3D Reconstruction using Small UAVs

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Keck INSTITUTE FOR SPACE STUDIES CALIFORNIA INSTITUTE OF TECHNOLOGY JET PROPULSION LABORATORY

C-UAS CENTER FOR UNMANNED AIRCRAFT SYSTEMS

NSF

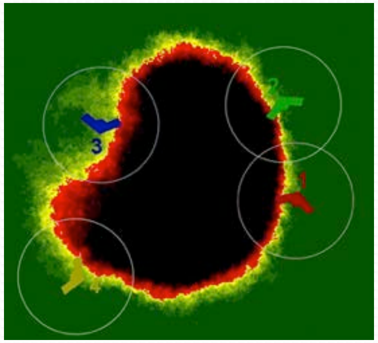
BRIGHAM YOUNG UNIVERSITY FOUNDED BYU 1875 PROVO, UTAH

What does “drone” bring to mind?

Center for Unmanned Aircraft Systems (C-UAS)

- http://c-uas.byu.edu/
- Sponsored by National Science Foundation under I/UCRC program *and* industry members
- Two universities currently involved:
  - Brigham Young University
    - Tim McLain, Randy Beard, Mike Goodrich, Eric Mercer, Karl Warnick, John Hedengren, Kevin Franke
  - University of Colorado
    - Eric Frew, Brian Argrow
- Virginia Tech and University of Sydney will be joining us very shortly

Center for Unmanned Aircraft Systems (C-UAS)



Cooperative Control

- Cooperative timing problems
- Cooperative persistent imaging
- Cooperative fire monitoring
- Consensus seeking

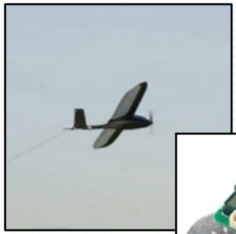
Path Planning
Trajectory Generation

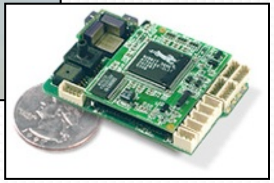
- 3D Waypoint path planning
- Wind compensation
- Collision avoidance
  - Optic flow sensor
  - Laser ranger
  - EO cameras

Image Directed Control

- Image stabilization
- Geo-location
- Vision-aided tracking & engagement

Autonomous Vehicles





- Autopilot design for small UAVs
- Attitude estimation
- Adaptive control
- Tailsitter guidance & control

Guiding Objective

Develop enhanced autonomous capabilities for small unmanned aircraft

Develop and utilize:

- Novel custom sensors
- COTS sensors
- Autonomy algorithms appropriate for computational resources
- Useful applications that improve our engineering capabilities

Goal: Approximate large UAS capabilities with low-cost, small UAS

C-UAS Research Thrust: Infrastructure Monitoring

- Investigate new ways to use sUAVs and various sensors to achieve specific objectives related to the monitoring and inspection of our infrastructure
  - Automated data collection, monitoring, inspection
  - Anomaly recognition and detection
  - Improved safety
  - Lower costs, improved data
  - Better modeling techniques
- Initiated in early 2013

Our Current sUAV Platforms:

Rightwing 81" ZXL (a.k.a. "Big Bird")

- 81" wingspan (very stable!)
- Can fly in 45+ mph winds
- Carries GoPro Hero 3
- Flies at 35-65 mph
- Flight time is 10-20 minutes

Draganfly X-4 Quadcopter

(Before Crash...)

(After Crash...)

- 4 rotor system
- Very mobile, but squirrely in wind
- Carries GoPro Hero 3 or Panasonic still
- Flies at 0-35 mph
- Flight time is 10-20 minutes

DJI Phantom 2 (a.k.a. "Gus")

- 4 rotor system
- Very stable flight, but no contingency
- Very transportable
- Carries GoPro Hero 3, Hero 3+
- Flies at 0-35 mph
- Flight time is 10-20 minutes

Our Current sUAV Platforms:

Skyjib 6 (a.k.a. "Captain America")
(custom built)

- 6 rotor system
- 360-degree gimbled camera
- GPS waypoint-programmable
- Moderately difficult to transport
- Stable flight with some contingency
- Can carry full-size DSLR camera
- Flies at 0-35 mph
- Flight time is 10-20 minutes

DJI S1000 (still needs a name!!)

