Type Service Under	4	(76) Improvement Length	2247.38 ft
(4) City	59000	**(43) Struct Main**	**3 Steel 02 Stringer/Girder**	(90) Inspection Date	02/26/2017
(5) Inventory Route	111000050	(44) Struct Appr	1 Concrete 04 Tee Beam	(91) Inspection Frequency	24
(6) Feature INT	UPRR	(45) Number Main Spans	22	(92) Critical Feat Insp (A) Fracture Critical (B) Underwater Insp	Y 24 02/26/2017
(7) Facility Carried	I-5 (HWY 001) NB	(46) Number Appr Spans	2	(94) Cost of Improvement	10389081
(8) Structure Number	N8588E001 30170	(47) Horizontal Clearance	31.23 ft	(95) Roadway Improvement	1038908
(9) Location	0.2 MI N OF BURNSIDE BR	(48) Maximum Span Length	217.00 ft	(96) Project Improvement	16622530
(10) Vert Clearance	19.50 ft	(49) Structure Length	2251.07 ft	(97) Year of Improvement	2011
(11) Mile Post	301.70 mi	(50A) Sidewalk Width LT	0.00 ft	(98) Border BRST-Code	
(12) Base Highway Network	1	(50B) Sidewalk Width RT	0.00 ft	**(100) Defense Highway**	**1**
(13) LRS Inventory Route	000100200S00	**(51) Bridge Roadway Width**	**31.23 ft**	(101) Parallel Structure	L
(16) Latitude	45° 31' 37.00"	(52) Deck Width	33.73 ft	(102) Direction of Traffic	1
(17) Longitude	122° 39' 54.86"	**(53) Vert Clear Over Deck**	**15.67 ft**	(103) Temporary Structure	

What Kind of Defects Do We Look For

Collision

What Kind of Defects Do We Look For

Cracks



Decay

What Kind of Defects Do We Look For

Scour

What Kind of Defects Do We Look For

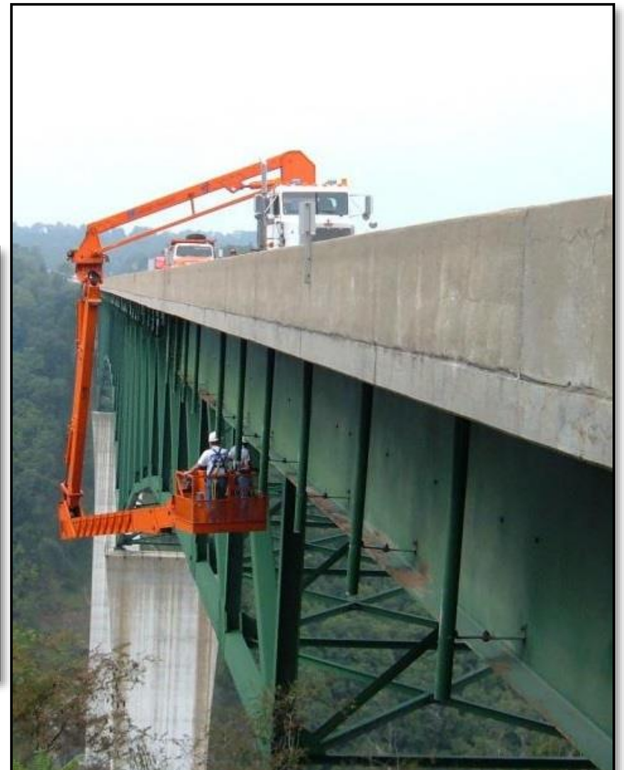
Corrosion and Paint Condition

Damaged and or Frozen Bearings

Access is Expensive and at Times Inconvenient

- Average Cost Traffic Control Per Day $2,500
- Average Cost of a Under the Bridge Inspection Truck (UBIT) $2,000 per day
- Busy Routes Allows Only Night Time Lane Closures
- Night Time Inspection Make Finding Defects Much More Challenging.

Motivation



- New tool in bridge inspector's tool box to help:
  - Provide mechanism to remotely view bridge elements at high resolution, while keeping both feet on ground
  - Reduce lane closures, snooper crane use, and climbing in some inspections
  - Enhance safety and reduce costs in some inspections

UAS for Structural Inspections

FAA COA

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

CERTIFICATE OF WAIVER OR AUTHORIZATION

ISSUED TO

Oregon State University

This certificate is issued for the operations specifically described hereinafter. No person shall conduct any operation pursuant to the authority of this certificate except in accordance with the standard and special provisions contained in this certificate, and such other requirements of the Federal Aviation Regulations not specifically waived by this certificate.

OPERATIONS AUTHORIZED

Operation of small Unmanned Aircraft System(s) weighting less than 55 lbs., in Class G airspace at or below 400 feet Above Ground Level (AGL) under the provisions of this authorization. See Special Provisions.

LIST OF WAIVED REGULATIONS BY SECTION AND TITLE

N/A

STANDARD PROVISIONS

1. A copy of the application made for this certificate shall be attached and become a part hereof.
2. This certificate shall be presented for inspection upon the request of any authorized representative of the Federal Aviation Administration, or of any State or municipal official charged with the duty of enforcing local laws or regulations.
3. The holder of this certificate shall be responsible for the strict observance of the terms and provisions contained herein.
4. This certificate is nontransferable.

Note-This certificate constitutes a waiver of those Federal rules or regulations specifically referred to above. It does not constitute a waiver of any State law or local ordinance.

SPECIAL PROVISIONS

Special Provisions are set forth and attached.

This certificate, 2016-WSA-101-COA, is effective from May 12, 2016 through May 11, 2018 and is subject to cancellation at any time upon notice by the Administrator or his/her authorized representative. Should a renewal become necessary, the Proponent shall advise the Federal Aviation Administration (FAA), in writing, no later than 45 business days prior to the requested effective date.

BY DIRECTION OF THE ADMINISTRATOR

FAA Waivers

- Oregon State University received a nationwide COA for using UAS for research purposes
  - < 400 ft., Class G Airspace
  - Line-of-sight
  - Operators must be "OSU Certified"
- Oregon State University can also fly under a nationwide COA under the FAA Pan-Pacific Test Range
  - Provides opportunities for "more-complicated" types of flights
- Aircraft have been registered with FAA and the State of Oregon

FAA – Part 107

Easier/Less Restrictive

- Pilot license replaced with remote pilot certificate
- Airworthiness certification not required
- NOTAM not required practice
- Visual observer not required
- Coordination with airports in Class G uncontrolled airspace not required
- Use of UAS educational purposes allowed

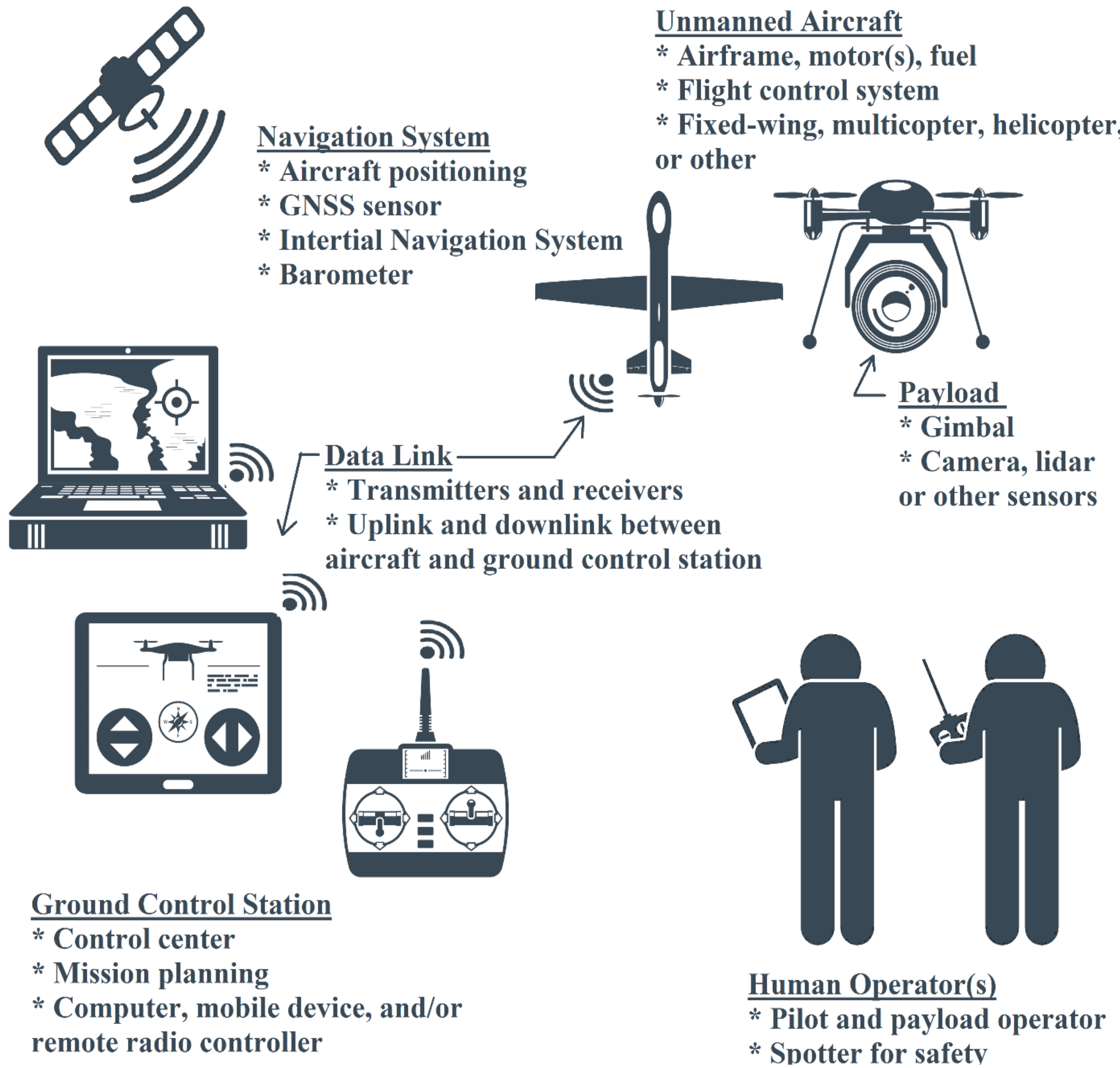
Requirements

- Aircraft must be registered
- VLOS
- Daylight and civil twilight only
- May not operate over nonparticipants
- < 400ft AGL (or within 400ft of a structure)
- Class G airspace only without waiver
- Min wx visibility of 3 miles

