Structure from Motion

Workshop on Point Clouds and Applications in Science
April 8-10, 2015, CICESE, Ensenada B.C.
Outline

Structure from Motion (SfM):

• How it works
• Our workflow
• Value of ground control points (GCPs)
• Potential with existing aerial photos
• Example multitemporal study
Digital Topography from the Stereoscopic Effect
Structure from Motion vs. Stereophotogrammetry

• Traditional stereophotogrammetry requires that we know the precise locations of the photos, and a fairly simple photo geometry.

• Structure from Motion simultaneously solves for the camera parameters and the scene geometry, and can support large changes in camera position.
Structure from Motion (SfM)

- Reconstructs 3D model of a scene from photographs with overlapping coverage taken from changing perspectives.

- Triangulates among features in different photos using Scale Invariant Feature Transform (Lowe, 2004; Snavely et al., 2008).

- Incorporation of aerial platform improves camera perspective and increases coverage compared to ground-based surveys.
Pros and Cons

Pros:
- Inexpensive
- User-friendly software and technology
- Very high-resolution data
- Colored point clouds

Cons:
- Cannot “see through” vegetation
- Usually cover much smaller areas than LiDAR
SfM Workflow

Field work and data collection

Data processing

Photo credit: Kate Scharer
Field Work

Choose platform

Select camera

Deploy and survey ground control points

Collect photographs

Motorized glider

Helium balloon

Helikite
Considerations

• Site conditions
  – Weather – especially wind
  – Terrain – steep or sub-horizontal

• Regulations
  – In America, using a tether avoids most issues

• Desired resolution
  – Smaller distance between camera and target yields higher density point cloud but photo footprint is smaller
Field Work

Choose aerial platform

Select camera

Deploy and survey ground control points

Collect photographs

Criteria:
- Time-lapse or remote-controlled triggering
- GPS tagging preferred

Nikon D5100

Easytag GPS

Canon Powershot SX230
Field Work

Choose aerial platform

Select camera

Deploy and survey ground control points (GCPs)

Collect photographs

GPS locations of prominent features are used during the processing phase to improve point cloud accuracy.
Field Work

Choose aerial platform

Select camera

Deploy and survey ground control points

Collect photographs
Proper photo collection

more detail provided by Agisoft:

-More photos are better than not enough

-Each photo should be maximally occupied by features of interest (but the full object does not need to be in every frame)

-For aerial data collection, aim for 80% forward overlap and 60% side overlap
Imaging a sub-planar feature

Collect photos from multiple locations but similar look angles
Imaging an interior (e.g. of a room)

Collect photos from the opposite side of the interior
Imaging an isolated object

Isolated Object (Incorrect)  Isolated Object (Correct)

Collect photos many angles
Data Processing

*Agisoft Photoscan Pro

Build structure (point cloud and camera parameters) → (Optional) Add GCPs → Build DEM → Build texture/orthophoto


*Alternative workflows presented in Westoby et al. (2012), James and Robson (2012), and Fonstad et al. (2013).
Ground Control Points (GCPs): a case study at the Washington Street Site

We compared our SfM DEM to an existing DEM to quantify the accuracy of structure from motion when GCPs are and are not used.
'B4' LiDAR Project led by the USGS and Ohio State University and funded by the NSF. Data collected by NCALM.

SfM point density (points/m²):

- 90% > 60
- 50% > 700

LiDAR point density (points/m²):

- 90% > 1
- 50% > 1.75

Johnson et al., 2014
Washington Street Site: No GCPs

SfM profile is shifted and tilted compared to the LiDAR

Johnson et al., 2014
Washington Street Site: No GCPs

Absolute vertical distances (meters) from each LiDAR point to nearest SfM point

90% < 41 cm
50% < 10 cm

Johnson et al., 2014
Washington Street Site: With GCPs

- Add GCPs from GeoXH GPS with 20 cm uncertainty
Washington Street Site: With GCPs

Absolute vertical distances (meters) from each LiDAR point to nearest SfM point

- 90% < 13 cm
- 50% < 3 cm

- Published LiDAR errors: 5-10 cm
- Bushes (and cars) have largest errors
- Steep slopes have larger errors in LiDAR data
- Geomorphic changes now stand out

Johnson et al., 2014
Washington Street Site: With GCPs

- SfM profile now mimics the shape of the LiDAR profile
- Slight remaining shift due to systematic error in the GPS base station

Johnson et al., 2014
Conclusion: although SfM is able to work out the rough 3D structure of the scene without any GCPs, there may be warping and tilting → we always use GCPs!

