Undergraduate Topographic Differencing Laboratory Exercise

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Introduction

- Undergraduate geoscience students learn about faulting processes by examining surface ruptures in high-resolution topography imagery and computing coseismic surface displacements.
- The exercise simulates a large earthquake along the Wasatch fault in Salt Lake City.

Activities:
- Examine and map the fault surface trace from topographic hillshades
- Use Cloud Compare Software to calculate the 3D surface deformation
- Determine type of fault activated and the earthquake magnitude

- ~4 hours to complete the full lab
Learning goals

• Visualize how earthquakes permanently deform landscapes
• Describe the relationship between fault slip, surface displacement, and earthquake magnitude
• Interpret quantitative geospatial datasets
• Practice writing scientific methods and interpretations for an experiment with uncertainty
Earthquake background: Fault geometry

- Along-strike length
- Down-dip width

Fault plane
Earthquake background: Surface displacement

30 cm of fault slip
Topographic differencing

Lidar: light detection and ranging
Coseismic displacement
Iterative Closest Point

- https://www.youtube.com/watch?v=uzOCS_gdZuM
Align the **pre-earthquake** and **post-earthquake** topography.
3D rigid deformation

\[
\text{Deformed point cloud} = \begin{pmatrix} 1 & -\gamma & \beta \\ \gamma & 1 & -\alpha \\ -\beta & \alpha & 1 \end{pmatrix}\left(\text{Undeformed point cloud}\right) + \begin{pmatrix} t_x \\ t_y \\ t_z \end{pmatrix}
\]

Rotation  Translation

Describing deformations with linear algebra

Full 3D rotation and translation

\[ \varphi = \begin{pmatrix} 1 & -\gamma & \beta & t_x \\ \gamma & 1 & -\alpha & t_y \\ -\beta & \alpha & 1 & t_z \\ 0 & 0 & 0 & 1 \end{pmatrix} \]

\( \alpha: x \text{ axis rotation} \quad \beta: Y \text{ axis rotation} \quad \gamma: Z \text{ axis rotation} \)

\( t_x: x \text{ translation} \quad t_y: y \text{ translation} \quad t_z: z \text{ translation} \)
Differencing on the Wasatch fault
Cloud Compare

3D point cloud and mesh processing software
Open Source Project

Daniel Girardeau-Montaut
www.danielgm.net/cc/
Open pre- and post-earthquake .las files at the same time
Apply all
Apply a coordinate system shift to transform the point to \((0,0,0)\).

Why?
1. Coordinates are too big.
2. Center of ICP rotation needs to be within the tile.
Point clouds:
RGB: Pre-earthquake
White: Post-earthquake
Cut window for topographic differencing

Select the pre-earthquake cloud

Use the scissors tool
Cut a box for ICP

Length: 500 m – 1km

Steps:
1. Left click to outline the square
2. Right click when done
3. Segment in
4. Green check
Cutting tool result
Show the cut pre-earthquake (RGB) with the full post-earthquake (White)
Cut the post-earthquake point cloud to be a little bit larger than the pre-earthquake point cloud.
Calculate distance to fault

Point picker

Measure distance between two points

\[ \Delta x \]
ICP differencing
Select cut point clouds

Click the green ice cream cone for cloud registration
ICP differencing

Role assignment

Aligned: Pre-earthquake
Reference: Post-earthquake

Swap to switch, if needed
ICP differencing

Final RMS: 2.11973 (computed on 50000 points)

Transformation matrix
1.000  -0.000  -0.000  0.373  
0.000   1.000   0.000   -0.179  
0.000  -0.000   1.000  -1.484  
0.000   0.000   0.000   1.000  

Scale: fixed (1.0)

Theoretical overlap: 100%

This report has been output to Console (F8)

Full 3D rotation and translation

$$\varphi = \begin{pmatrix}
1 & -\gamma & \beta & t_x \\
\gamma & 1 & -\alpha & t_y \\
-\beta & \alpha & 1 & t_z \\
0 & 0 & 0 & 1
\end{pmatrix}$$

**α**: x axis rotation

**β**: Y axis rotation

**γ**: Z axis rotation

**t_x**: x translation

**t_y**: y translation

**t_z**: z translation

t_x: E-W displacement (positive East)
t_y: N-S displacement (positive North)
t_z: Vertical displacement (positive Up)
For organization, delete the tile once finished with ICP.
Good lesson

• If you do something wrong, it is often best to quit and restart Cloud Compare.
• No undo tool
Pre-earthquake  Post-earthquake  Mapped rupture
ICP results

What type of fault was activated?
Are all measurements exactly consistent with this type of fault?
What are the sources of error?
Fault slip

Fault slip:

The surface displacements align with 2.43 m of fault slip.
Fault area:

- Vertical displacement (m):
  - 0.6
  - -1.5
- Fault Length: 50 km
- Plan-view width: 10 km
  width = \frac{10 \text{ km}}{\sin(\text{dip})} = \frac{10 \text{ km}}{\sin(60)} = 20 \text{ km}

Fault outline in black

Magnitude calculation:

- Slip = 2.43 m
- Area = 20 km x 50 km = 1000 km²
- \( M_o = 7.7 \times 10^{19} \text{Nm} \)
- \( M_w = 7.2 \)