- 8 rotor system
- 360-degree gimbled camera platform
- GPS waypoint-programmable
- Quite difficult to transport
- Stable flight with some contingency
- Can carry multiple sensors (e.g., GoPro & LiDAR)
- Flies at 0-35 mph
- Flight time is 10-20 minutes

sUAV Platforms in Action

Recent project funded by a large oil/gas firm

Current Research Effort: Sub-centimeter measurement accuracy with SfM Computer Vision

Objective: Achieve sub-cm measurement accuracy of model objects using only SfM computer vision with images obtained from a sUAV.

Methods: (1) Investigate different platform types

(2) Investigate different camera types

(3) Include metadata in the SfM processing

(4) Optimize image capture

Conditions: (1) Must use COTS SfM software

(2) Fly under FAA recreational provisions

Effect of Different Platforms on Model Quality

Fixed wing model

Quadrotor model

- We are experimenting with different aerial platforms to investigate the amount of improvement in a computer vision model that can be obtained.
- Noticeable difference in the model qualities….sharper resolutions and ~10% improvement in distance accuracy
- Interpretation: UAV "staring" can drastically improve the 3D reconstruction

Evaluation of Camera Types

GoPro Hero 3:

Pros: Lightweight, HD video, continuous still frame shooting, tough as nails

Cons: *only* 12MP resolution; battery life; fisheye lens distortion in large computer vision models; no metadata

Evaluation of Camera Types

GoPro Hero 3+ and new lenses:

5.4mm flat lens

50mm flat telephoto lens

Pros: No more fisheye; potential to get very high resolutions (~0.2cm^2/pixel)

Cons: sensors are heavier and off-balance; stabilization gyros don't work; proper focusing; no metadata

Evaluation of Camera Types

Sony NEX-5R Digital Camera:

Pros: Decent resolution (16MP) and HD video

Cons: Heavy sensor; no automated continuous shooting mode; no metadata

Evaluation of Camera Types

Nikon D7100:

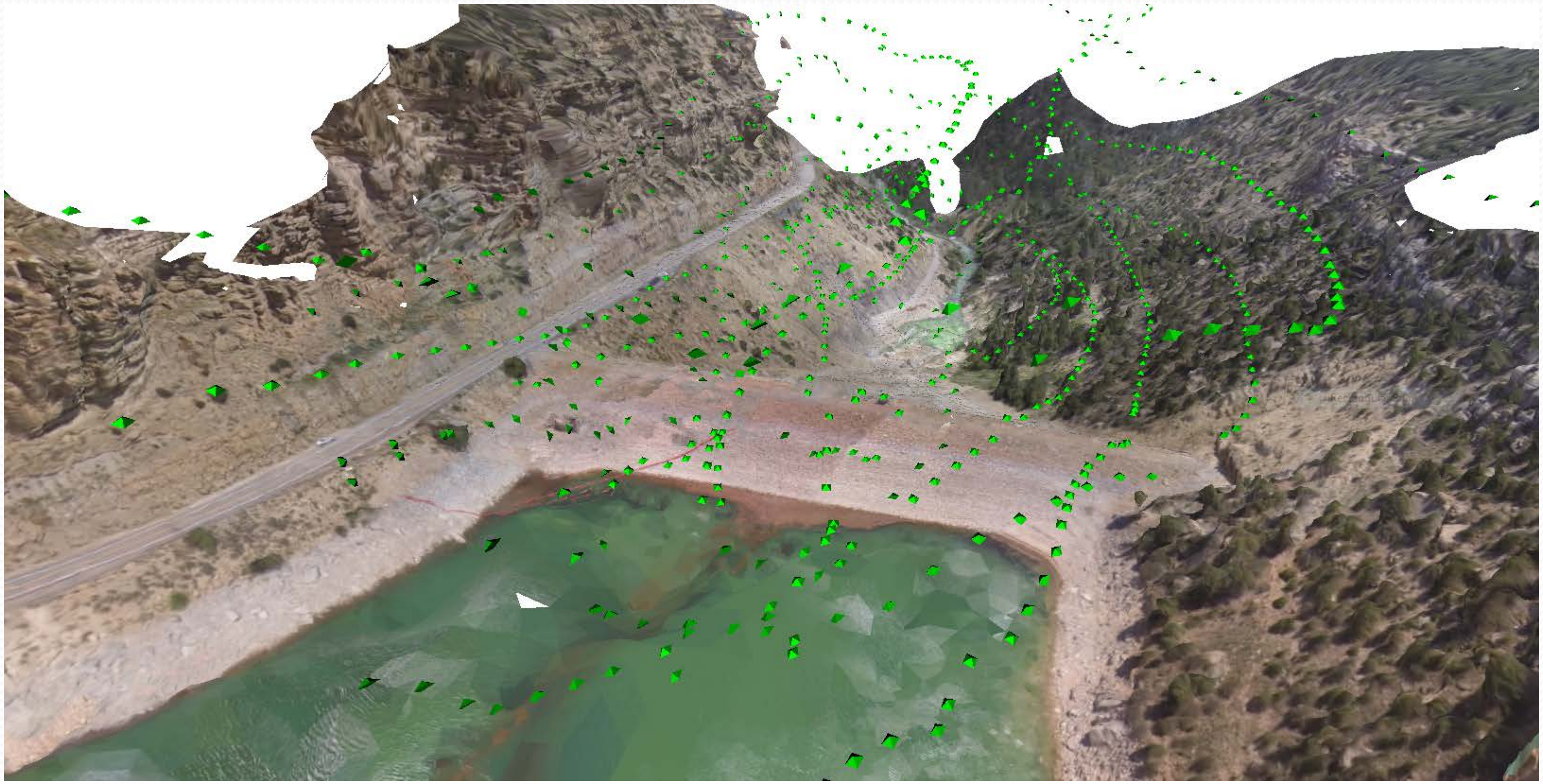
Pros: Much higher resolutions (24MP, RAW images); potential to tag photos with metadata; potential to add telephoto lenses to improve resolution