Unmanned aircraft systems

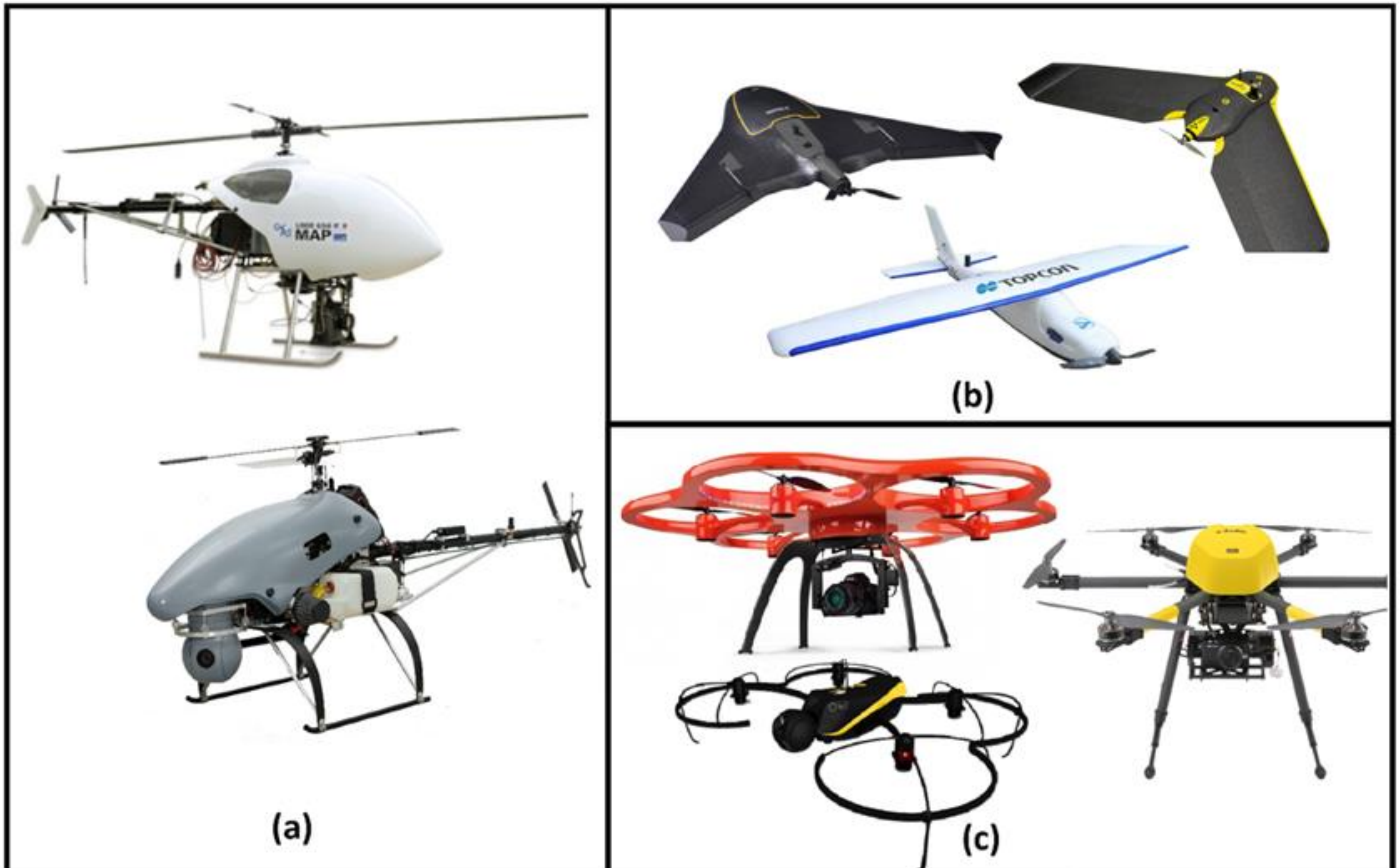
UAS Definition (FAA)

- Not just the aircraft
- Also all associated
  - Support equipment
  - Control station
  - Data links
  - Telemetry
  - Communications
  - Navigation equipment



Aircraft Types

(a) Helicopters (b) Fixed-wing (c) Multi-rotor

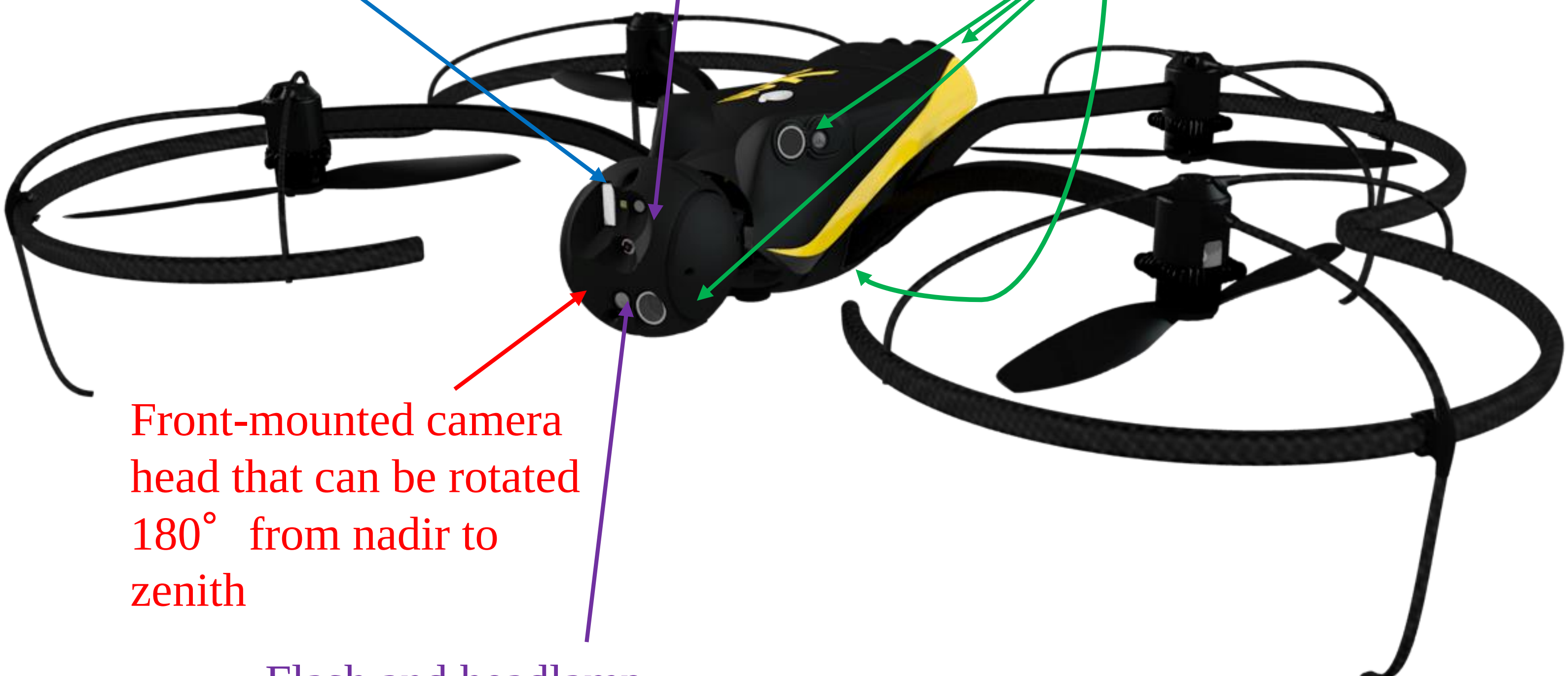


SenseFly eXom (albris)

HD video camera, 38 MP still camera

Thermal IR camera

Navcams and ultrasonic sensors



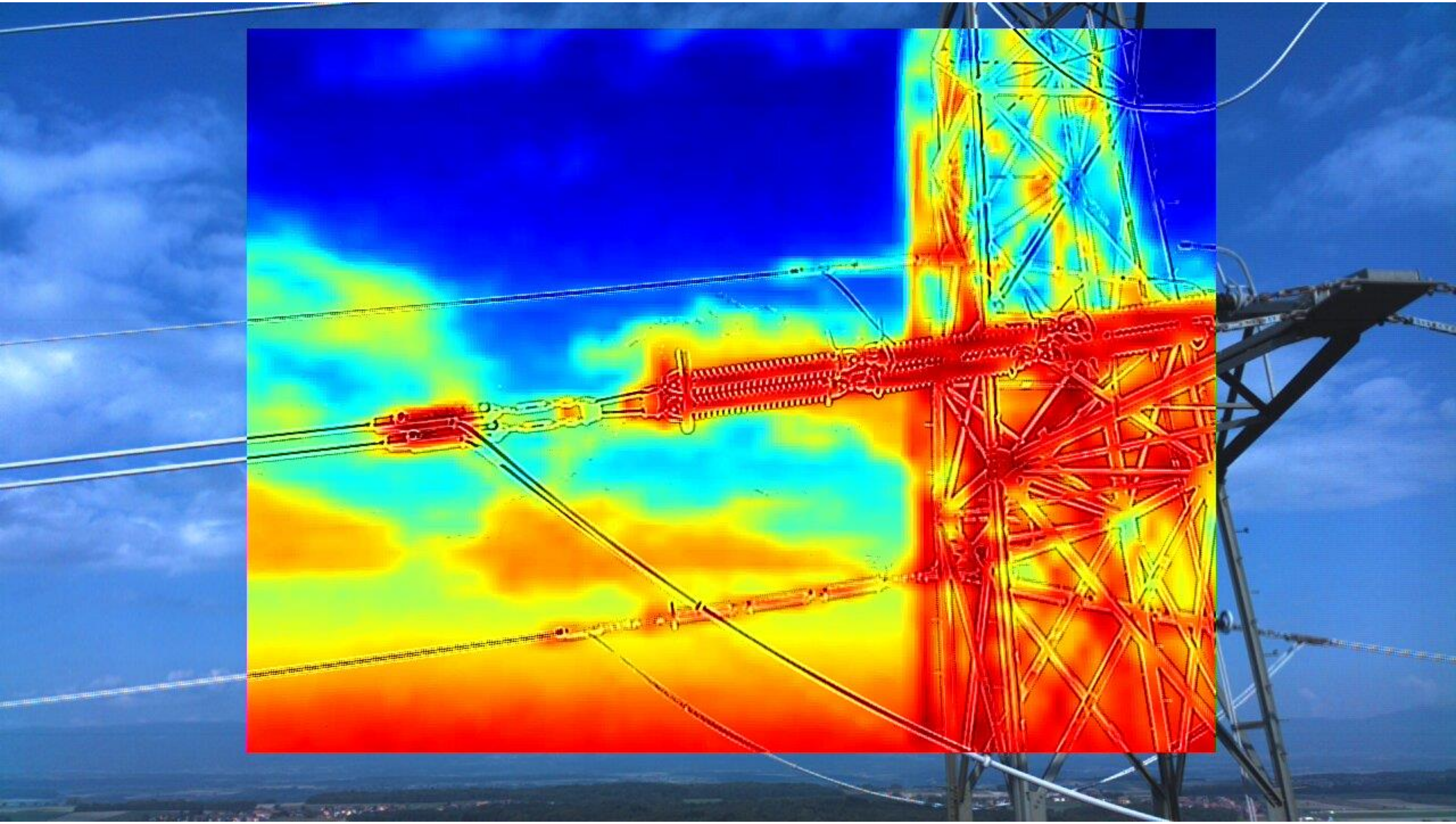
Front-mounted camera head that can be rotated 180° from nadir to zenith