If images are collected from a camera that does not have GPS, GCPs must be used to create a spatial/geospatial reference frame.
Agisoft Lens
Washington Street Site Interpretation

Channel/bar offset: 3 m*

Scarp height: 0.8 m

Fan margin offset: 20-25 m

*Corresponds with slip estimates for ca. 1690 earthquake

Johnson et al., 2014
Example: Jointing and magmatic dikes as a precursor to the development of volcanic plugs

Townsend et al. (in press)

Use geologic evidence to test flow localization theories

Characterize systematic set of dike-perpendicular joints in sedimentary host rock
Used orthophoto (5 mm resolution) to measure the length and orientation of the joints.

Showed that perpendicular joints are associated with magma emplacement and thermal pressurization in host rock. Fracturing is precursor to host rock erosion and sustained flow.
SfM from existing aerial photos

Because rigid photo geometry and camera position/orientation details are not important in SfM, we can extract elevation data from any set of aerial photos – provided they have sufficient overlap.
Example: Stream profile analysis in Montana

- SfM: 2.7 m/pixel, 27 pictures
- NED: 10 m/pixel

Example:
  Stream profile analysis in Montana
Example: Assessment of the 1992 Lander’s earthquake rupture zone width and complexity.

Does rupture width and complexity depend more on lithology and surface cover thickness, or structural maturity of the causative fault?

Point cloud generated using aerial photos from just after the earthquake.
Use in multitemporal studies

Suitable for repeat surveys if:

• Satellite methods do not provide sufficient resolution (time and/or space)

• Alternative methods (e.g. laser scanning) are too costly or logistically complicated
Example: Degradation of the El Mayor-Cucapah earthquake scarp
Degradation of the 2010 El Mayor-Cucapah earthquake scarp
Degradation due to flooding
Quantitative comparison

2010-to-2013 absolute vertical change

Absolute distance (m)
General Applications in Active Tectonics

CICESE, April 2015
Barrett Salisbury
Arizona State University
Outline

• southern San Andreas, ballooning
• central (creeping) San Andreas, UAV
• Preliminary Pre- and Post-event comparison, Napa, CA
• Fun outcrop modeling, Antarctic Peninsula
• Examples of closed objects
southern San Andreas
Figure 1

Wallace Creek
130 m, ~3,780 yrs; ~33 mm/yr
475 m, ~13,250 yrs; ~36 mm/yr

Carrizo Plain

Phelan Creeks
~230 m, ? yrs

study area

Figure 2

Wallace Creek young alluvial fan offset
33.9 ± 2.9 mm/yr

Phelan Creeks offset

Wallace Creek active channel offset

Age before present (yrs)
Central Creeping San Andreas

Toke and Arrowsmith, 2013 SCEC Annual Report
LEFT-STEPPING (RIGHT-LATERAL)
A Crack Set along SAF at the DLV Site

Toke and Arrowsmith, 2013 SCEC Annual Report
A) Photolog of T4 - Southeast Wall

B) Logging of oblique cracks in the main fault zone.

C) Oblique View of Faults

Toke and Arrowsmith, 2013 SCEC Annual Report
Preliminary
Pre- and Post-event Comparison
2003 Napa watershed survey

Napa earthquake airborne laser mapping data (Hudnut, et al., 2014)

2003 = 2 pts/m²
2014 = 40 pts/m²

August 24, 2014, Mw 6.3

Pre event acquired for watershed management
Post event challenging to fund and acquire
Some alignment problems with post-event data (low signal to noise)
Cloud to cloud difference (using CloudCompare software)

SB = Swath boundary
V = Vegetation change
RZ = Rupture zone

C2C absolute distances (m)
Outcrop Studies

• Antarctic Peninsula, Brown Bluff
Outcrop Studies

Antarctic Peninsula, Brown Bluff
Closed Objects