A calibration-free astrometric clinometer

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Abstract. The growing interest in geophysical and structural monitoring goes hand in hand with the need of designing efficient and affordable technology to prevent disasters due to natural hazards or structural collapses. In this regard space techniques based on Earth observation and Global Navigation Satellite Systems have recently become of paramount importance for continuous monitoring, especially in those countries where hydrogeological hazard is relevant. Both above-mentioned techniques can measure accurately tiny horizontal and vertical displacements of free field or infrastructures. However, to decouple translational and rotational movements, the usage of independent ground sensors, i.e., clinometers/tiltmeters is still needed. These instruments can measure constantly small changes from the vertical level. Currently, the most sensitive tiltmeters are essentially bubble levels absorbed in electrolytic solutions, able to detect tiny variations in inclination. Tiltmeters are very sensitive to temperature variations, and they must be calibrated at the factory before selling. Due to aging, the calibration procedure should be repeated rather frequently to guarantee nominal performances, operation that is often long and expensive and not very easy to carry out, requiring a uninstall-calibrate-reinstall operation. This need is particularly present in low-end inclinometers while state-of-art tiltmeters can be more resilient, but they cost up to several thousand euros.

A space-derived concept for measuring tilt variations is hereby proposed, based on the astrometric reduction of star field images. This system is basically a transfer of a technology used for decades, namely a star-tracker, optical device used to measure the attitude of satellites in space. The idea is to use a very small telescope and a commercial webcam integrated in a device strictly coupled to the free field or structure to be monitored. Overnight many star field images are collected and referenced respect to star catalogues through a process called plate-solving. The boresight (azimuth and altitude) is continuously measured, accounting for Earth precession and nutation, and normal (averaged) points are formed, one each night of observation.

A long-term setup used to assess performances showed a sensitivity in the range of 10-20 urad and a repeatability of few urad [1], in the middle range, in terms of precision, between low-end (MEMS accelerometers) and high-end clinometers.

This instrument does not need to be calibrated and it is expected to be weakly sensitive to aging, thus it is expected to minimize operating and maintenance costs. On the other hand, being based on night observations with clear sky, it is suitable only for

applications where very slow movements are envisaged, i.e., when few normal points (measurements) per week are sufficient for the specific monitoring purpose. Being geophysical monitoring and structural health monitoring, when slow drifts or oscillations are a concern, based on the very low-frequency domain, ISTAR finds its natural placement in this market niche.
This device has been already tested in an operating environment, i.e., a fast historic landslide in Roncovetro (RE) where a network of DISPLAYCE GNSS [2] has been setup by INGV. One of these permanent stations (RV01) is co-located with an ISTAR device, fixed on the same pole holding the GNSS antenna. Using a reference GNSS station outside the landslide area to adjust this station, indicated that RV01 is subject to movements partly due to pure translations (deep ground induced) and partly due to rotations of the pole holding the GNSS antenna (surface induced). Figure 1a and 1b show the GNSS and ISTAR observations separately and Figure 1c shows how the ISTAR device allows separating the rotations from the GNSS measurements.

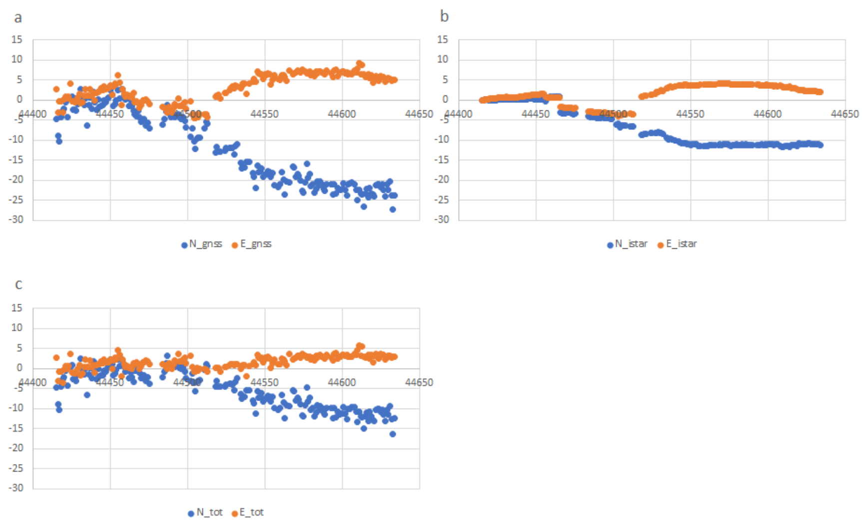

Fig. 1. Upper left: (a) GNSS displacements (landslide + rotations). Upper right (b): ISTAR displacements (rotations). Lower left (c): residual displacements (landslide only). In blue North direction, in orange East direction. Vertical scale is in millimeters. Time spans from June 8th, 2021, to March 13th, 2022.

References

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