Structure-from-Motion

Chris Crosby (UNAVCO)
with content from Ed Nissen, Ramon Arrowsmith, Kate Shervais, Chelsea Scott

- Choice of survey platform
- Acquisition concepts
- Exercise

~500 points/m² coloured point cloud along a ~1 km section of the 2010 El Mayor-Cucapah earthquake rupture generated from ~500 photographs captured in 2 hours from a helium blimp
<table>
<thead>
<tr>
<th>Photo characteristics</th>
<th>Survey considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Camera focal length</td>
<td>• Angle of photographs</td>
</tr>
<tr>
<td>• Camera sensor size</td>
<td>• Overlap between photographs</td>
</tr>
<tr>
<td>• Aspect ratio of photograph</td>
<td>• Platform</td>
</tr>
<tr>
<td>• Effective megapixels of camera</td>
<td>• Targets/GPS</td>
</tr>
<tr>
<td>• Distance between camera and feature</td>
<td>• Surface texture</td>
</tr>
<tr>
<td>• Scale of feature</td>
<td>• Lighting</td>
</tr>
</tbody>
</table>
SfM from Unmanned Aerial Vehicles (UAV)

- DJI Phantom 4 Pro quadcopter (~$1500)
- DJI Mavic Pro (~$1k)
- Pulse Aerospace Vapor (>$50k)
- senseFly eBee (~$10k)
SfM from Unmanned Aerial Systems (UAS)

**Pros**

- App-based survey design effectively automates data collection.
- Reasonably affordable, easy to fly.
- Camera quality ok.

**Cons**

- Subject to FAA regulations (Part 107) + state and local constraints.
- Short flight durations.
- Crashes are not uncommon.
- Limited payload capacity. Larger cameras require a larger, more expensive UAS.
Fact Sheet – Small Unmanned Aircraft Regulations (Part 107)

For Immediate Release

June 21, 2016
Contact: Les Dorr or Alison Duquette
Phone: 202-267-3883

The new rules for non-hobbyist small unmanned aircraft (UAS) operations – Part 107 of the Federal Aviation Regulations (PDF) – cover a broad spectrum of commercial uses for drones weighing less than 55 pounds. Here are the highlights of the new rule.

Operating Requirements
The small UAS operator manipulating the controls of a drone should always avoid manned aircraft and never operate in a careless or reckless manner. You must keep your drone within sight. Alternatively, if you use First Person View or similar
SfM from tethered balloons

Allsopp helikite (~$2k)

Brooxes picavet (~$100)

Ramon's balloon (~$100s)
Pros

- Easy to drag across target area.
- Once in the air can remain there.
- Can carry large SLR cameras.
- No FAA regulations!

Cons

- Requires helium, which can be expensive (>\$100 per canister), and fiddly picavet.
- Cannot be automated.
- Difficult to deploy in windy conditions.
The camera should have one essential feature and one preferable one:

**Essential** Time lapse setting – remotely takes photo every $x$ seconds

**Preferable** Internal or external GPS tagging

Cheap, lightweight cameras can be used but lower-quality lenses can lead to large radial distortions in the photographs.

These can lead to warping of the topography unless they are dealt with.
Camera lens distortions

\( f = \text{focal length} \)
\( c_x = \text{principal point x coordinate} \)
\( c_y = \text{principal point y coordinate} \)

\( k_n = n^{\text{th}} \text{ radial distortion coefficient} \)
\( p_n = n^{\text{th}} \text{ tangential distortion coefficient} \)

skew coefficient between the x and the y axis.
Camera lens distortions

- Doming can be mitigated by calibrating the camera parameters by photographing a calibration target

- Doming can be mitigated by georeferencing using ground control points

- Doming can be mitigated by incorporating a few oblique camera angles (in red)

See: James & Robson (2014), Mitigating systematic error in topographic models derived from UAV and ground-based image networks, *Earth Surface Processes and Landforms*
## SfM & MVS software

Bemis *et al.* (2014). Ground-based and UAV-Based photogrammetry: A multi-scale, high resolution mapping tool for structural geology and paleoseismology. *Journal of Structural Geology*

### Table 1

Examples of open source and commercial software for photo-based 3D reconstruction.