Flash and headlamp

Flight planning software designed to facilitate inspection projects

Albris navcams and ultrasonic sensors

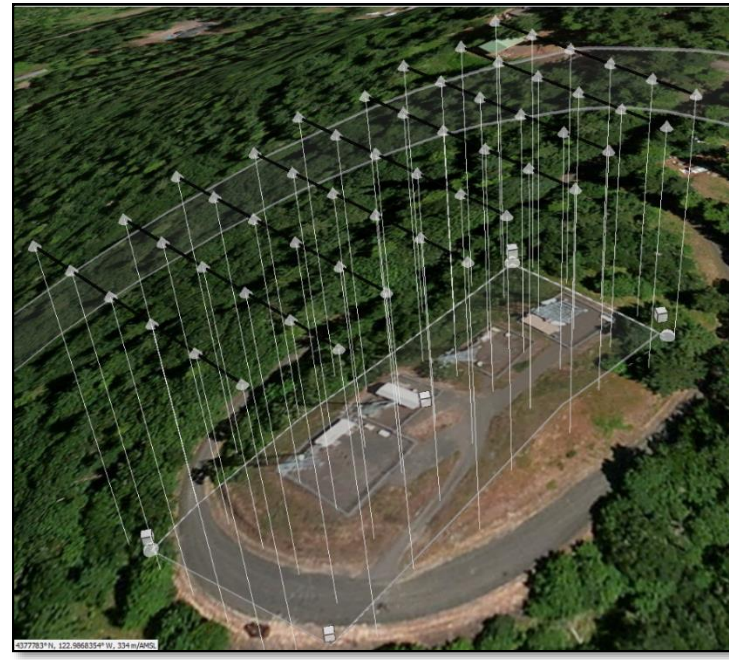
Thermal imagery

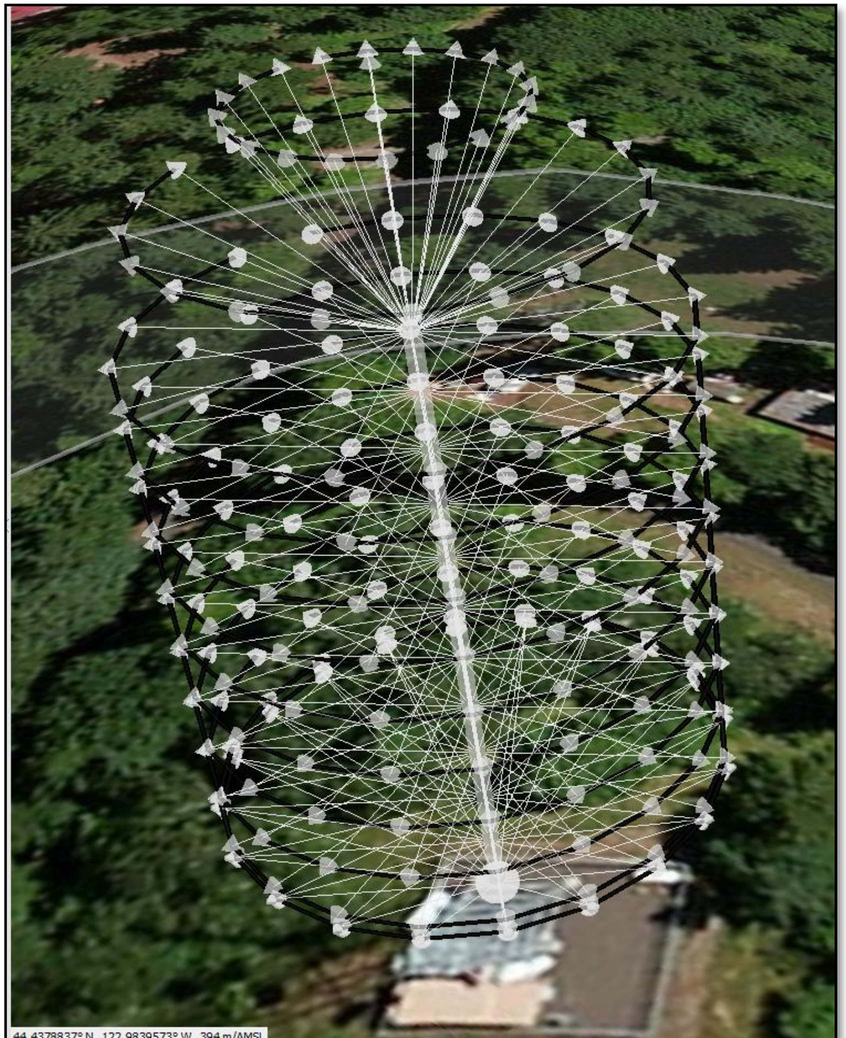


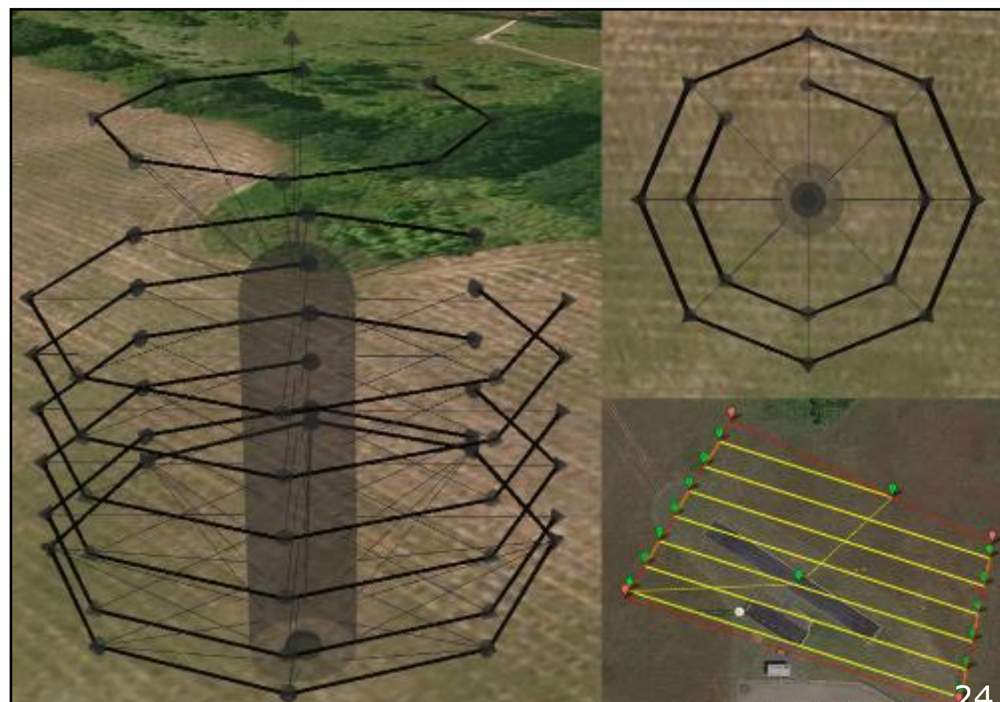
Ground Control Station

Manual flights with sensor assistance

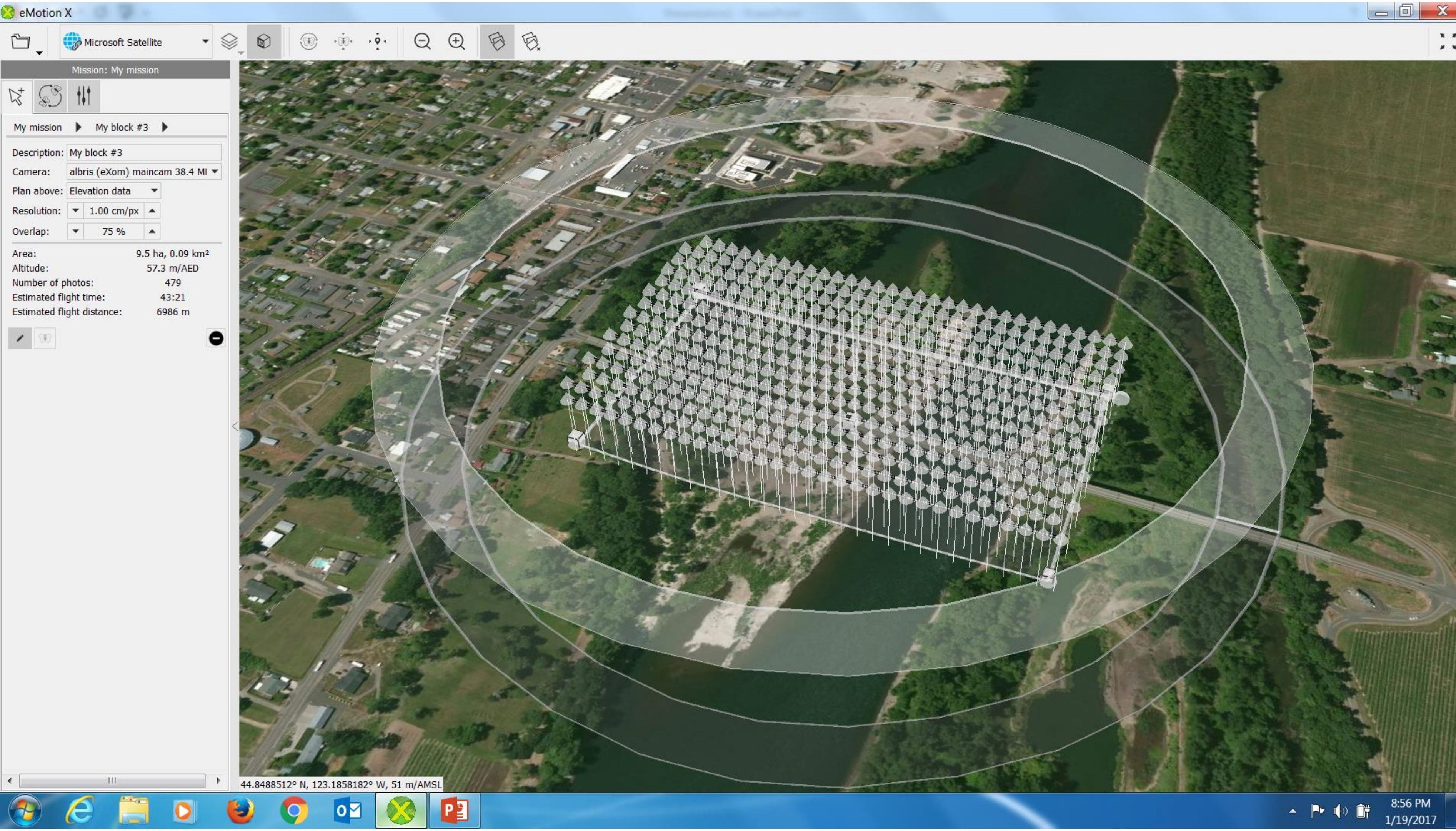
Waypoint missions







Horizontal mapping mission



Flight Methods

Manual Mode with Sensor Assistance	Waypoint Mission Mode
Advantages • Operator can carefully position the camera to view a specific feature of interest • Close-up photos • Less time	Advantages • Overlapping photos can be developed into a 3D model • Systematic flights assure features are fully photographed • Less human interaction

DJI S900

- 30x optical zoom camera (Sony WX500)

