Emerging Technologies for Event Reconnaissance: Current and Future Opportunities

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Outline

• Opportunities
  – Remote sensing
    • High-resolution optical imagery
    • Synthetic Aperture Radar (SAR)
    • LIDAR- airborne and terrestrial
  – Data fusion
    • Real-time vs. post-reconnaissance

• A recent experience
  – 2008 Wenchuan, China earthquake

• Remaining Challenges
Remote Sensing

- Acquiring data using sensors **not** in direct physical contact with the area being studied

**Optical satellite imagery**

- Resolution as high as 0.4 m
- Identification of damage
- Cloud cover an issue

**SAR**

- Resolution as high as 1 m
- Identification of damage
- Measure movements
- Cloud cover **not** an issue

**LIDAR**

- Resolution as high as 0.4 m
- Identification of damage
- Measure movements
- Cloud cover **not** an issue

Hilley et al. (2004)

Kayen et al. (2006)
Remote Sensing Data

- Collection of digital data within distinct bands of electromagnetic spectrum

![Graph showing wavelengths and remote sensing technologies]

- LANDSAT-7: 8 bands, 15 - 30 m res
- SPOT-5: 5 bands, 2.5 - 20 m res
- IKONOS, KOMPSAT: 5 bands, 1 - 4 m res
- Quickbird: 5 bands, 0.6 - 2.4 m res
- GeoEye-1: 5 bands, 0.4 - 1.6 m res
- Envisat: C band (4-8 cm), 30 m res
- TerraSAR-X: X band (2.4 - 4 cm), 1 - 16 m res
- COSMO-SkyMed: X band (2.4 – 4 cm), 1 – 30 m res

from Lillesand et al. (2004)
The Airborne Laser Terrain Mapping (ALTM) system combines the precision of LIDAR (Light Detection and Ranging) with the absolute accuracy of GPS to measure topography.

- A powerful laser pulses thousands of times per second, scanning across the Earth beneath the survey aircraft.
- The position of the aircraft is estimated using GPS equipment in the aircraft and at ground control stations.
- An Inertial Measurement Unit (IMU) is used to remove the effects of aircraft attitude.
- All three data streams (laser ranges, IMU information, and GPS positions) are merged and processed to generate a series of topographic points.
- **Accuracy** < 10 cm
- **First and last return** of the laser is recorded
- New development: full waveform digitizer

Slide from Roberto Gutierrez (UT-CSR)
Comparison of NED, SRTM, Lidar Topography: Coryell Creek, Texas

Slide from Roberto Gutierrez (UT-CSR)
Solana Beach, California

Red = erosion  
Blue = accretion
Ground-based LIDAR

**Riegl z210i**
Rotating LASER Mapper:
- ~400m Range, ~800m area
- Accuracy~1.0 cm
- Targets: 7.2M in 15 minutes
- Scan window: 80° by 336°

**OpTech ILRIS-3D**
Fixed window LASER Mapper
- ~ 1.5 km Range
- Accuracy~0.5 cm
- Targets: 1.8M in 15 minutes
- Fixed window: 40° by 40°

*USGS-Geologic Division System (R. Kayen)*

*(from R. Kayen, USGS)*
A: Scan

B: Register

C: Fuse

D: Quantify
Deformation

(Kayen et al. 2006)
SAR / InSAR

- SAR is an active system that can penetrate clouds, data is difficult to interpret visually
- SAR Interferometry (InSAR): Difference two images to detect surface deformation or topography
- Detect **cm to mm-level** defo
- InSAR ground resolution is **10-90 m**
- New satellites: higher spatial resolution, sensitivity

Images from earth.esa.int/applications/data_util/SARDOCS/spaceborne/Radar_Courses

Slide from Sean Buckley (UT-CSR)
Landslide Monitoring - Berkeley

Hilley et al. (2004)
Use in Post-Event Reconnaissance

**Remote Sensing Data**
- HR Pre-Event Optical
- HR/MR/LR Pre-Event SAR/Optical
- HR Pre-Event Optical
- LIDAR

- Pre-event Products
  - Base Map
  - Building Inventory

- Post-event Products
  - Generalized Damage Locations
  - Detailed Damage Patterns
  - Failure Geometries

