Special issue: terrestrial remote sensing for areal deformation monitoring

Alessandro Capra[1] · Marco Scaioni[2] · Andreas Wieser[3]

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The development of new instruments, sensing techniques, and algorithms has opened a new era in the field of terrestrial deformation monitoring and related applications. Robotic total stations with reflector-less range measurement and increasingly also image assistance (Scherer and Lerma 2009), terrestrial laser scanners (Vosselman and Maas 2010), and digital photogrammetry (Barazzetti et al. 2010) allow the acquisition of dense point clouds within a short time, thus yielding detailed snapshot representations of surfaces and a basis for measuring deformations over wide areas. In addition, ground-based interferometric radar (Monserrat et al. 2014) can be used to derive differential deformation with very high resolution, in particular with respect to persistent scatterers as discussed already by Ferretti et al. (2001).

The amount of data provided by these systems is typically much larger than with traditional geodetic techniques, and they potentially represent areal deformations without a need for generalization from displacements of a few carefully selected control points. However, there is no direct point-to-point correspondence between the point clouds obtained at different epochs and thus entirely new algorithms are required in order to analyze deformations (see Dermanis (2011) and Fuentes Santibanez (2012)).

New concepts for areal deformation monitoring (ADM) are being developed and investigated including instrumental advances, sensor and process models, and data processing techniques. All of these require thorough validation and assessment before they can be safely applied in critical monitoring applications.

This special issue features six selected contributions originally presented at the 2nd Joint International Symposium on Deformation Monitoring (JISDM) held in Nottingham on September 2013 and subsequently further elaborated for peer review and publication. They introduce new instrumental developments, compare technologies and review the state-of-the-art with respect to their impact on areal deformation measurements, and propose new methods for deformation analysis. The affiliations of the authors of these papers are located in different countries across the globe (Germany, Greece, Italy, the Netherlands, People's Republic of China, Switzerland, the UK), highlighting internationally recognized relevance of research into areal deformation monitoring.

The first article in the special issue (Papastamos et al. 2015) describes the application of total stations for the measurement of control point 3-D displacements with nearly millimeter accuracy. During a project for the excavation of the Athens underground metro railway, this technique was exploited to assess tilting of some chimneys resulting from ground deformation due to tunneling. While such deformations are usually assumed as a 2-D effect, here the theodolite measurements pointed out the evidence of clear 3-D rigid movements of the chimneys in different directions. This outcome was in full agreement with the new theoretical models of ground deformations in the investigated area.

✉ Alessandro Capra
capra.alessandro@unimore.it

Marco Scaioni
marco.scaioni@polimi.it

Andreas Wieser
andreas.wieser@geod.baug.ethz.ch

[1] University of Modena and Reggio Emilia, Via Vignolese n. 905, 41100 Modena, Italy

[2] Department of Architecture, Built Environment and Construction Engineering (ABC), Politecnico di Milano, Via Ponzio 31, 20133 Milano, Italy

[3] Institute of Geodesy and Photogrammetry, ETH Zürich, Stefano-Franscini-Platz 5, 8093 Zürich, Switzerland

The second paper (Holst and Kuhlmann 2015) deals direct-ly with the problem of areal ground deformation. Here, subsi-dence results from dewatering during lignite mining opera-tions. Usually bivariate models are applied for describing height changes, which approximate the ground movements measured at discrete benchmarks. Due to the possible pres-ence of fault edges in the region of interest, a heuristic algorithm is introduced for their detection and separation from the smooth ground movement. The approach is demonstrated using simulated and real data based on high-precision leveling. As an extension, the authors propose to additionally assess the likeliness of a fault edge within the measured data by calculating curvature radii if densely sampled measurements are available, for example, obtained using airborne laser scan-ning (see Vosselman and Maas 2010) or advanced differential InSAR techniques (Zhang et al. 2015).

The paper Charalampous et al. (2015) presents a new mea-surement system (QDaedalus) for monitoring rigid structures with modal frequencies greater than 5 Hz and sub-millimeter displacements which can replace (or enhance) contact sensors like accelerometers and strain gauges. QDaedalus consists of a clip-on CCD camera attached to the telescope of an electronic theodolite. In the paper, the application of such a system is presented for monitoring a rigid prototype beam and for estimating its modal frequencies up to 30 Hz. A noise level below 0.03 mm has been achieved.

In the paper Scaioni et al. (2015), the concept of image-based deformation measurement (IBDM) is addressed and some examples from the experience of the authors reported. Application domains range from civil and mechanical engi-neering to geosciences, but potentially many others could be concerned. Such methods are based on processing of the im-ages captured by digital cameras thanks to photogrammetric (Luhmann et al. 2013) and Computer Vision techniques (Hartley and Zissermann 2006; Baker et al. 2011). Attractive properties of IBDM are the non-contact observational capability, the large spatial coverage along with the high-acquisition rate, as well as the high degree of automation that can already be obtained. Application methods are divided into three categories: (1) photogrammetric coded-target measure-ment for precise observation of single control points, (2) surface-point tracking to reconstruct dense displacement fields, and (3) comparison of surfaces obtained from dense image matching (Haala 2013). Different camera configura-tions (single-camera and stereo-camera systems, multi-station networks) and geometric models to transform points from image to object space are also discussed.

The next paper (Lindenbergh and Pietrzyk 2015) discusses the problem of measuring deformations and detecting changes in objects surveyed with static and mobile laser scanning. Such applications are typically quite challenging, due to the measurement of non-specific points, the required interpolation and object extraction methods, the propagation of errors that are accumulated over time, and the enormous amounts of data collected within a short time by up-to-date sensors, calling for efficient computational methods. The paper reviews recent methods and applications to multiple domains in the form of a method breakdown, thereby distinguishing methods aiming at pure binary change detection from the ones that also try to quantify changes. The direction of detectable changes in connection with measurement geometry and the reference state are also analyzed.

The last paper in this issue (Soni et al. 2015) describes the application of terrestrial laser scanning (TLS) and close-range photogrammetry (CRP), along with conventional survey tech-niques to the monitoring of a set of masonry arches during a major station refurbishment. This project is part of the Thameslink Programme at Network Rail, which runs from Bedford to Brighton through Central London (UK). Firstly, the paper investigates the capabilities and advantages of using TLS compared to more traditional survey methods and encompasses a case where significant movements occur over an extended period of time. Inter-epoch comparison demon-strates a capability to detect change but highlights a requirement to understand the structure and data quality in making valid interpretations. Secondly, the paper compares TLS and CRP techniques as monitoring tools for creating point cloud data on the same set of masonry arches. Given such volumes of data, the additional challenge is to visualize observed changes and communicate those changes and their signifi-cance to the engineers who must make informed decisions from the data in a timely fashion.

At the end of this Editorial, the guest editors would like to thank all people who have contributed to this Special Issue: the authors of the papers, the anonymous reviewers, and the Editorial Office of *Applied Geomatics* for conducting a high-quality review and editing process for all the published papers. The guest editors would also like to thank the organizers of the 2nd Joint International Symposium on Deformation Monitoring in Nottingham for promoting and supporting this special issue. Special mention goes to Prof. Xiaolin Meng (University of Nottingham). We hope that these papers will not only highlight the broadness of this new field of research but will also spark further ideas and thus contribute to the advances in a current, hot topic in geomatics..

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