UAS Test Bridge Inspections Completed

(1) Independence Bridge

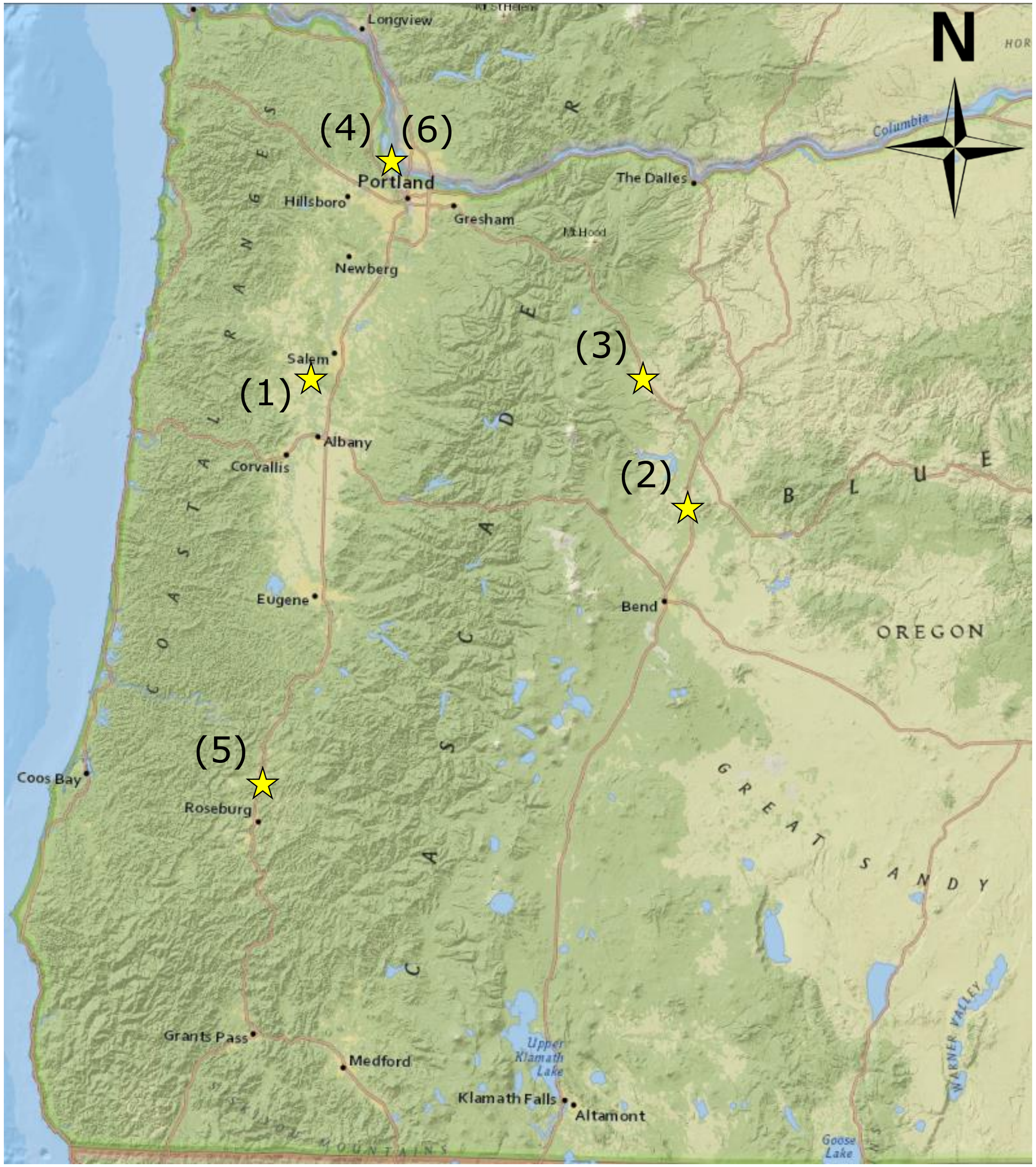
(2) Crooked River Bridge

(3) Mill Creek Bridge

(4) St. Johns Bridge
  - Preliminary

(5) Winchester Bridge

(6) St. Johns Bridge
  - Detailed

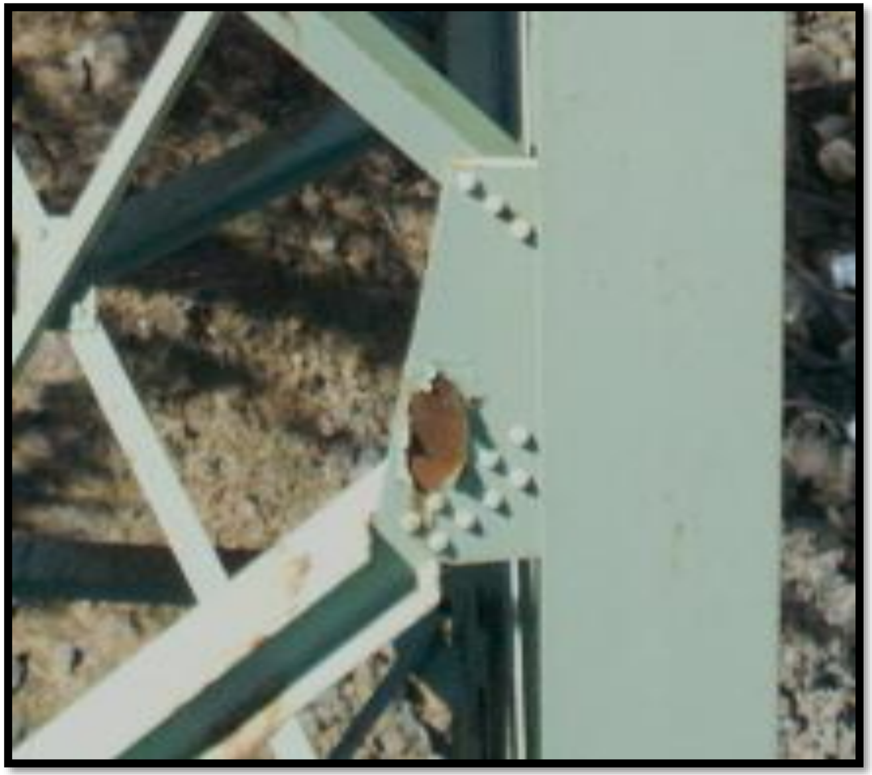


UAS Test Inspections Imagery

Cracks

Pin Connections

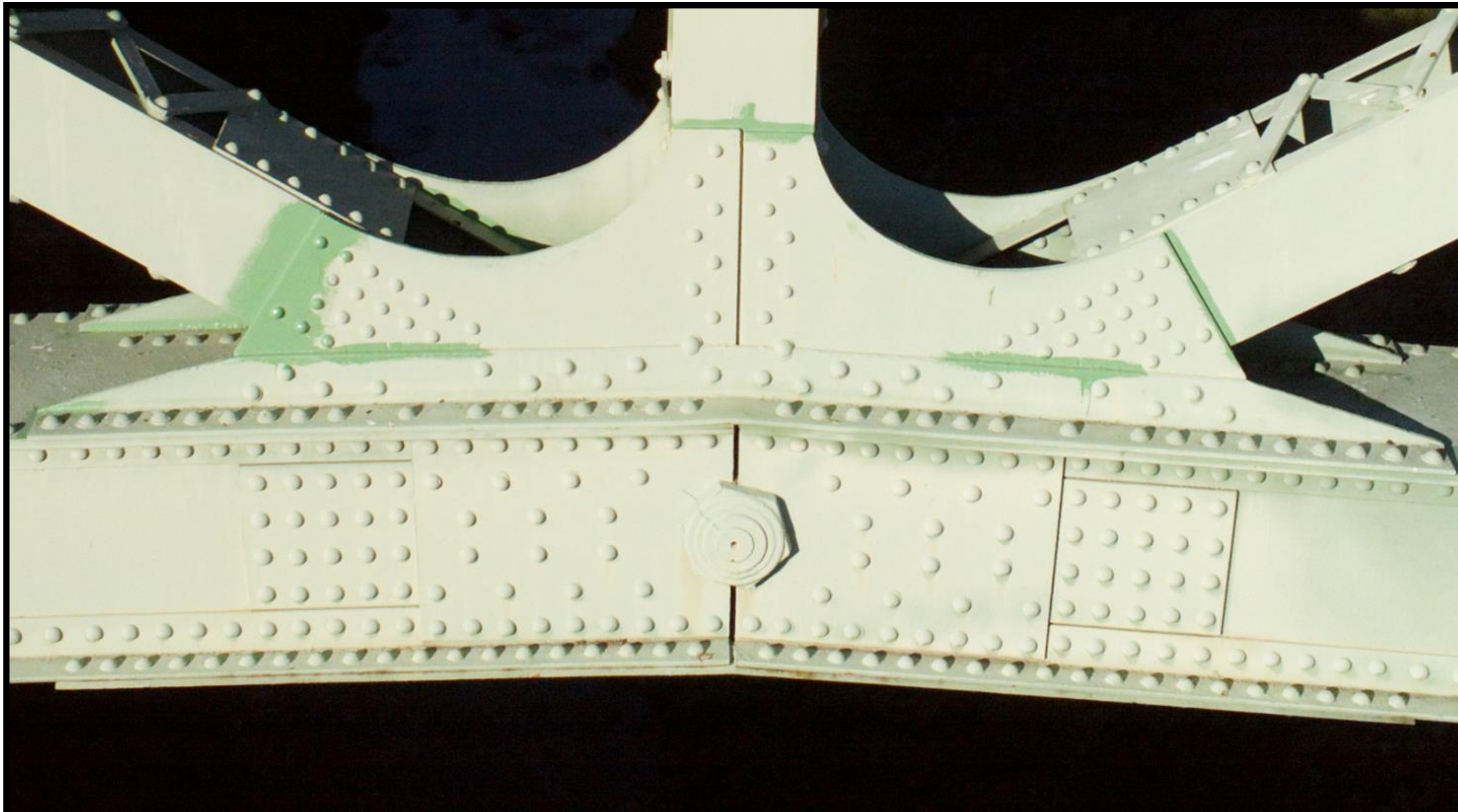
UAS Test Inspections Imagery



Paint Failure

Pack Rust

UAS Test Inspections Imagery



UAS Test Inspections Imagery

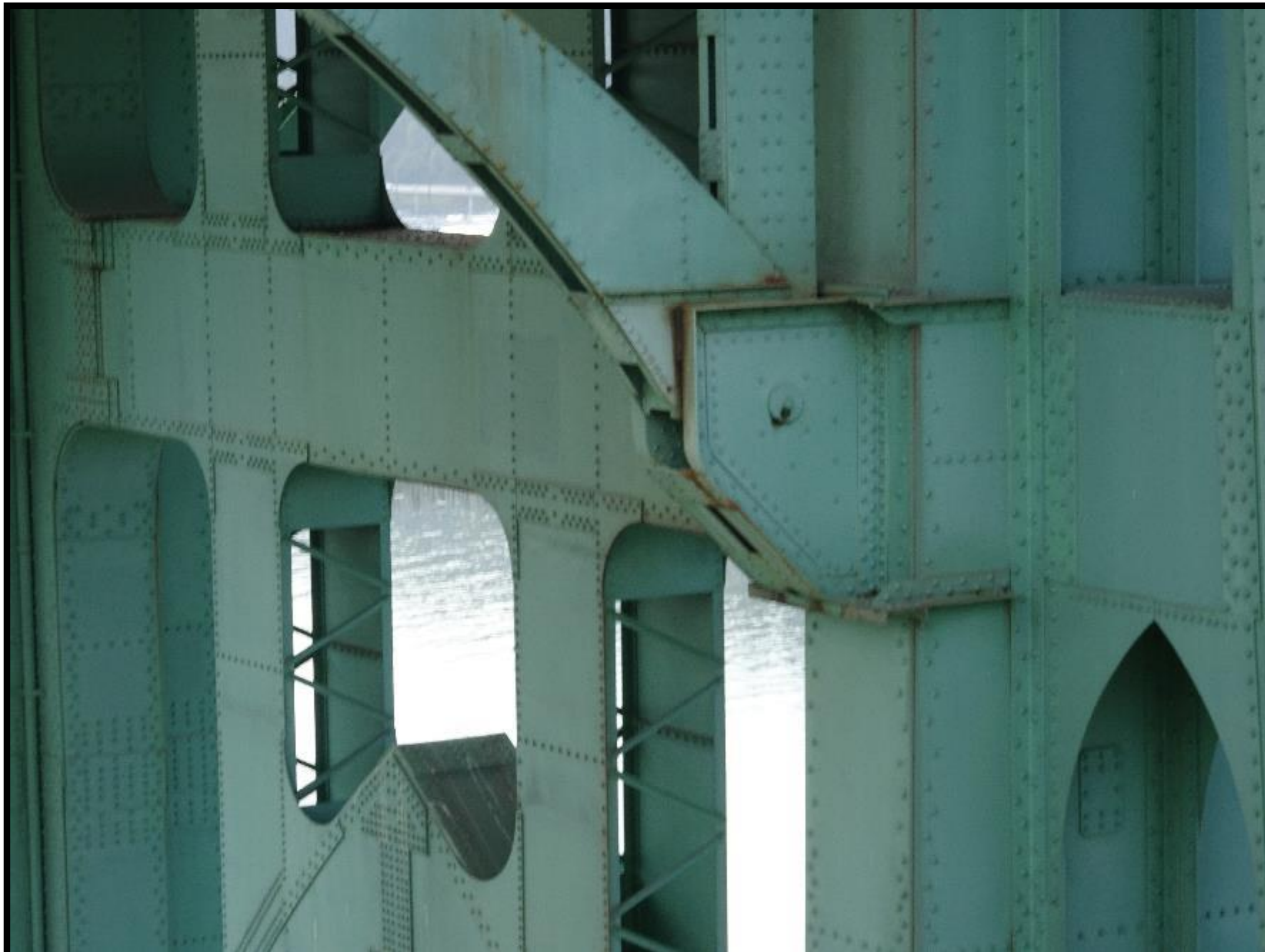
UAS Test Inspections Imagery

UAS Test Inspections Imagery

UAS Test Inspections Imagery

UAS Test Inspections Imagery

