Enhanced deformation monitoring by means of data fusion I

Monday, 07.04.2025, 10:50 - 12:20, Room Haller

D. Bolkas, M. Olsen, E. Che, C. Simpson

First steps towards creating multi-sensor DEMs using optimal weighting for change estimation and monitoring applications

Digital elevation models (DEMs) are an important data product used in several geodetic applications to estimate changes associated with infrastructure management, rockfalls, landslides, soil migration, and beach loss and accretion. Current data acquisition methodologies often require integration of several point-cloud datasets from diverse platforms and sensors into a single DEM by leveraging the advantages of each dataset. However, optimizing the combination of these datasets is challenging because each dataset/sensor/platform has different measurement capabilities and acquisition methodologies, resulting in varying uncertainty structures. Further, the accuracy of individual point measurements can vary substantially within a single dataset. Rigorous uncertainty estimation is necessary to determine the optimal combination of measurements from these multi-sensor datasets to reliably estimate the elevation for each DEM cell. This paper uses rigorous error propagation and variance component estimation (VCE) to estimate the uncertainty throughout each point-cloud dataset. The updated uncertainty estimation then allows each dataset to be optimally weighted in the combined DEM. To demonstrate this methodology, we use datasets from terrestrial laser scanning (TLS), small uncrewed aircraft surveys (sUASs) with both imaging (photogrammetric) and Light Detection and Ranging (lidar) sensors to develop multi-epoch and multi-dataset DEMs for a test site at the Tumwata Village (Oregon, USA). The proposed method results in more robust DEMs with higher reliability, providing elevations with lower uncertainty compared to those developed without VCE. Finally, the elevations are accompanied by their own individual uncertainty estimations, which is useful to determine significant areas of change when analyzing multi-epoch datasets for change estimation or monitoring applications.

Keywords: Digital elevation model, Multi-sensor fusion, Laser scanning, UAS lidar, Point cloud, Variance component estimation

N. Dal Santo, A. Michelini

A data fusion approach for combined Terrestrial Radar Interferometry (TRI) and Robotic Total Station (RTS) monitoring

Terrestrial Radar Interferometry (TRI) and Robotic Total Station (RTS) are nowadays two well-established monitoring techniques used in numerous fields of application, including open-pit mining, civil engineering, natural hazard prevention. These two technologies have rather complementary characteristics, in fact RTS provides a measurement of the 3D displacement on specific points while TRI provides a dense 1D map of the Line of Sight (LoS) displacement component. More and more frequently, TRI and RTS are often used simultaneously within the same monitoring campaign, to improve the redundancy of the overall monitoring system. Furthermore, their complementarity makes them excellent candidates to be combined to improve the information gathered from monitoring data. This work aims to present a data fusion approach that allows the estimation of a dense deformation vector field starting from RTS and TRI measurements. The proposed methodology has been applied on a slope monitoring dataset, in order to verify its validity and evaluate possible limitations.

Keywords: Terrestrial Radar Interferometry, Robotic Total Stations, Prisms, Data fusion, Vector field

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T. V. Pattela, L. Disperati, E. D'Addario, D. Rappuoli

Multi-Temporal GNSS, RTS, and InSAR for Very Slow-Moving Landslide Displacement Analysis

Very slow-moving landslides threaten infrastructures and safety, yet detecting their subtle, long-term displacements remains challenging. The eastern slope of Mount Amiata, Tuscany, Italy, where high-precision geodetic monitoring is required to control the very slow-moving landslides affecting the area, represents an example of this issue. Namely, in this study we assess whether the joint exploitation of multi-temporal GNSS (continuous and periodic), Robotic Total Stations (RTS), and Persistent Scatterer InSAR techniques allows us to provide a coherent picture of very slow-moving landslide areas. While GNSS provides useful long-term displacement data, it may be affected by low signal-to-noise ratios, limiting precision to cm-mm level. Hence, to refine the outputs, we implement statistical time-series analysis, including weighted linear regression and 95% confidence intervals. RTS delivered high-precision 3D data associated to local-scale measurements, while InSAR extended coverage to wider areas, resolving East-West and Vertical components from Sentinel-1 data. We highlight that, since 2019, the monitoring network has recorded horizontal displacements averaging 8 mm/y and vertical movements reaching -6 mm/y, well correlating with local morphology and bedrock geology characteristics. We also perform a comparison of GNSS and RTS measurements with InSAR datasets, highlighting the limitations of InSAR in vegetated and geometrically complex terrains, while also confirming its value in capturing large scale displacement trends. The findings demonstrate that, despite their individual limitations, the joint exploitation of GNSS, RTS, and InSAR allow us to provide a comprehensive framework for very slow-moving landslide areas. The scalable, cost-effective multi-source system here developed represents a robust approach for monitoring very slow-moving landslides, supporting risk mitigation strategies in landslide-prone regions.

Keywords: Very slow-moving landslides, GNSS, RTS, PSInSAR, Statistical time-series analysis

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A. Seidel, M. Even, H. Kutterer, M. Westerhaus

Surface displacement monitoring and geophysical source modeling at the gas storage cavern field Epe

The surface above gas storage caverns experiences strong and complex displacements often of a seasonal nature depending on the usage of the caverns. As the pressure inside a cavern is lower than in the surrounding rock the cavern converges continuously which leads to a subsidence bowl at the surface. Precise measurements with high spatial and temporal resolution of these displacements is important for monitoring the caverns but also for assessing potential risks for infrastructure in the area. Multitemporal SAR interferometry (InSAR) can produce dense spatial measurements of surface displacements. When jointly analyzed with GNSS and in situ measurements, accurate estimates of the 3D surface displacement field can be achieved. We measure and model surface displacements at Epe storage cavern field in North Rhine-Westphalia Germany with time series of up to 9 years of InSAR, GNSS and leveling data. The observed surface displacement caused by cavern convergence is partially superposed by other strong displacement effects such as the surface response to groundwater level changes. With statistical component methods we are able to separate these effects and create a geophysical source model to validate our measurements. With such a model, we can estimate future surface deformation and displacements at places without measurements based on a causal relation to the cavern usage. Our predicted displacements show a good agreement with InSAR time series, GNSS and leveling. Furthermore, we observe an additional displacement component over a fen that supposedly originates from changes of groundwater levels.

Keywords: Storage caverns, 3D surface displacements, Subsidence monitoring, Geophysical model

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