Applying Structure-from-Motion to Airborne Snow Observatory imagery from SnowEx Year 1 to build high resolution surface models

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Background

• Structure from Motion
  • A photogrammetric method that uses overlapping 2d images to estimate the 3d structure of an area or object
Background

• Structure from Motion
  • Flexible and scalable depending on desired target, camera functionality, and platform

Fire Hydrant: ~20 pictures (person + smartphone)
Atwater Study Plot: ~100 pictures (DJI Phantom 2 + Sony A5100)
Senator Beck Basin Domain: ~350 pictures (King Air A90 + Phase One A/S iXU180-R)
SfM and Snow: Motivation

- Same concept as differential mapping with lidar
  - Low cost and effective (lidar is expensive, cameras are cheap)
- Rapidly advancing UAV technology
- High resolution lidar from space vs high resolution imagery from space

Google Earth; 2006

Google Earth; 2016
SfM and Snow: Challenges

- Vegetation
- Illumination
- Surface structure (or lack thereof)
SfM and Snow/Ice: Previous Work

AK Arctic, manned: *Nolan et al.*, 2015

Canadian prairies and mountains, unmanned: *Harder et al.*, 2016

Himalaya glaciers, spy imagery & ASTER: *Maurer et al.*, 2016
Case Study: Atwater Study Plot, LCC, UT

Salt Lake City, Utah

Little Cottonwood Canyon

Atwater Study Site

3000 m² (~1 acre)
Case Study: Atwater Study Plot, LCC, UT

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Ground control point locations
Case Study: Atwater Study Plot, LCC, UT

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- Elevation Profile across the DSM March 7\textsuperscript{th}, 2017
Case Study: Atwater Study Plot, LCC, UT

Orthophoto
March 7th, 2017
Case Study: Atwater Study Plot, LCC, UT

Orthophoto
March 7th, 2017

Hillshade
March 7th, 2017
Case Study: Atwater Study Plot, LCC, UT

Total Snow Depth
March 7th, 2017

New Snowfall
(March 4th - 7th, 2017)

We crashed the UAV.
Case Study: Atwater Study Plot, LCC, UT

Total Snow Depth
March 7th, 2017

New Snowfall
(March 4th - 7th, 2017)

Low Positional Error (< 3cm vertical)
Very High Point Density (> 1 million points)
Millimeter Scale Resolution (~4 mm)
Accurate depth (rmse 5 cm)

We crashed the UAV.
Scaling Up: ASO and SfM

• Plot scale $\rightarrow$ watershed scale (e.g. 1 acre to 1000 acres)

• RGB camera integrated with lidar unit (separate from CASI imaging spectrometer)

• Because flight lines are optimized for the CASI there is sidelap built in

• Acquisition timing is manually set, so frontlap can be optimized
Scaling Up: ASO and SfM

• Status quo for ASO: snow depth from lidar, RGB/classification/albedo (++) from imaging spectrometer

• The integrated Phase One medium format 100 mp RGB is intended to colorize the point cloud

• Here, I show you can also use the imagery to build DSMs via SfM
Surface Model: SBB 2/16

- Image tie points, 100 images
- 12 sec acq rate
Surface Model: SBB 2/16

- Dense cloud, > 7 million points
Surface Model: SBB 2/16

- 3d model
- Orthophoto
Surface Model: SBB 2/21

- Image tie points, 373 images
- 5 sec acq rate
Surface Model: SBB 2/21

- Dense cloud, >14 million points
Surface Model: SBB 2/21

- < 0.5 m resolution
- DSM

- Coming soon! Comparison to ASO dem, SfM snowdepth, validation of snow depth with ASO & ground measurements

SfM DSM difference 2/21 – 2/16
Caveats

• Cameras are cheap, but this camera is built into the ASO lidar unit, and therefore takes advantage of the IMU for orthorectification (for snow depth positional accuracy is paramount!)

• For SnowEx ASO was collecting in high resolution mode- flying closer to the surface and with flight lines spaced closer together- under normal operating procedure the dense point clouds might not be quite this dense (more testing to come in the Tuolumne)
Looking Forward: Do we need lidar?

• Yes.
• SfM has some important limitations, namely vegetation and acquisition restriction to daylight hours (unknown density → SWE)
• There is great promise is combining SfM and lidar to improve point cloud density (and fill in for each other if one fails) and produce sharp colorized point clouds at higher resolution than combining the lidar and imaging spectrometer RGB
• It depends.
• If you are interested in differential snow depth mapping outside of areas with dense canopy, SfM is a great alternative to lidar
• Spaceborne capabilities of imagery vs. lidar
Questions?

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