UAS Test Inspections Imagery

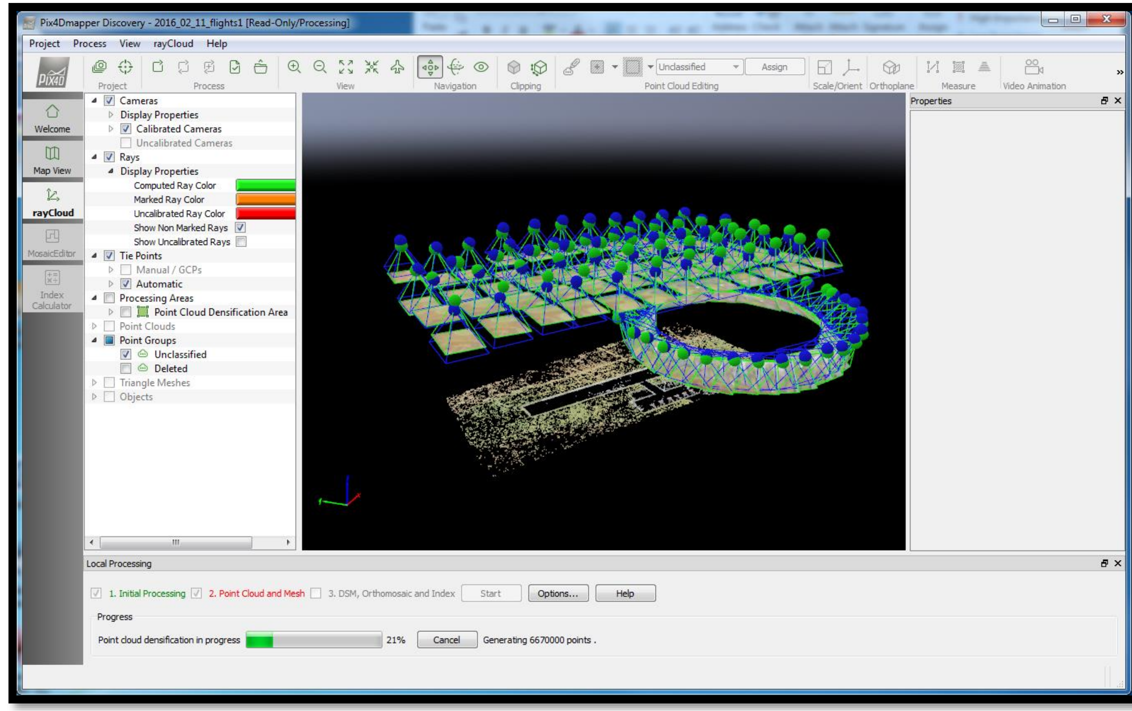


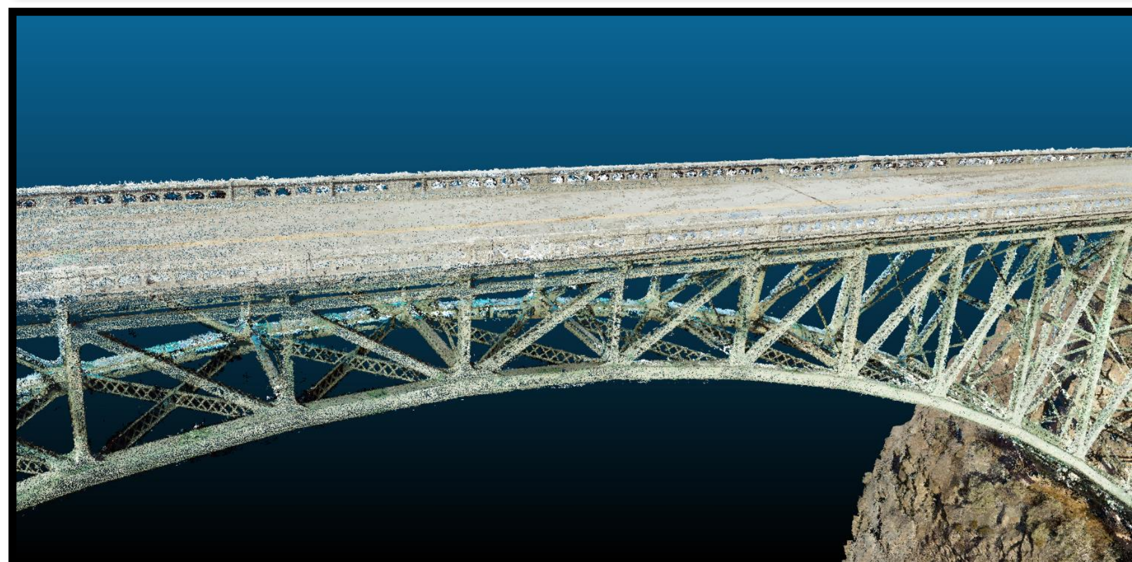
Structure from Motion (SfM)

- 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

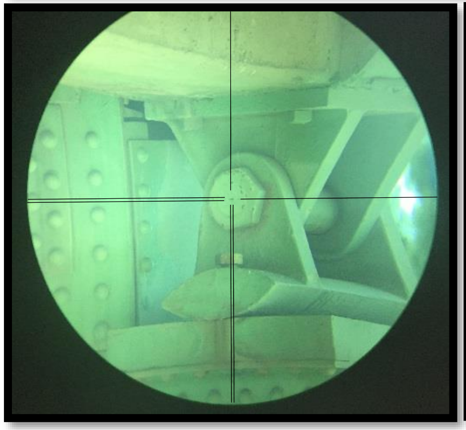
Structure from Motion (SfM)

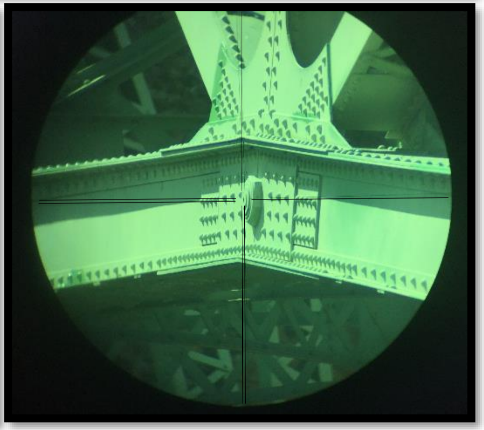
- Basic processing steps:
  - Image matching step
    - Algorithms, such as the scale invariant feature transform (SIFT) keypoint detector (Lowe, 2004)
  - Recovery of camera parameters and 3D reconstruction
  - Typically employs bundle adjustment
  - Dense point generation
  - Output products
    - Point clouds and orthoimages





