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Data fusion of robotic total station and time-lapse camera to assess the surface three-dimensional deformation of a landslide.

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The assessment of the surface spatially-distributed three-dimensional (3D) deformation is crucial in landslide monitoring, as it represents the landslide kinematics. However, there is a lack of technologies that can provide this datum effectively and they are often limited by financial and/or logistic issues. We have developed a methodology to fuse displacement data obtained by robotic total station (RTS) and time-lapse camera, whose images we processed with digital image correlation (DIC). Our technique adopts the 3D RTS measurements at specific points (i.e., corresponding to reflective prisms) to calibrate a transformation from the two-dimensional (2D) spatially-distributed DIC observations into 3D data. The algorithm involves a series of steps: i) DIC measurements are orthorectified on an available digital elevation model and represented in the local coordinate system of the time-lapse camera, obtaining the 2D displacement vectors that lie on the image plane (z and x components). ii) The RTS data are rototranslated into the camera coordinate system. iii) The ratio α between the z component of the RTS displacement vector and the module of the RTS displacement vector is calculated in the available measurement points. iv) The point values of α are spatially interpolated over the landslide active domain. v) The DIC displacement map of the z component is divided by α to obtain the spatially-distributed module of displacement (the third displacement component is simply derived using the Pythagoras Theorem). vi) The results are rototranslated from the camera coordinate system into the geographic coordinate system. The most critical element of the data fusion is the spatial interpolation of α across the landslide domain. Actually, the availability of a dense network of RTS measurement points, compared to the landslide extension, is not common in real monitoring. Therefore, α might suffer strong approximation in the presence of complex kinematics. Nevertheless, since α is a composition of non-independent displacement components, it is expected to vary smoothly and, therefore, it should be efficiently interpolated even with a limited number of measurement points. We conducted simulations with synthetic data to quantify the uncertainty contribution of α interpolation, which is generally <10%. We successfully applied the RTS-DIC data fusion to the monitoring dataset of the Mont de La Saxe Rockslide, during a period of strong reactivation, with displacement rates from ~0.1 m day^{-1} to >10 m day^{-1}. We proved the efficacy of the methodology by comparing the obtained results with the independent measurements of a ground-based interferometric synthetic aperture radar, obtaining a median deviation < 0.09 m. The proposed monitoring solution has the advantage of involving low-cost and widely-used technologies, therefore it can be easily adopted in many other sites and monitoring contexts.