Cons: Heavy sensor; only compatible with a “heavy-lift” UAV system

Arthur V. Watkins Dam
Long, Semi-Linear Structure

- Dam is 36 feet high
- We flew 7 miles of the dam in about 12 minutes
- Model contained heavy distortion due to our GoPro fisheye lens

Joe's Valley Reservoir Dam
Large, finite object; terrain anomalies of interest



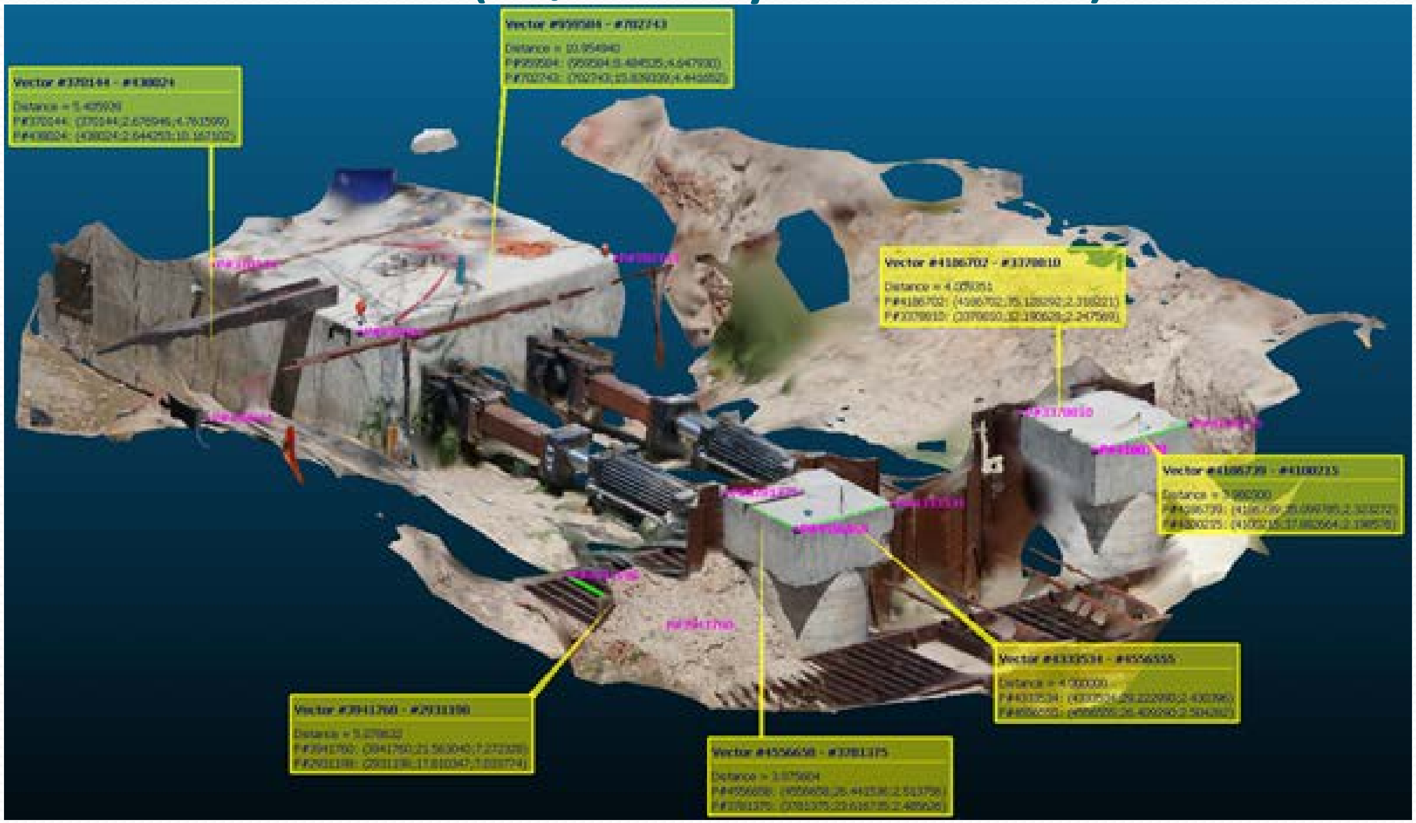
- Dam is about 750ft wide and 187ft high
- Located in Emery County southwest of Price
- Measurement accuracy is between 30-40 cm

