Registering (aligning) multiple topographic datasets and topographic change detection

The **Iterative Closest Point** algorithm: a method for registering (aligning) two sets of points

Fig. 4. Iterative point-based registration of phantom face range data
Iterate

Find closest points

Transform point cloud

\[ \phi = \begin{pmatrix} 1 & -\gamma & \beta & t_x \\ \gamma & 1 & -\alpha & t_y \\ -\beta & \alpha & 1 & t_z \\ 0 & 0 & 0 & 1 \end{pmatrix} \]
Find closest points
Transform point cloud
Find closest points

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Transform point cloud
Pre-earthquake LiDAR survey
Pre-earthquake point cloud
Post-earthquake LiDAR survey
Post-earthquake point cloud
Pre-earthquake point cloud
The Challenges of LiDAR differencing

• Data are irregularly spaced (we can rasterize them, but we lose information doing so).

• There can be large mismatches in point density (typically the newer dataset is denser than the older one).

• There may also be large errors in absolute point positioning (for instance at the edges of scan lines, as we saw at El Mayor).
The **Iterative Closest Point** algorithm: a method for registering (aligning) two sets of points.
The **Iterative Closest Point** algorithm: a method for registering (aligning) two sets of points

- the two point clouds are first split into square “windows”, 50 m in diameter
- ICP is run separately on each pair of windows. (An additional “fringe” of 5 m is included in the post-event window in order to capture the coseismic displacement)
- ICP finds the displacement and rotation that best aligns the pre-event and post-event point clouds.
- This alignment corresponds to the local coseismic displacement for that window.

*see Nissen et al. (2012), Geophys. Res. Lett., for details*
Pre-earthquake point cloud

Post-earthquake point cloud
Pre-earthquake point cloud

Post-earthquake point cloud
Pre-earthquake point cloud

Post-earthquake point cloud

Find closest points
Find closest points
Transform point cloud
Iterate

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Case studies

Interseismic GPS velocities, 1996-2000
from Hashimoto et al. (2009)
Case studies

Coseismic GPS velocities from March 11 2011 from Ozawa et al. (2011)

during earthquake elastic strain is released

between earthquakes elastic strain accumulates

squeezed

stretched

11 March 2011 Tohoku earthquake (M_w 9.0)

Japan Sea

Okhotsk Plate

Pacific Plate

Japan Trench

Coseismic GPS displacements 5 m

slip distribution

30 m 20 m 10 m

92 mm/yr

Elevation (km)

Fig. 1b
Case studies

between earthquakes elastic strain accumulates
during earthquake elastic strain is released
The 2008 Iwate-Miyagi earthquake (Mw 6.9), Japan

Figure 2

13 June 2008 Iwate-Miyagi earthquake

13.06.2008 ruptures

--- other active faults
The 2008 Iwate-Miyagi earthquake (Mw 6.9), Japan

Takada et al. (2009), Earth Planets Space

Japan Geographical Survey Institute
The 2008 Iwate-Miyagi earthquake (Mw 6.9), Japan

Pre-earthquake DEM (2m)
The 2008 Iwate-Miyagi earthquake (Mw 6.9), Japan

Post-earthquake DEM (1m)
The 2008 Iwate-Miyagi earthquake (Mw 6.9), Japan
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Dense 3-D displacements in an area InSAR cannot image

Upward “rebound” in response to removal of load in landslide?

ICP doesn’t work where the characteristic shape of the topography has changed, such as in large landslides
The 2008 Iwate-Miyagi earthquake (Mw 6.9), Japan

Photos by Tadashi Maruyama
The 2011 Iwaki earthquake (Mw 6.7), Japan
The 2011 Iwaki earthquake (Mw 6.7), Japan

ALOS interferogram (ascending track)

The Iwaki earthquake produced two sub-parallel surface ruptures along the SW-dipping Yunotake and Idosawa faults. The Idosawa rupture is spanned by repeat LiDAR in an area where InSAR data are largely incoherent.

b

11-14 April 2011 Fukushima earthquakes

Abukuma Highlands

12.04.2011
M_w 5.9

11.04.2011b
M_w 5.5

11.04.2011a
M_w 6.7

13.04.2011
M_w 5.3

14.04.2011
M_w 5.1

11.04.2011 ruptures
other active faults

10 km
The 2011 Iwaki earthquake (Mw 6.7), Japan

ALOS interferogram (ascending track)

The Iwaki earthquake produced two sub-parallel surface ruptures along the SW-dipping Yunotake and Idosawa faults. The Idosawa rupture is spanned by repeat LiDAR in an area where InSAR data are largely incoherent.

InSAR model from Fukushima et al. (2013), BSSA
The 2011 Iwaki earthquake (Mw 6.7), Japan

The Iwaki earthquake produced two sub-parallel surface ruptures along the SW-dipping Yunotake and Idosawa faults. The Idosawa rupture is spanned by repeat LiDAR in an area where InSAR data are largely incoherent.

Pre-event data: 2 m Bare Earth DEM, Kokusai Kogyo Co. Ltd.
The 2011 Iwaki earthquake (Mw 6.7), Japan

The Iwaki earthquake produced two sub-parallel surface ruptures along the SW-dipping Yunotake and Idosawa faults. The Idosawa rupture is spanned by repeat LiDAR in an area where InSAR data are largely incoherent.

Post-event data: 1 m Bare Earth DEM, Aero Asahi Corp.
Idosawa F. max slip 2m

Field measurements of vertical fault slip by Tadashi Maruyama

Indicative of slip at ~200-600 m depth

In many places, only a small proportion of the slip makes it to the surface
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This is a common phenomenon for thrust faults that rupture upwards through unconsolidated sediment.
In many places, only a small proportion of the slip makes it to the surface. This is a common phenomenon for thrust faults that rupture upwards through unconsolidated sediment. However, this is a bedrock normal fault.
y-axis rotations in windows which contain surface faulting
these rotations are present even in areas with low scarp heights, suggesting fault slip is lost in the very near surface (less than 50 m), perhaps to bedding plane slip or warping
ICP LiDAR differencing: strengths and weaknesses

**Synthetic Aperture Radar Interferometry (InSAR)**

InSAR measures deformation in the satellite line of sight. **Pixel matching** usually only measures horizontal displacements.

**ICP** can resolve displacements and rotations in 3-D.

**Pixel matching** can be applied to LiDAR imagery, but requires gridding (rasterization) of the point clouds, resulting in information loss.

**ICP** works on the original point clouds.

**InSAR** is good at measuring far-field deformation but often break down close to surface faulting.

**LiDAR** is typically focused along active faults, so ICP will be useful for obtaining near-field deformation.