<table>
<thead>
<tr>
<th>Software</th>
<th>URL (valid on 17 May, 2014)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Freely available</strong></td>
<td></td>
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<tr>
<td>VisualSFMin</td>
<td><a href="http://www.3dflow.net/technology/samantha-structure-from-motion/">http://www.3dflow.net/technology/samantha-structure-from-motion/</a></td>
<td>SfM only, but with more advanced camera models than all above (Farenzena <em>et al.</em>, 2009). Provides output compatible with several dense matching algorithms.</td>
</tr>
<tr>
<td><strong>Web sites and services</strong></td>
<td></td>
<td></td>
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<tr>
<td>Photosynth</td>
<td><a href="http://photosynth.net/">http://photosynth.net/</a></td>
<td>Also available as standalone software.</td>
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<tr>
<td>Arc3D</td>
<td><a href="http://www.arc3d.be/">http://www.arc3d.be/</a></td>
<td></td>
</tr>
<tr>
<td>Pix4D</td>
<td><a href="http://pix4d.com/">http://pix4d.com/</a></td>
<td></td>
</tr>
<tr>
<td><strong>Commercial</strong></td>
<td></td>
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<tr>
<td>Acute3D</td>
<td><a href="http://www.acute3d.com/">http://www.acute3d.com/</a></td>
<td>Software, originally based on close-range photogrammetry, now also implements SfM. Underlying SfM engine is 3DF Samantha</td>
</tr>
<tr>
<td>3DF Zephyr Pro</td>
<td><a href="http://www.3dflow.net/">http://www.3dflow.net/</a></td>
<td></td>
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</table>

*Note:* Table modified from [http://www.lancaster.ac.uk/staff/jamesm/research/sfm.htm](http://www.lancaster.ac.uk/staff/jamesm/research/sfm.htm).

SfM = Structure from Motion; MVS = Multi-View Stereo.


Agisoft Photoscan Pro: $549 for an academic licence.

- Workflow includes both SfM and MVS, and builds DSM and orthophoto
- Intuitive graphical user interface (GUI)
- Data are georeferenced automatically if camera GPS stamps are available
- Camera calibration with Agisoft Lens
- Vertically-oriented orthophoto possible for trenching (see Reitman et al., 2015, BSSA)
It is important to capture each part of the target or target area with photos taken from several different locations. There needs to be significant overlap between images.

This image shows a test area in California where we made comparisons between SfM topography and airborne lidar. We used 230 photos taken in ~1 hour from a helium balloon.

Johnson et al. (2014), Rapid mapping of ultrafine fault zone topography with structure from motion, Geosphere
Resolution and precision of SfM topography

Johnson et al. (2014), Rapid mapping of ultrafine fault zone topography with structure from motion, Geosphere
Resolution and precision of SfM topography

SfM ~700 pts/m²
5 cm resolution DEM

Johnson et al. (2014), Rapid mapping of ultrafine fault zone topography with structure from motion, *Geosphere*
Resolution and precision of SfM topography

**B4 LiDAR** ~4 pts/m²
0.5 - 1 m resolution DEM

**SfM** ~700 pts/m²
5 cm resolution DEM

Johnson *et al.* (2014), Rapid mapping of ultrafine fault zone topography with structure from motion, *Geosphere*
Resolution and precision of SfM topography

Note errors of >50 cm concentrated around edge of dataset. These probably reflect a trade-off in the bundle adjustment between estimates of the radial distortion of the camera lens and the topography.

Johnson et al. (2014), Rapid mapping of ultrafine fault zone topography with structure from motion, Geosphere
Distortion errors around the edge of dataset can be removed by deploying and surveying ground control points (using differential GPS), identifying these in the aerial photographs, and fixing the locations before the bundle adjustment.

Johnson et al. (2014), Rapid mapping of ultrafine fault zone topography with structure from motion, Geosphere
Available Resources

SfM slides, theory and applications; practical considerations.

How-to manuals for both field data collection and Agisoft PhotoScan processing.
SfM exercise

Build your own model using your own photographs of a target on campus. Make sure you have a way of transferring your photos onto the computer!

Bemis et al. (2014).

Westoby et al. (2012).

Tips
• Choose a target with some texture
• Ensure plenty of overlap between photos
• Capture the target from a variety of angles
• Try to capture the object in ~20 – 30 photos
SfM exercise

SfM Pro? Show us how you are using it in your research or teaching.

Email results to:

ramon.arrowsmith@asu.edu
SfM exercise

In the free trial version of Agisoft Photoscan, you are unable to save point clouds or gridded DEMs that you create.

However, if you had bought the license, you could then do the following:

File > Export Points

- save point cloud with attributes in a number of formats including .LAS and ASCII, and in a number of coordinate systems including UTM

File > Export DEM

File > Export Orthophoto

Generate Report

- the report contains a summary of the 3D model and data collection metrics
SfM exercise

Example products
Top left: artificially shaded DEM
Top right: orthophoto
Bottom left: camera locations (black dots) and image overlap (colours show #photos)