Aligning point clouds and topographic change detection

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Aligning point clouds and topographic change detection

- Multi-temporal topography
- Earthquake examples:
  - scientific motivation
  - aligning (registering) topography data with ICP
  - 2008 Iwate earthquake (Japan)
  - 2011 Fukushima earthquake (Japan)
  - 2010 El Mayor Cucapah earthquake (Mexico)
- Other applications
• There is now a “baseline” of lidar topography on many active faults in the western US
• After an earthquake, repeat lidar data can be collected and differenced
3-D earthquake deformation from repeat lidar
3-D earthquake deformation from repeat lidar

Pre-earthquake point cloud
3-D earthquake deformation from repeat lidar
3-D earthquake deformation from repeat lidar

Post-earthquake LiDAR survey
3-D earthquake deformation from repeat lidar

Post-earthquake point cloud
3-D earthquake deformation from repeat lidar

Pre-earthquake point cloud
3-D earthquake deformation from repeat lidar

The Challenges of LiDAR differencing

- Data are irregularly spaced (we can rasterize them, but lose information doing so)
- There can be large mismatches in point density (legacy datasets vs modern surveys)
- ... and mismatches in data quality and metrics (third party vs research-grade)
- Treatment of vegetation returns in forested areas
3-D earthquake deformation from repeat lidar

- The **iterative closest point** algorithm (ICP) is a method for registering (aligning) irregular point clouds, well known in computer vision and medical imaging.
- ICP minimizes closest point pair distances using iterative **rigid-body transformations**, each one comprising a **translation** $[t_x, t_y, t_z]$ and a **rotation** $[\alpha \beta \gamma]$.

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

ICP iterations = 1
White: Original point cloud
Red: ICP aligned point cloud

pointclouds.org/documentation/tutorials/interactive_icp.php
3-D earthquake deformation from repeat lidar

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1. Split both datasets into square cells

2. ICP is run on each equivalent pair of cells.
   The **translation** $[t_x \ t_y \ t_z]$ corresponds to the cell displacement

3. This is repeated for the next pair of cells

Iterative Closest Point algorithm (ICP)

Pre-earthquake cell

Post-earthquake cell
Iterative Closest Point algorithm (ICP)
Iterative Closest Point algorithm (ICP)

Pre-earthquake cell

Post-earthquake cell

Find closest points
Iterative Closest Point algorithm (ICP)

Iterate

Find closest points

Transform point cloud

\[
\phi = \begin{pmatrix}
1 & -\gamma & \beta & t_x \\
\gamma & 1 & -\alpha & t_y \\
-\beta & \alpha & 1 & t_z \\
0 & 0 & 0 & 1
\end{pmatrix}
\]
Iterative Closest Point algorithm (ICP)

Find closest points

Transform point cloud
Iterative Closest Point algorithm (ICP)

Find closest points

Transform point cloud
Iterative Closest Point algorithm (ICP)

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Transform point cloud
Iterative Closest Point algorithm (ICP)

Find closest points
Transform point cloud

earthquake displacement
3-D earthquake deformation from repeat LiDAR point clouds

Caveats

- ICP will not work if there are large changes to the shape of the cell, e.g. through landsliding
- ICP will generate spurious results in areas that are very planar

11 April 2011 Fukushima-Hamadori earthquake

Nissen et al. (2014), *Earth Planet. Sci. Lett.*
11 April 2011 Fukushima-Hamadori earthquake

Toda & Tsutsumi (2013), BSSA
11 April 2011 Fukushima-Hamadori earthquake

[Map showing the area affected by the earthquake with GPS displacements and other active faults indicated.]
11 April 2011 Fukushima-Hamadori earthquake

2006 pre-event 2 m DEM
11 April 2011 Fukushima-Hamadori earthquake

2011 post-event 1 m DEM
11 April 2011 Fukushima-Hamadori earthquake

Photos from Toda & Tsutsumi (2013), BSSA
2005-2011 vertical displacements
2005-2011 vertical displacements

(distance from fault scarp (m))
- Slip at depths of a few hundred meters appears to vary smoothly.
- In many places, only a small proportion of the slip makes it to the surface.
• these rotations are present even in areas with low scarp heights
• suggests fault slip is lost in the very near surface (10s of meters) rather than at depths of kilometers
Indicative of shallow slip (10s – 100s m)

Surface offsets

Darfield rupture (Quigley et al. 2010)

Izmit rupture (Rockwell et al. 2002)

- Slip at depths of a few hundred meters appears to vary smoothly
- In many places, only a small proportion of the slip makes it to the surface
- Reflects off-fault deformation in the shallow subsurface?