Little Cottonwood Canyon Rockfall
Large geological object, difficult to inspect

- Over 750 feet high
- We were able to collect all necessary images in less than an hour
- Poor weather and a software glitch resulted in the crash of our UAV

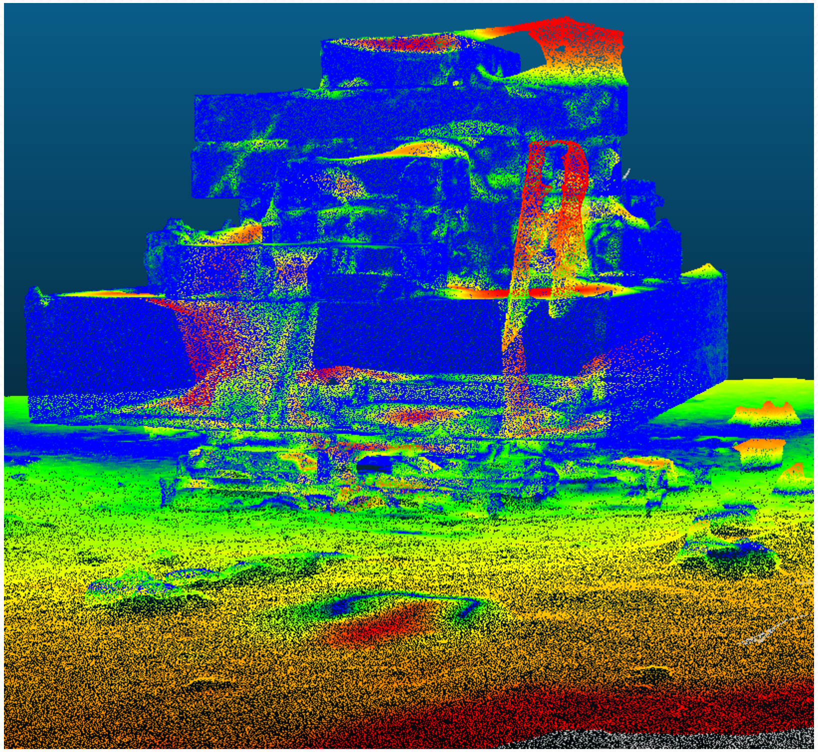
Salt Lake Airport Pile Load Tests

Small infrastructure objects, accurate measurements (w/Dr. Kyle Rollins)



- Two large actuators pushing a large pile cap supported by six piles
- Located adjacent to the Salt Lake Airport
- Handheld Sony NEX-5R camera took over 100 images in less than 3 minutes
- Model measurement accuracy within 2.5cm (1 in)

New Zealand Pile/Liquefaction Test
Small infrastructure objects, accurate measurements (w/Dr. Kyle Rollins)