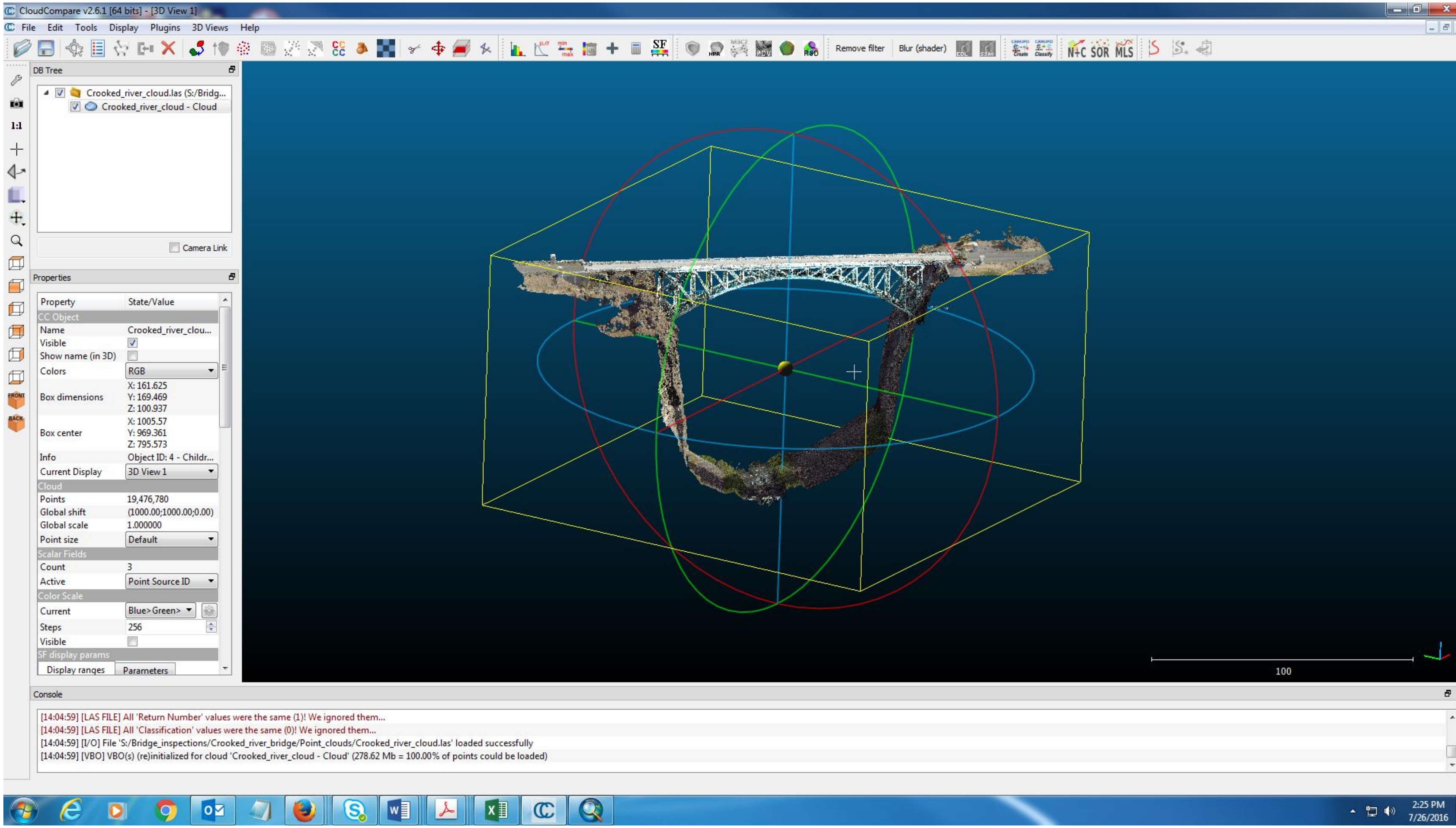
Ground control – photo targets for SfM



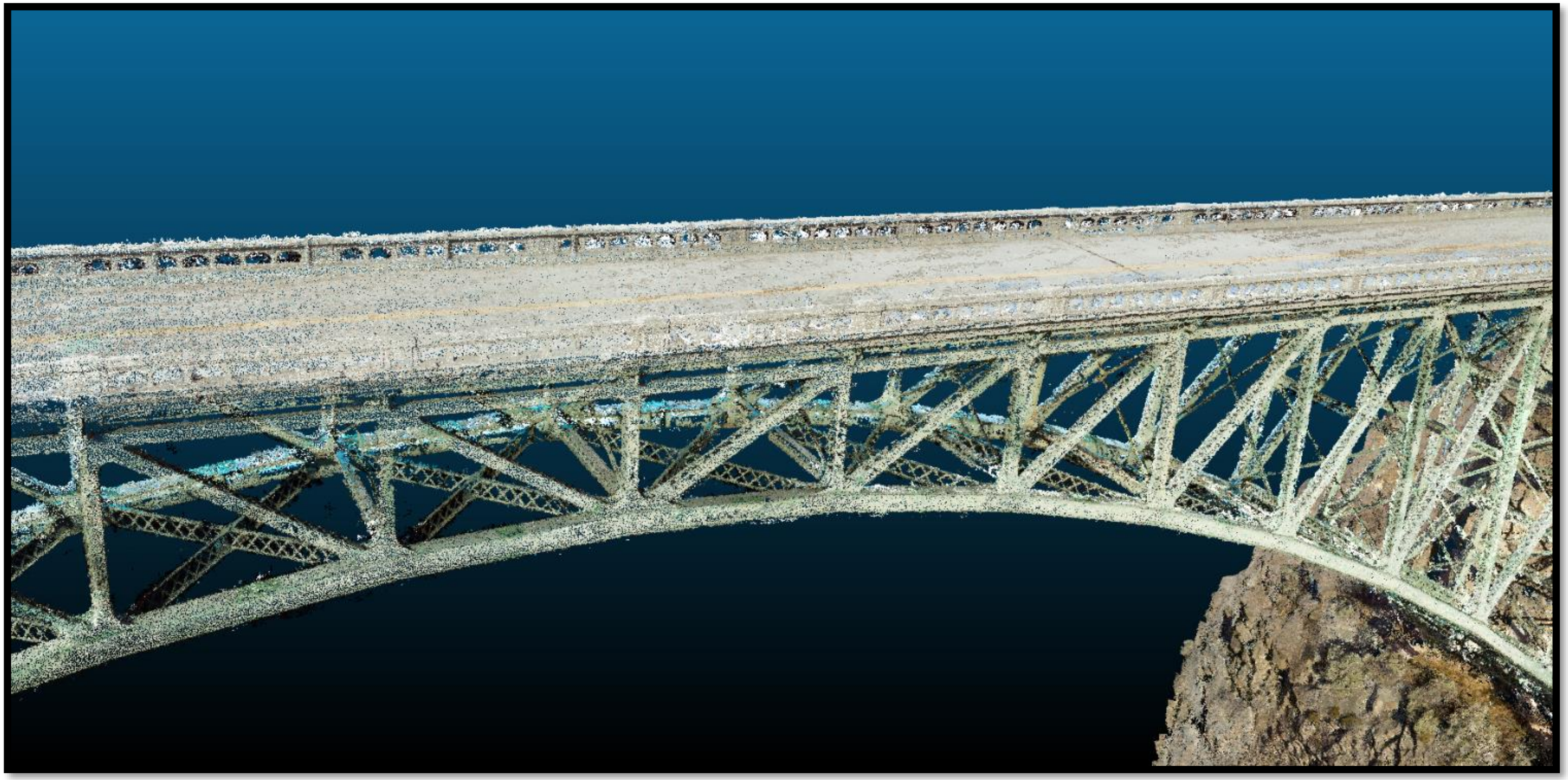


Crooked River Bridge Point Cloud: fly-through

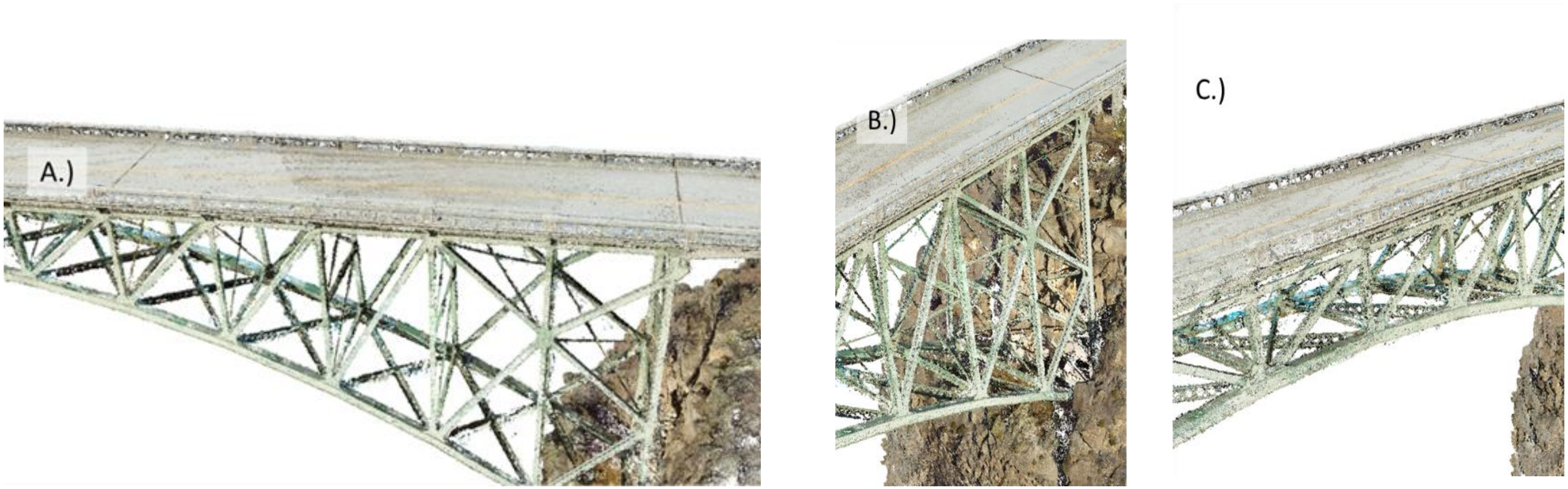
Point cloud of Crooked River Bridge

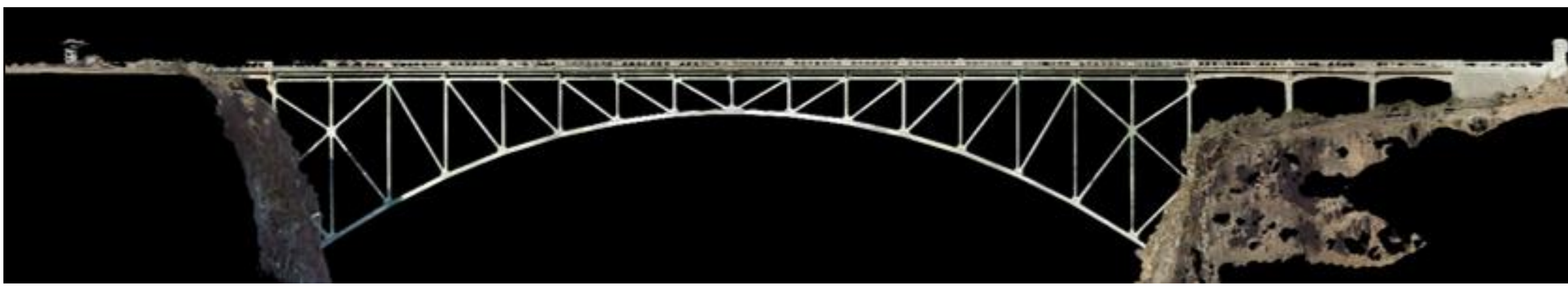


Point cloud of Crooked River Bridge



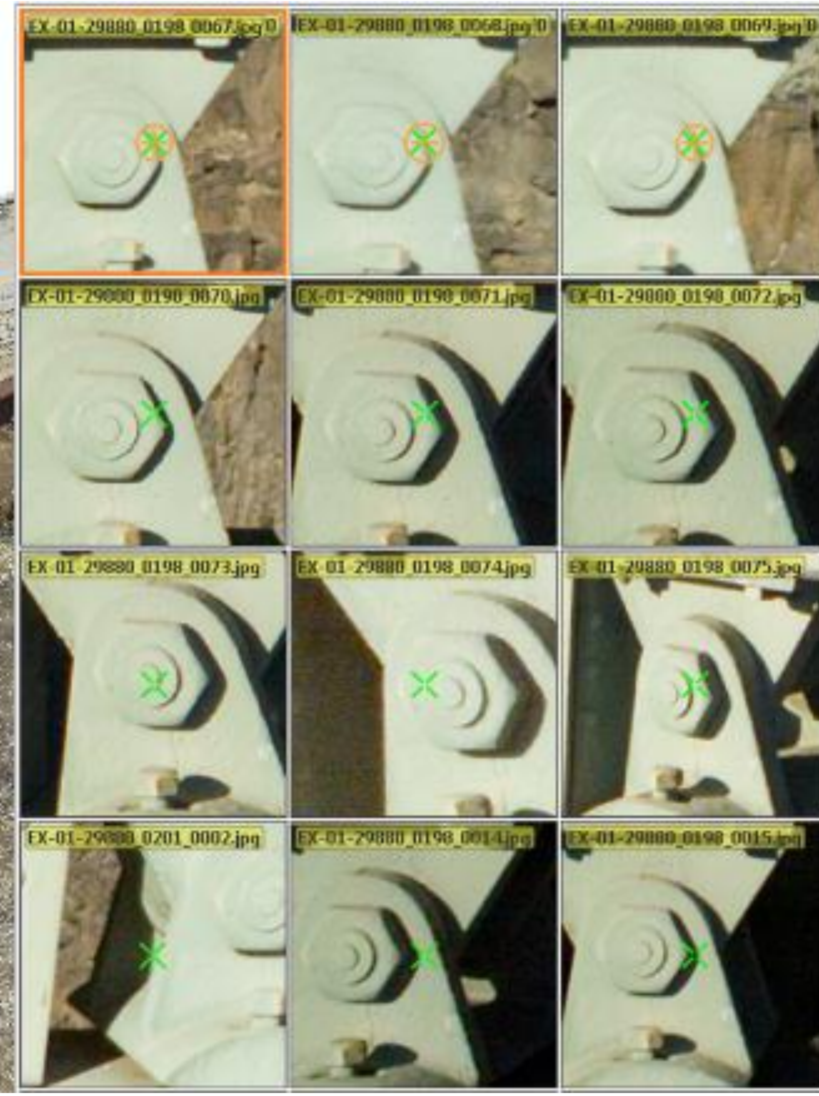
Orthophoto of Crooked River Bridge

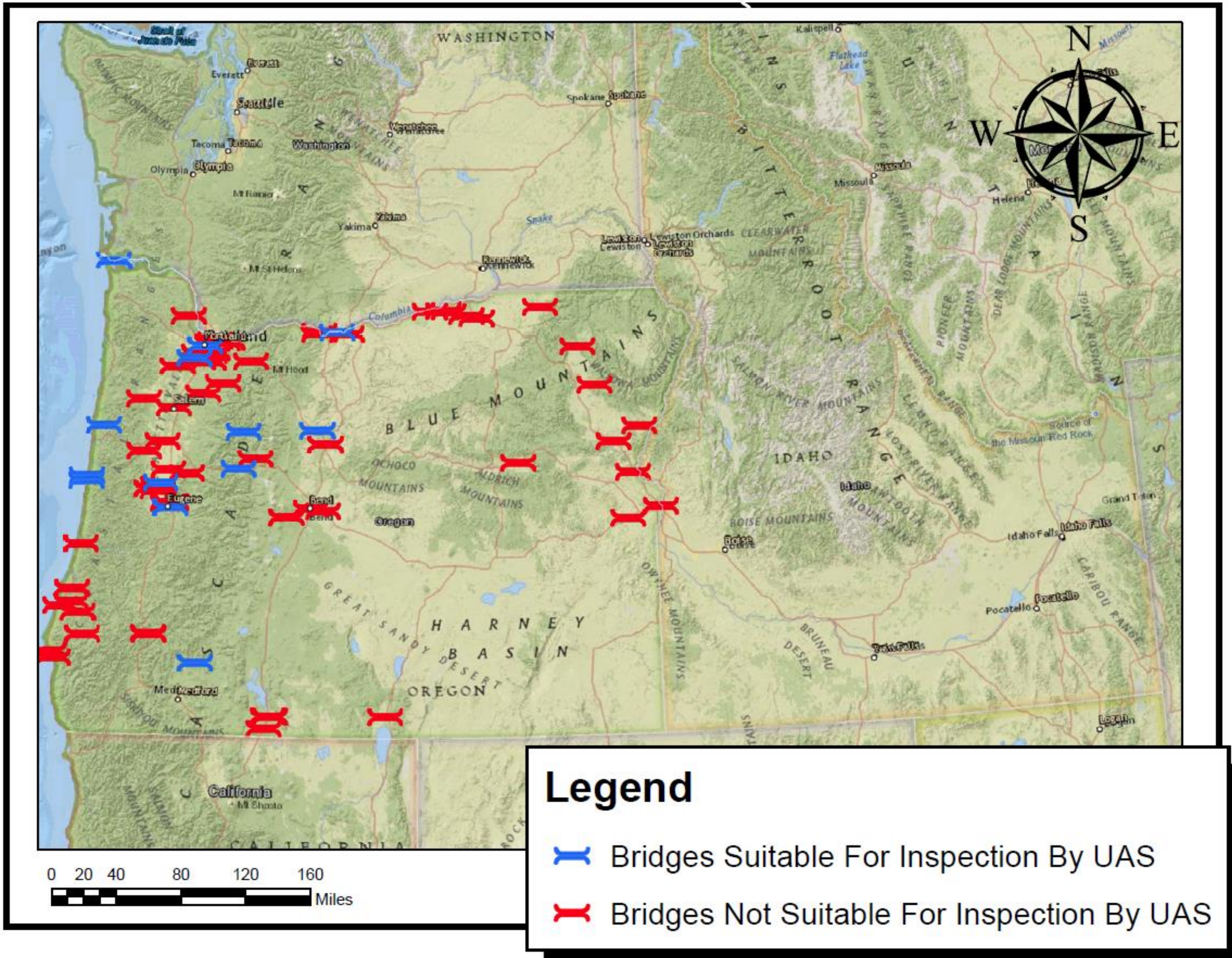




An orthophoto of the profile of the Crooked River Bridge produced from processing the images using SfM. (from Javadnejad et al. 2017, with permission)

