New Tools and Techniques of Remote Sensing for Geologic Hazard Assessment

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Abstract

The use of earth surface remote sensing in geology is increasing thanks to the continuous development of sophisticated sensors and the improvements in digital image processing techniques. Here we focused on new remote sensing tools and techniques capable of delivering high-resolution data for geologic hazard investigations. These include airborne imaging systems such as UAVs (Uninhabited Aerial Vehicles) and LiDAR (Light Detection and Ranging), as well as new radar sensors onboard of Earth-orbiting satellites. We emphasize the applications of advanced synthetic aperture radar interferometry (InSAR) techniques referred to as multi-temporal interferometry (MTI). With the free imagery availability from the current (since 2014) European Space Agency (ESA) Sentinel-1 mission, MTI can now be more affordably exploited for long-term (years), regular (weekly-monthly), precise (mm) measurements of ground displacements over large areas (thousands of km^2). This, in turn, means improved detection and monitoring capability of landslide/slope instability, seismic and volcanic hazards.

Keywords

Remote sensing • Geologic hazard • UAV • LiDAR • Satellite InSAR

1 Introduction

Remote sensing is often defined as the process of obtaining information about an object, area or process via the analysis of data (typically images) acquired by terrestrial or air- or space-borne sensors. For background information on remote sensing principles and digital image processing and interpretation, we refer the readers to textbooks and manuals (e.g., [1–3]).

Systematic use of remote sensing in geology began in the 20th century, thanks to an increased availability of airphotos. Initially, black and white photography was used in reconnaissance geologic mapping [4]. Another important step was the launch of Earth Resource Technology Satellite-1 (ERTS-1) in 1972, which heralded the exploitation of space-borne sensors for mapping of the Earth's resources.

Here we discussed selected innovative remote sensing techniques and their applications in investigations of landslides/slope instabilities, as well as seismic and volcanic hazards. These hazards can affect wide areas and require synoptic (and possibly low-cost) information for their assessment. We also provide representative references on the uses of new remote sensing techniques in studies of specific geologic hazards.

2 Innovative Remote Sensing Techniques and Applications

2.1 Uninhabited Aerial Vehicles

UAVs, also referred to as Unmanned Aerial Systems (UAS), Remotely Piloted Aircraft Systems (RPAS) or simply drones, typically require a human operator on the ground [5]. Drones can have onboard various types of simple or sophisticated imaging sensors. However, they usually include light digital cameras used to gather very high-resolution (cm-dcm) images. Given the flexibility in survey scheduling, the UAVs are especially suitable for rapid assessment of geologic hazards during the emergency response phase (e.g., [6]). Furthermore, with the extended flight endurance (several hours), a day-long surveillance capability is secured for monitoring active geologic hazards (e.g., volcanos, landslides).

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Importantly, being usually low-flying platforms, UAVs can acquire images also under low altitude cloud conditions. However, their application can be restricted (or even unfeasible) in the presence of strong winds. The aviation regulations can also significantly limit the use of UAVs.

While airborne LiDAR and satellites provide, respectively, (sub)regional and regional to global scale coverage, UAVs are best suited for acquisition of very high-resolution images over smaller areas and local-scale applications (e.g., 3D mapping, [7]; engineering geological surveys, [8]).

2.2 LiDAR

A good overview of LiDAR technology is given by Tratt [9]. LiDAR relies on a laser beam scanning which generates spatially "continuous" very high-resolution imagery (clouds of points) of the ground surface and associated natural and artificial features. One can distinguish between Terrestrial Laser Scanner (TLS) and Airborne Laser Scanner (ALS), or Airborne Laser Swath Mapping (ALSM), with the former being more suitable for local-scale applications, and the latter for regional studies. TLS and ALS can achieve, respectively, dcm and cm spatial resolutions and sub-cm and dcm measurement precisions.

ALS is exploited to produce high-resolution topographic maps and digital elevation models (DEM) for local to wide-area geo-hazard studies. Digital cameras are typically employed during airborne LiDAR surveys to acquire high-resolution optical images. Furthermore, surface change detection is provided through repeated TLS or ALS surveys. This approach has been used for landslide motion and soil erosion volume estimates [10] and volcanic activity assessment and monitoring (e.g., [11] and references therein). Importantly, good results can also be obtained in the presence of dense vegetation. For example, Cunningham et al. [12] reported an interesting case of mapping of seismogenic faults in forested mountainous terrain.

However, multi-temporal LiDAR has significant costs especially in case of airborne surveys. Regular repeated measurements are more feasible with TLS, which, nevertheless, requires the presence of a human operator during the scans. One important drawback is that the TLS and ALS instruments are expensive.

2.3 Satellite Multi-temporal Interferometry (MTI)

Conventional differential interferometry (DInSAR) and advanced MTI techniques e.g., Persistent Scatterers Interferometry—PSInSAR™/PSI and related approaches, as well as Small Baseline Subset—SBAS and similar methods [13], rely on radar imagery acquired by satellites periodically re-visiting the same area of interest. Using these techniques, we can obtain measurements of distance changes between the space-borne radar sensor and the ground surface features (e.g., human-made structures such as buildings, roads, but also rock outcrops and bare ground) that backscatter electromagnetic radiation emitted by the radar.

Where vegetation cover is scarce, MTI can provide precise (mm-cm resolution), high-density measurements (from tens/hundreds to thousands points/km^2) on slow (mm-dcm/year) deformations of the ground surface or human-made structures. Radar satellites offer regional to global coverage and nearly all-weather ("see" through the clouds) measurement capability. In the last 10 years, the MTI users have benefited from the improved spatial (from 3 to 1 m) and temporal (from 11 to 4 days) resolutions of the new generation radar sensors (COSMO-SkyMed constellation and TerraSAR-X). Since 2014, the applications of MTI in geologic hazard investigations can take advantage of the Sentinel-1 radar satellite mission of the European Space Agency. Sentinel-1 provides regular global-scale coverage, high temporal resolution (from 12 to 6 days) and, importantly, free imagery [14].

Radar interferometry has been exploited in studies of ground deformations related to earthquake and volcanic hazards since the 1990s, (e.g., [15]). An overview of the applications of MTI and other space-borne techniques in specific geohazard investigations, as well as relevant literature, can be found in a comprehensive ESA report [16]. The use of conventional InSAR and MTI in research oriented engineering geology investigations of landslides and unstable slopes has been thoroughly discussed in scientific literature (e.g., [17–19]).

3 Conclusion

New generation aerial and space-borne sensors and innovative remote sensing techniques are capable of delivering high-resolution imagery needed to produce detailed topographic maps and digital elevations models. The background topographic information can be frequently updated and represents essential input for geologic hazard mapping and assessment.

Furthermore, high-precision measurements of ground surface displacements can be delivered by repeated LiDAR surveys and MTI. Satellite radars are well suited for multi-scale (from regional to local scale) ground deformation monitoring because of wide/global-area coverage and regular schedule with increasing re-visit frequency (e.g., Sentinel-1 mission). Thanks to this, the detection of geologic hazards (e.g., active volcanos or unstable slopes) and their monitoring can be now more effective, especially when combined with suitable ground truth.

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