Landslide deformation monitoring

Development and evaluation of an automated processing chain for the analysis of satellite image time series

A research carried out in the framework of the EUR-OPA Major Hazards Agreement by:

EOST – CNRS UMS830 University of Strasbourg (France)

Abstract:
Slow-moving landslides are widespread in many landscapes with significant impacts on the topographic relief, sediment transfer and human settlements. Their area-wide mapping and monitoring in mountainous terrain, however, is still challenging. This study targets to develop an automatic processing chain to better exploit the growing archives of optical remote sensing images, which offer a great potential for the operational detection and monitoring of landslides in such areas.

Time-series of Pléiades satellite images reveal surface changes and displacement of the La Valette landslides (red outline).
Introduction

Landslide deformation monitoring with satellite image time series

The aim of the Project “Development of cost-effective ground-based and remote monitoring and early warning system for detecting debris flow/landslide initiation” is to test and implement geophysical techniques for landslide long-term monitoring and landslide detection. Two types of approaches are pursued: the development and test of 1) ground-based geophysical sensors such as seismometers and geophones, and of 2) remote sensors such as high resolution satellite imagery. Open source processing algorithms are being developed to define the deformation pattern (at the surface or in depth) of landslides. One of the work packages of the project is dedicated to the development of an automatic image processing chain for the analysis of optical satellite image time-series to detect and monitor slow-moving landslides.

Surface changes and displacements can be observed from sequences of optical satellite images but existing methods still produce many false alarms, are difficult to deploy, and computational expensive. They are thus not sufficiently reliable for operational monitoring.

To address those issues, this work package implements a user-friendly photogrammetric processing chain covering for sub-pixel image correlation and time-series analyses of very-high resolution (VHR) satellite images targeting the detection and monitoring of slow-moving landslides.

The study site is the Ubaye valley located in the Southern French Alps. Slow-moving landslides are a widespread phenomenon in the area due to clay-rich and highly-fractured bedrock.
Sub-pixel image correlation

Image correlation is an image matching method to find corresponding objects in images sequences. If the images are precisely co-registered it can be used to measure the displacement for every image pixel [1]. By upsampling the original images to higher resolution the measurement precision can be improved to sub-pixel precision (1/10th and more).

Multiple pairwise image correlation (MPIC)

The developed processing chain extends an open-source library for image-correlation [2] in that it measures the surface displacement among multiple pair combinations of a time-series. This allows producing multiple redundant measurements which are combined to improve the reliability of the detection and the measurement accuracy.

Methods and Data

Processing and testing

A time-series of 9 Pléiades (0.5 m/pixel) satellite images acquired over the Ubaye valley between 2012 and 2014 is processed using high-performance computing infrastructure. The accuracy of the landslide detection is assessed against an inventory manually elaborated by experts. The accuracy of the landslide deformation measurements is assessed against continuous GPS (CGPS) measurements [3].
Results

Accuracy of detection and deformation measurements

The processing chain detects 169 active landslides [4] in the study area, many of which have not been registered in inventories elaborated in previous studies [5]. Detailed field surveys and manual image interpretation show **99.8% of true positives** (detections confirmed in the field) with only approximately **27% of false negatives** (landslides observed in the field but not detected). Limitations mainly arise for deformation under dense vegetation which remains difficult to be measured with optical remote sensing data. A comparison of the measured surface displacements against CGPS measurements shows an **RMSE (root mean squared error)** of 0.26 m.

Landslide kinematics

Most of the detections qualify as slow-moving flow-type landslides. The average displacement rates for the entire study period range from 0.001 to 0.061 m.d⁻¹. The **highest displacement rates of 0.17 m.d⁻¹** were measured during the period 2013/07/31–2013/09/21 on the Sanières rockslide which was triggered in early 2013.

A global analysis of the surface velocities of all landslides also showed **that in particular larger and faster tend to accelerate during the periods from autumn to spring** [4]. The observed acceleration coincides with an increase in the rainfall during those periods. This is in line with the results of several previous studies suggesting the hydrological conditions as one of the main controlling factors on the landslide dynamics. The derived displacement fields provided valuable insights into the spatio-temporal pattern of the surface deformation.
**Results**

**Application to high-resolution open source ESA Sentinel-2 imagery**

The increasing availability of free optical satellite image time-series (SITS) with very-high spatial resolution and high temporal resolution (e.g. Sentinel-2, Landsat-8) offers enhanced possibilities for the detection and monitoring of landslides. Since redundant measurements with large image archives and over wide areas require considerable computational resources, the processing chain makes use of parallel and distributed computing on a high-performance computing (HPC) infrastructure.

**Optimized processing chain as a service on HPC platforms**

The processing chain exploits temporal information contained in a time-series of satellite ortho-images. An overview of the complete processing chain is provided in Figure 1. The processing is based on open source photogrammetric libraries (e.g. MicMac -Rosu et al., 2015; Pierrot-Deseilligny et al., 2015-) and home-made algorithms in Python and C++.

The algorithm has been implemented as a service on High-Performance Computing platforms (ESA GEP and University of Strasbourg Processing Cluster) for detecting and quantifying surface displacement at sub-pixel precision using resolution upsampling. An application of the service for the monitoring of large and rapid landslides with Medium Resolution Images (10 m spatial resolution) at high temporal frequency (5 to 15 days; Sentinel-2, Landsat-7/8) as outlined with the example of the Harmalière landslide, Trièves Valley) for which the monitoring of the development of the failure in time was possible for the period July-October 2016.

The service is able:
- to yield a velocity time-series distributed over the body of an existing landslide. Such information can complement on-site observations (seismology, geodesy) for understanding the mechanics of the failure;
- to stack all the combinations of image pairs to detect unstable pixels over time that can be used as a source of information for creating landslide inventory maps.

Overview of the processing chain of sub-pixel correlation, quality control and landslide deformation quantification.
Conclusions and perspectives:

A service for measuring horizontal surface displacements from a time-series of optical satellite images has been developed and is being integrated on several High Performance Computing facilities for the landslide community. The service uses an image correlation technique (e.g. MicMac library) for detecting and quantifying displacement at sub-pixel precision. The developed algorithm MPIC (Multiple-Pairwise Image Correlation) exploits the redundancies from all the possible combination pairs of the satellite image time-series to improve the detection and measurement accuracy. The service is able to yield a velocity time-series distributed over the body of an existing landslide and to stack all the combinations of image pairs to detect unstable pixels over time that can be used as a source of information for creating landslide inventory maps.

Contact

CERG – European Centre on Geomorphological Hazards
3 rue de l’Argonne, F-67083 Strasbourg Cedex
www.cerg.eu

EOST/IPGS – University Strasbourg
A. Stumpf (andre.stumpf@unistra.fr)
J.-P. Malet (jeanphilippe.malet@unistra.fr)
D. Michéa (david.michea@unistra.fr)

References