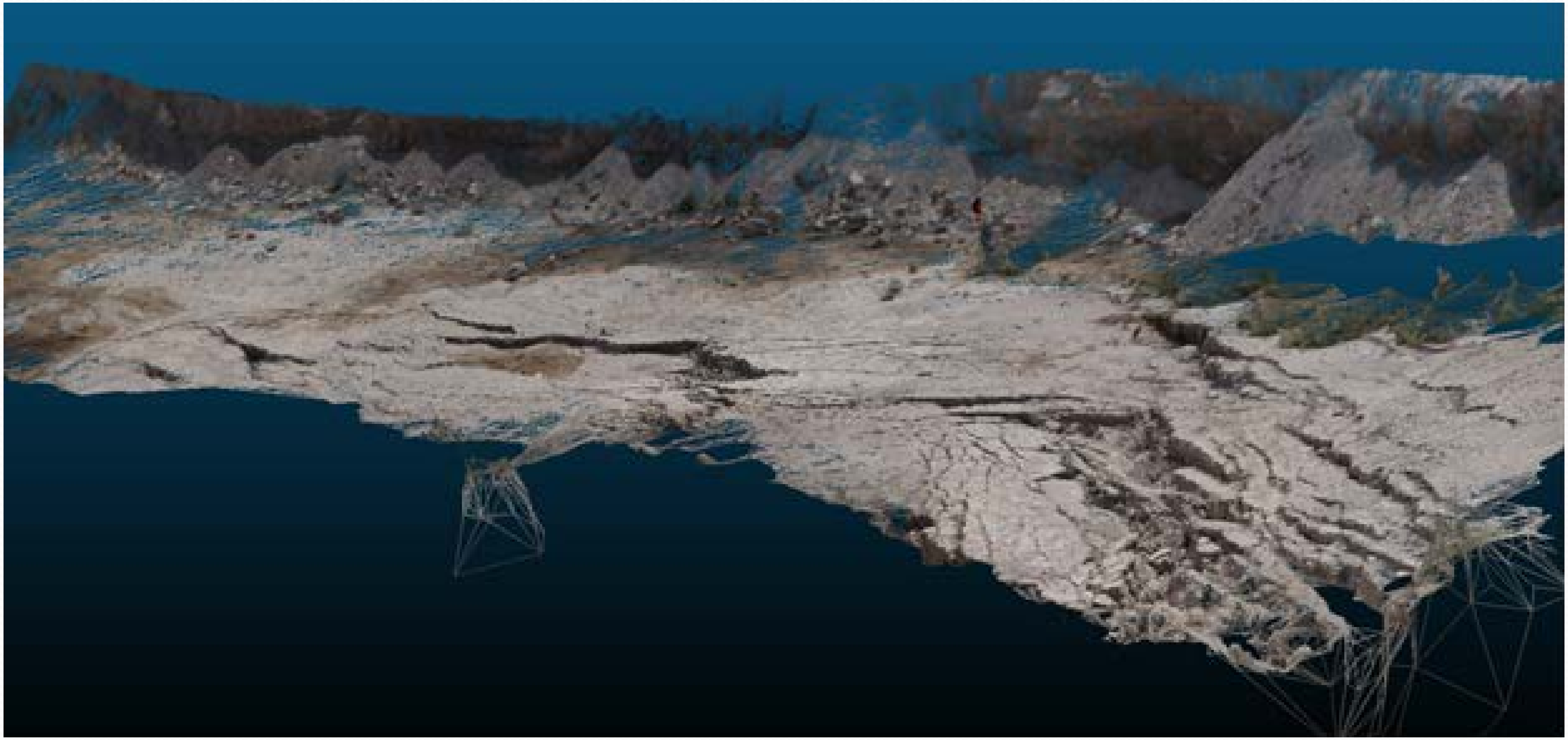
- Loaded piles in blast-induced liquefied soil; soil settlements on the order of several inches were induced
- Handheld Nikon D7100 captured ~650 images in less than 10 minutes
- Pile settlement measurement errors were less than 8 mm

Rock Outcrop Modeling Application
Recent project funded by a large oil/gas firm

- Recently flew a geologically significant rock outcrop in Utah
- Our sUAV models are still being processing, but here is a screenshot
- sUAV-based Nikon D7100 located approximately 1000 ft from cliffs
- Point cloud density of the base model is approximately 3-cm. Model measurement error is less than 0.15% (<6.5 cm)

Geotechnical Earthquake Engineering Reconnaissance

Here are some screenshots of handheld CV models of liquefaction damage from 2014 Chile