**Technical Needs**
- Rapid Post-Event Activities
  - Emergency Response
  - Earthquake Reconnaissance
  - Rapid Loss Estimate
  - Detailed Studies of Earthquake Effects
  - Long-Term Post-Event Activities

“Where should we focus our efforts?”
“How much will it cost to recover?”
“What can we learn for next time?”
Rapid Response

- Reconnaissance of 2004 Niigata-ken Chuetsu Earthquake in Japan
  - Significant landslides
  - Difficult access

- Annotated IKONOS image from C. Scawthorn of Kyoto Univ.
  - Landslides visually identified
  - Liquefaction identified
  - Notes regarding damage, ground motions, previous reconnaissance activities
  - Provided as JPEG
Long-Term Study

Investigation of landslide distribution from Niigata-ken Chuetsu earthquake

Adapted from Rathje et al. (2006) Soils & Foundations
Data Trade-offs

For satellites, aerial coverage represents scene size.
For LIDAR, aerial coverage represents maximum daily coverage.
HR, MR, and LR: high, moderate, and low resolution

Spatial Resolutions

0.6 m

10 m

30 m

Bam, Iran
Aerial Coverage

Wenchuan (China) Earthquake

M 7.9

Niigata Earthquake

M 6.6

50 km
Data Fusion

• Geo-referenced data and observations from multiple sources can improve interpretations
  – Satellite imagery
  – Geology
  – Topography (Global DEM from SRTM, LIDAR)
  – Digital photographs
  – Fault rupture, ground shaking

• Google Earth provides a platform for data fusion, as well as other GIS programs
2008 Wenchuan Earthquake

*M 7.9m, ~ 200 km of fault rupture*

- Affected area larger than 10,000 km²
- Significant landslides in mountainous area
Wenchuan Earthquake

• LANDSAT Imagery
  – Cloud-free pre-event imagery (April 2007/2008)
  – Post-event imagery (May 2008) with significant cloud cover at edge of mountains

• High-resolution data
  – Post-event IKONOS (IK) imagery purchased by USGS and made available to researchers
  – Pre- and post-event Quickbird (QB) imagery purchased by Remote Sensing Consortium over localized areas
LANDSAT Imagery

Pre-event Imagery

Post-event Imagery

100 km
Landslide Identification

Pre-event LANDSAT

Post-event LANDSAT

~ 5 km x 5 km area

Post-event IKONOS
• Change Detection (LANDSAT)
  – Mid-infrared band (Mid IR, 1.55-1.75 μm) best distinguished landslides and minimized clouds
  – Clouds manually masked out
  – DNs converted to reflectance
  – Pre- and post-event imagery histogram matched
  – Difference $> +0.10 \rightarrow$ landslides

$> +0.06$  $> +0.10$  $> +0.14$
Results

- Heavy concentration of landslides near Ying Xiu and Miansi
- Fewer landslides to the west of epicenter
Miansi (PGA~0.92 g)

LANDSAT Analysis

IK Visual Interpretation

4 km
Ying Xiu (PGA~0.96 g)

**LANDSAT Analysis**

Affected by proximity to clouds

**QB Visual Interpretation**

- Landslides
- Urban damage

2 km
Data Fusion (Slope angles)

Slope angles derived from 90 m, gap-filled SRTM global DEM

Geology

LS Area Ying Xiu: Granite
LS Area West: Metamorphic schist, griotte
LS Free Area: Fractured sedimentary rocks
Remaining Challenges

• Training reconnaissance personnel
  – GPS, digital cameras
  – Geo-referencing (Google Earth)
  – Satellite imagery

• Development of coordinated field and remote sensing teams
  – True integration of data from these teams

• Acquisition time/interpretation time for remote sensing data