Imagery Management




WASHINGTON
OREGON
IDAHO
BLUE MOUNTAINS
HARNEY BASIN
GREAT SANDY DESERT
OCHOCO MOUNTAINS
Seattle
Tacoma
Olympia
Everett
Spokane
Yakima
Portland
Salem
Eugene
Bend
Medford
Boise
Missoula
Helena
Idaho Falls
Pocatello
Twin Falls
California
N
S
W
E
0 20 40 80 120 160
Miles
Legend
Bridges Suitable For Inspection By UAS
Bridges Not Suitable For Inspection By UAS

Research Key Findings

- 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
- 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

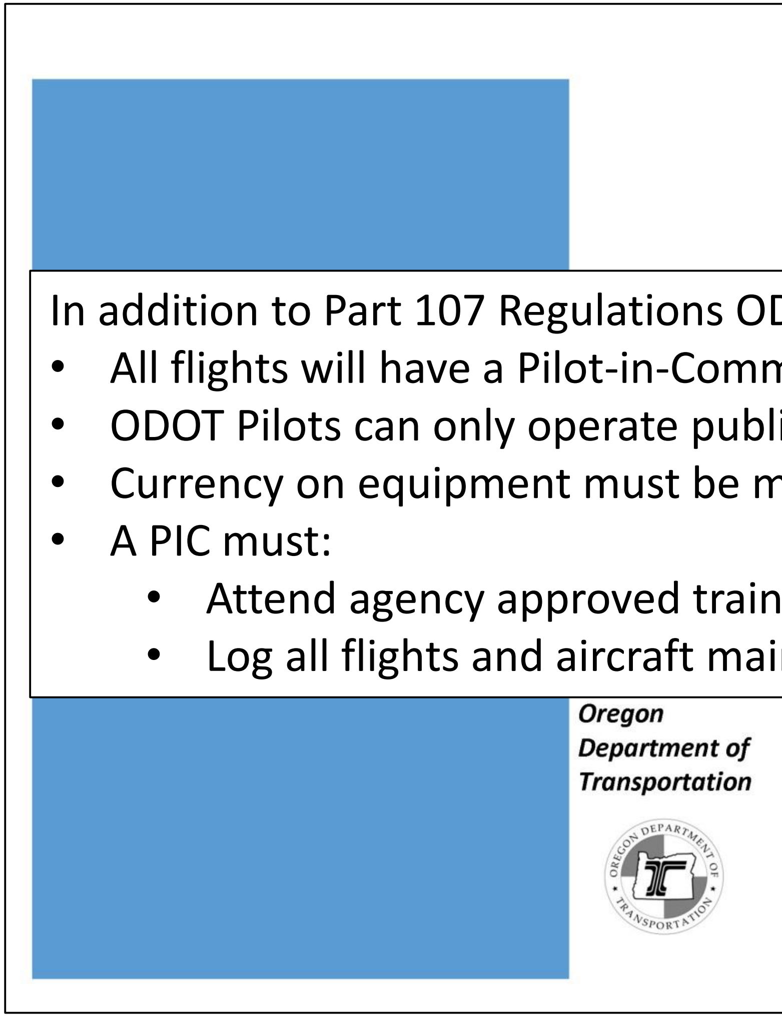
Acknowledgements

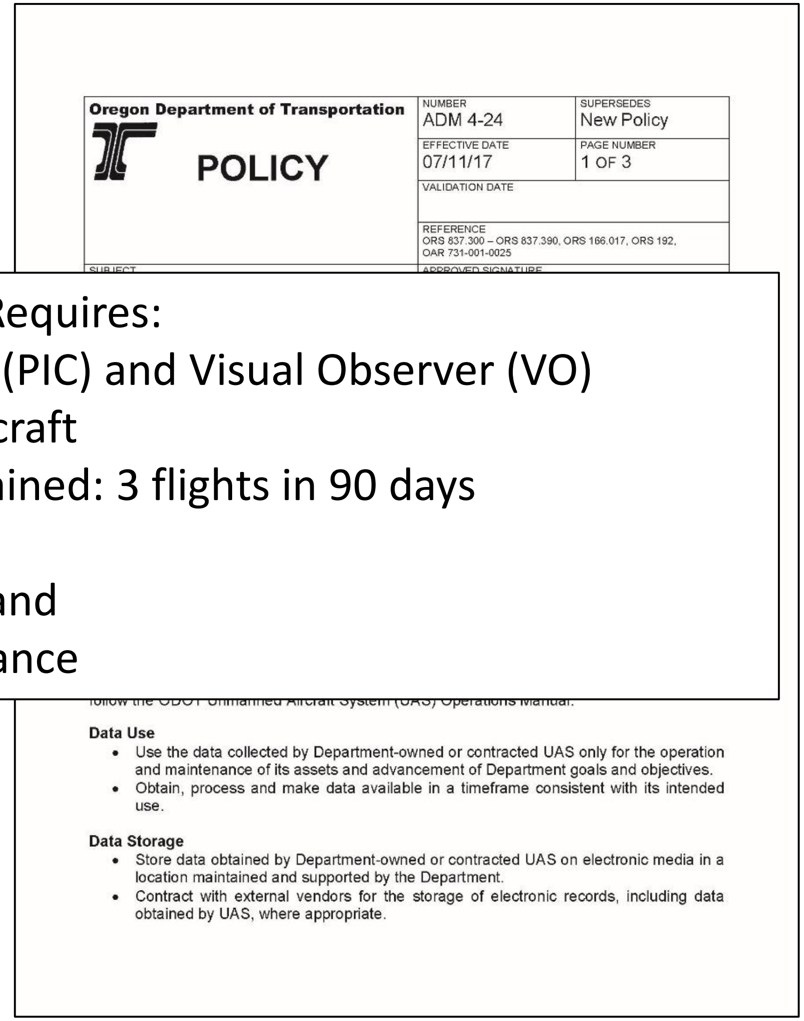
- ODOT and Pactrans funded this study
- Matt Gillins, OSU graduate student
- Erick Cain, ODOT bridge engineer
- Joe Li and ODOT TAC
- OSU graduate students Farid Javadnejad, Kory Kellum, and Richie Slocum assisted with UAS flights

ODOT UAS Program

In addition to Part 107 Regulations ODOT Requires:

- All flights will have a Pilot-in-Command (PIC) and Visual Observer (VO)
- ODOT Pilots can only operate public aircraft
- Currency on equipment must be maintained: 3 flights in 90 days
- A PIC must:
  - Attend agency approved training, and
  - Log all flights and aircraft maintenance


Oregon Department of Transportation



Oregon Department of Transportation POLICY	NUMBER ADM 4-24	SUPERSEDES New Policy
	EFFECTIVE DATE 07/11/17	PAGE NUMBER 1 OF 3
	VALIDATION DATE	
	REFERENCE ORS 837.300 – ORS 837.390, ORS 166.017, ORS 192, OAR 731-001-0025	

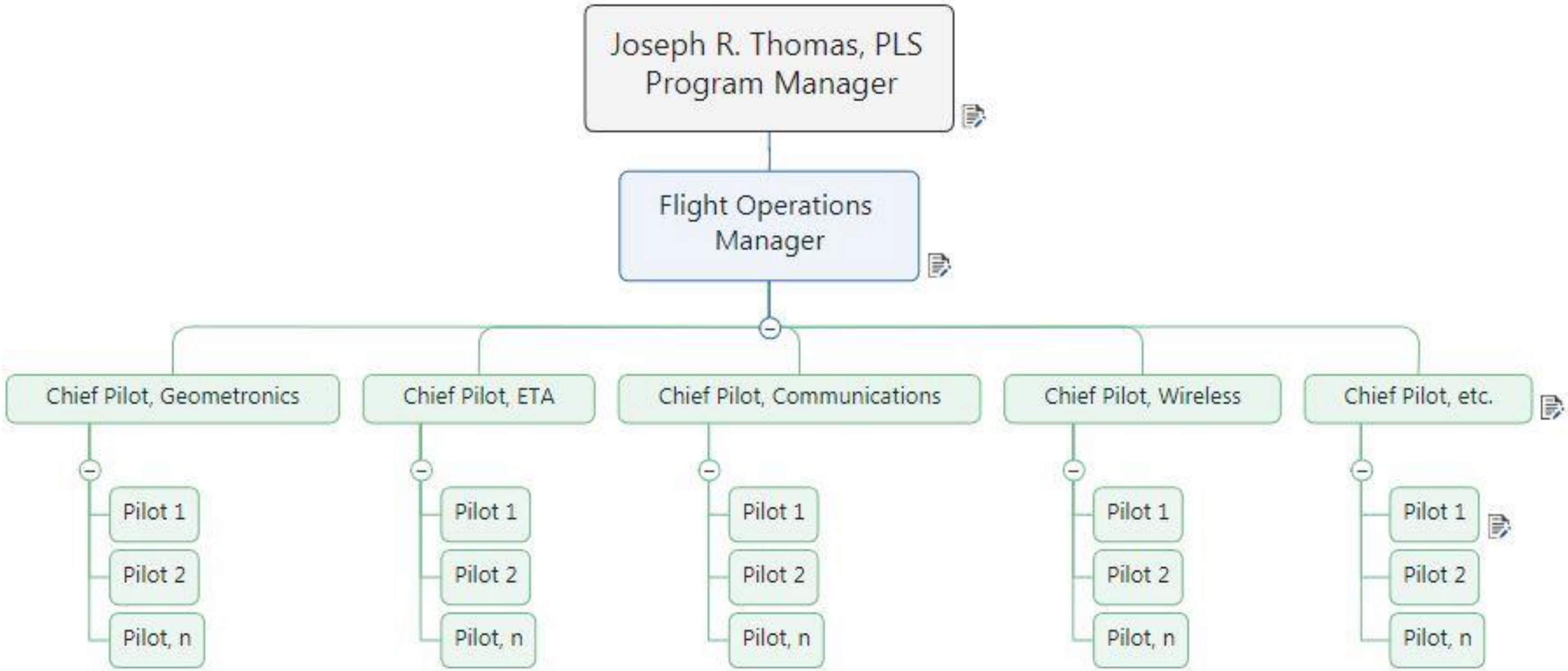
Data Use
- Use the data collected by Department-owned or contracted UAS only for the operation and maintenance of its assets and advancement of Department goals and objectives.
- Obtain, process and make data available in a timeframe consistent with its intended use.

Data Storage
- Store data obtained by Department-owned or contracted UAS on electronic media in a location maintained and supported by the Department.
- Contract with external vendors for the storage of electronic records, including data obtained by UAS, where appropriate.