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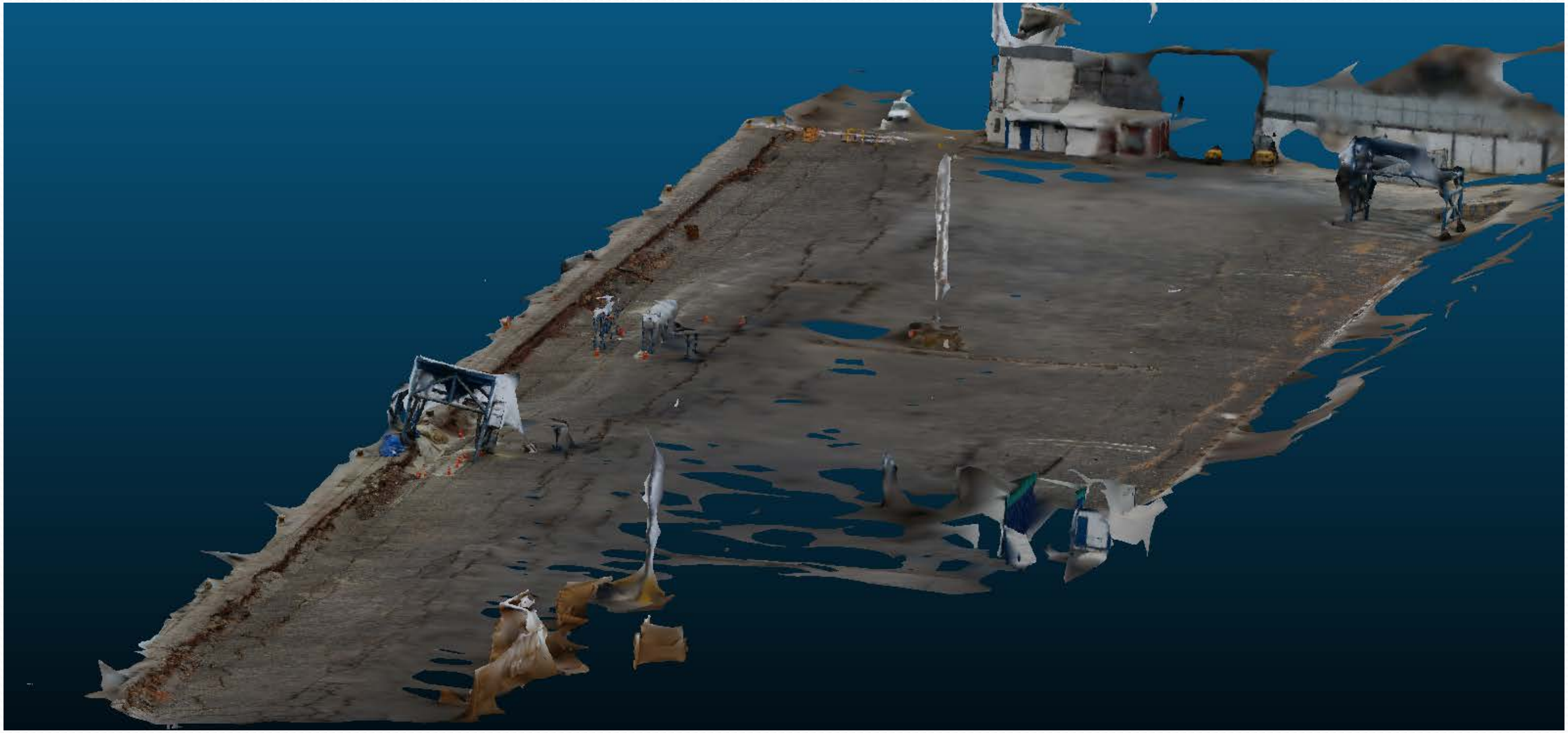

Questions/Comments for workshop to consider:

- Due to its proximity, sUAVs can be used to develop high resolution models using low-cost equipment and sensors.
- Imagine what could be done with high-cost equipment!
- Some objects do not lend themselves well to space-borne remote sensing (e.g., beneath bridges, outcrop overhangs). Could sUAVs be a potential solution for modeling these types of objects?
- How can UAVs compliment space-borne remote sensing?
- sUAVs have many advantages, including low cost, easy maintenance, portability, and rapidity.
- sUAVs have three major obstacles: legality of flight, poor endurance, and weather limitations