ODOT UAS Program

- Pilots
  - 18 Certified Remote Pilots
    - Organized throughout ODOT's Regions
- Airframes
  - Aibotix Aibot X6V2 (Geometronics)
  - DJI Inspire 2 (Geometronics)
  - DJI Matrice 210 (Engineering Technology Advancement)
  - DJI Phantom 4 Pro (Engineering Technology Advancement)
  - GoPro KARMA (10) (ODOT Communications)
- Sensors
  - Sony A7R
  - Zenmuse X4S (2)
  - Zenmuse Z30

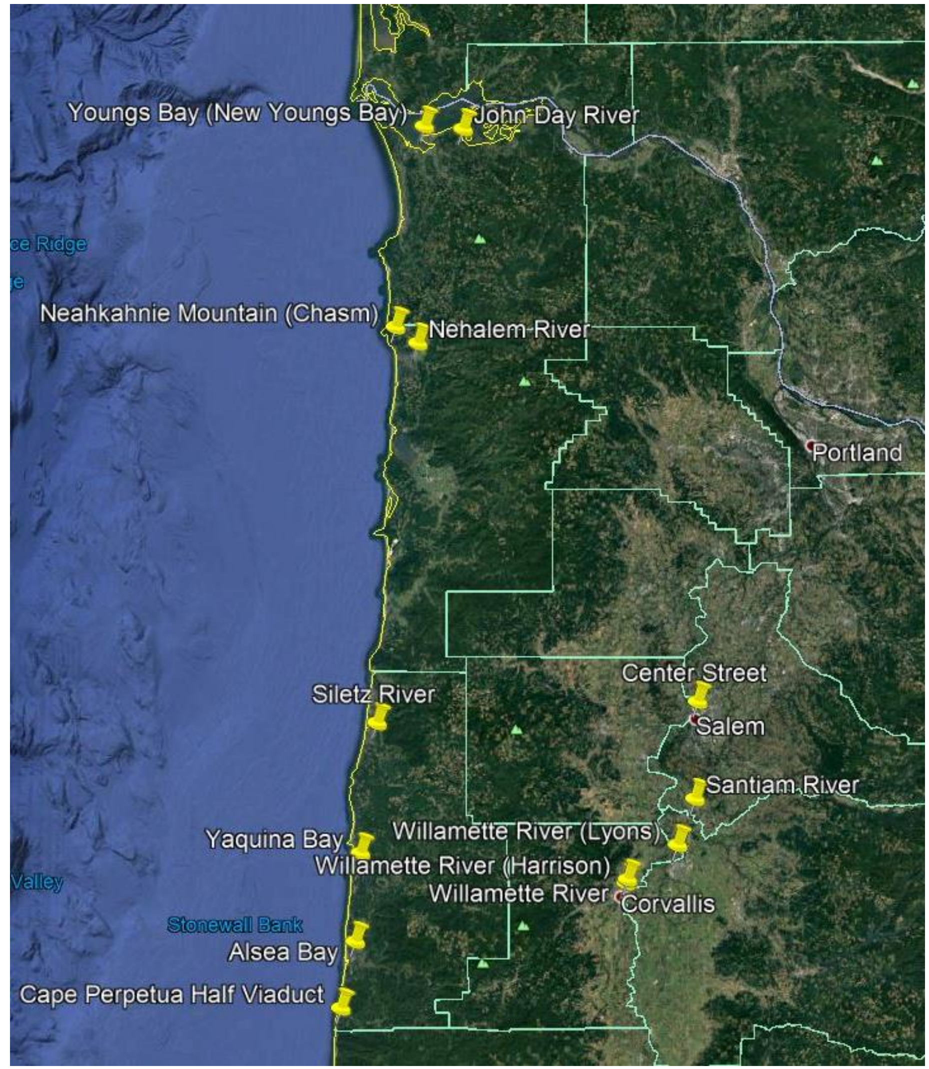
ODOT UAS Program



Building on OSU Research

Summer 2018

- 13 Bridges identified as test sites
- Focused in Region 2
- “Proving” OSU’s Research
- Members from Bridge and Engineering Automation Sections on research team



Next Steps

1. Can we fly the structure under rules defined in Part 107 and ODOT's UAS Operation Manual?
2. Review airspace for each structure and request FAA authorizations if necessary
   A. Three structures are in Class D airspace

(221)
1093
LUSARDI (Pvt)
205 - 22
717
(654)
SALEM
Center Street
FLY 'N' W (Pvt)
206 - 15
122.6
SALEM RCO
MC MINNVILLE
NOTAMs/Supplement
Class D eff hrs
(7S5)
institution
27
MCNARY (SLE)
CT - 119.1* C ATIS 124.55
213 *L 58 122.95
Class D excluded
below 1500' MSL
Independence
1449
(320)
ANKENY NATIONAL
WILDLIFE REFUGE
Turner
(Pvt)
FLYING E
325 - 23
TURNO
athlet
fie

Next Steps

1. Can we fly the structure under rules defined in Part 107 and ODOT's UAS Operation Manual?
2. Review airspace for each structure and request FAA authorizations if necessary
   A. Three structures are in Class D airspace
3. Identify equipment
   A. DJI Matrice 210 w/X4S and Z30

DJI Matrice 210

DJI Matrice 210

- Zenmuse X4S
    - 1” CMOS Sensor
    - 20 MP Stills (DNG, JPEG, RAW)
    - 4K Video (MOV, MP4)
    - 8.8mm F2.8 Lens
    - 6 Stop Dynamic Range
    - Mechanical Shutter

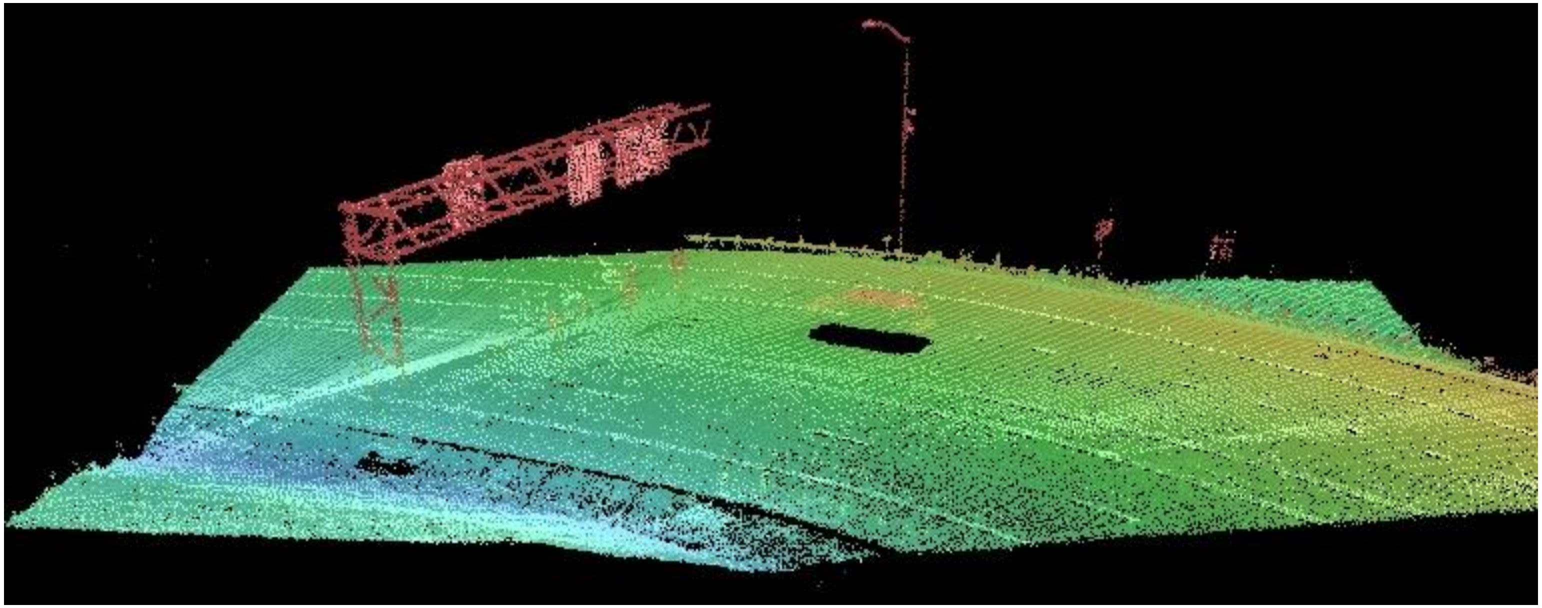
- Zenmuse Z30
    - 1/2.8” CMOS Sensor
    - 2.13 MP JPEG Stills
    - 1080 Video (MOV, MP4)
    - 30x Optical Zoom
    - Electronic Shutter
    - https://www.youtube.com/watch?v=bU6vlMrD32A

Next Steps

1. Can we fly the structure under rules defined in Part 107 and ODOT's UAS Operation Manual?
2. Review airspace for each structure and request FAA authorizations if necessary
   A. Three structures are in Class D airspace
3. Identify equipment
   A. DJI Matrice 210 w/X4S and Z30
4. Practice, practice, practice
   A. How does the equipment handle under a structure?
5. What does success look like?
   A. Can we see things with UAS that were impossible or difficult to see before?

Additional UAS at OSU: Transportation System Monitoring

- Investigate UAS-based lidar for detection & monitoring of transportation networks system.
- Use deep learning to process point clouds and extract features of interest.

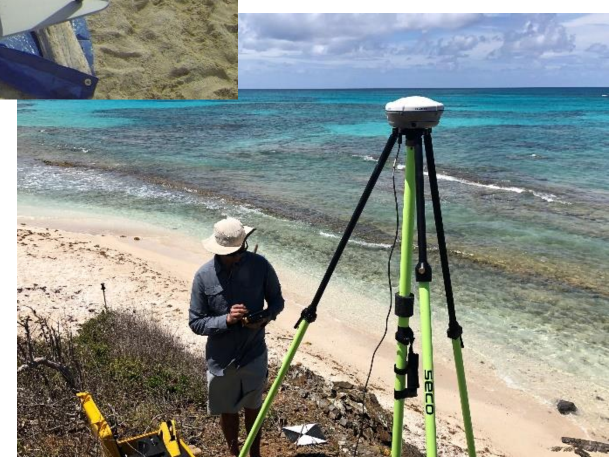


Additional UAS at OSU : Shallow Bathymetric Mapping

- Investigate UAS-based SfM for mapping bathymetry in coastal environments.

- Develop standard operating procedures for optimal data collec and processing

Buck Island, U.S. Virgin Islands – Richie Slocum

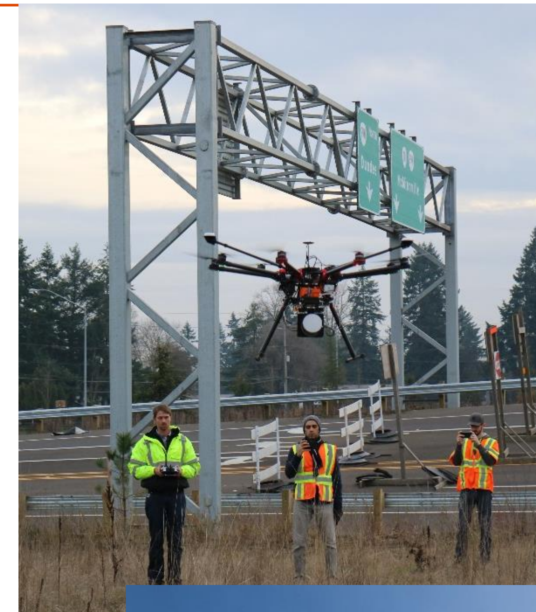


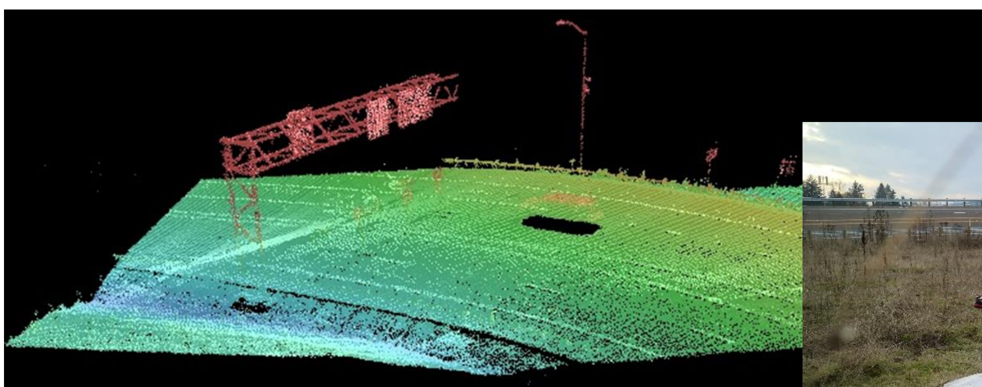
UAS in Transportation Expo

July 30th – 31st, 2018

Topics to include:

- UAS applications in transportation
- How to initiate a UAS program within a transportation agency/organization
- Flight Demonstration
- Hands on data processing workflow





For more info: blogs.oregonstate.edu/uasintransportation/

Questions?

Final Report Available here:
http://www.oregon.gov/ODOT/Programs/ResearchDocuments/SPR787_Eyes_in_the_Sky.pdf