Advances of Engineering Geodesy and Artificial Intelligence in Monitoring of Movements and Deformations of Natural and Man-Made Structures

G. Retscher, G. Mentes, and A. Reiterer

Abstract

Rapid developments in engineering, microelectronics and computer sciences have greatly changed both the instrumentation and the methodology in engineering geodesy. Advanced technology is needed to meet the challenges of today. In dynamic monitoring, for instance, there is an urgent need for continuous geodetic measurements to determine complex movements. The development of an early warning system is possible only when exact knowledge of the process of the object's movement (e.g. of a landslide area) and all the other physical parameters are available. Special emphasis is laid on the following research areas: detection of potential movements on a large scale, an efficient and continuous observation of critical areas and knowledge-based derivation of real time information about actual risks in order to support an alert system. The necessary tools range from conventional terrestrial measurements and alignment technology—GNSS, InSAR, geotechnical instrumentation—to software systems such as GIS, Spatial Decision Support Systems (SDSS), and so on. For the development of alert systems, the application of Artificial Intelligence (AI) techniques in engineering geodesy is studied. AI, in general, means studying and designing intelligent agents. An intelligent agent is a system which perceives its environment and takes actions to maximize its chances of success. Methods used for uncertain reasoning are probabilistic in nature, such as Bayesian networks, which represent a general tool that can be used for a large number of problems. The achievements of the work in these fields in the past 4 years are presented and discussed in this paper.

Keywords

Alert systems • Artificial intelligence (AI) in engineering geodesy • Dynamic monitoring • Kinematic and dynamic behaviour of objects • Monitoring and system analysis

1 Introduction

This contribution provides a report of the work of the IAG Sub-Commission 4.2 over the past 4 years. The main achievements in this period are highlighted and discussed. Newly developed sensors and algorithms have been applied and integrated into alert systems, e.g. for monitoring of landslides and for other tasks in engineering geodesy. AI technologies can also be employed in alert systems. These two research fields are discussed in more detail, including the

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work and the results that have been achieved by the working groups WG 4.2.3 and 4.2.4.

2 Investigation of Kinematic and Dynamic Behaviour of Landslides and System Analysis

Surface mass movements can cause a lot of damages. Forecasting landslides is of crucial importance due to the potentially serious consequences to society. It is a difficult and complex task which needs understanding of the relationships between landslide generating processes (geological, geophysical, hydrological, meteorological, etc.) and movements of the sliding block and its surroundings. In addition to the continuous recording of geophysical, hydrological, meteorological, and other parameters, there is an urgent need for continuous 3-D geodetic measurements to determine the complex movements of landslide prone area to understand the kinematic and dynamic behaviour of landslides. There is a chance to develop an early warning system only in exact knowledge of the process of the landslide area' movement and of all the other physical parameters. According to these requirements the working group laid special emphasis on the following research areas: detection of potential landslides on large scale; an efficient and continuous observation of critical areas; and a knowledge-based derivation of real time information about actual risks in order to support an alert system (Kahmen et al. 2007).

The main task of the working group in the last 4 years was the development of 3-D geodetic measurement techniques. In most cases, different geodetic measuring methods were used simultaneously on the test sites, both to get more precise information about the movements and to test and compare the single measuring systems. For detection of landslide prone areas, InSAR technique was used (Riedel and Walther 2008). The InSAR technique was also combined with terrestrial geodetic measuring techniques for continuous observation of surface movements. For terrestrial geodetic measurements new instruments and methods were developed and tested. Instead of geodetic measurements carried out in periodical campaigns a great stress was laid on the continuous geodetic measurement techniques to get data series directly comparable with continuously collected hydrological (water table, stream stage, pore pressure, etc.), meteorological (e.g. precipitation, temperature), etc. data series for the study of dynamic processes of landslides and to get more reliable and comprehensive information for the development of early warning systems.

In Germany, at the Institute of Physical Geodesy of the Darmstadt University of Technology and at the Braunschweig University of Technology, ground-based microwave interferometry was used to monitor surface displacements in a quarry (Niemeier and Riedel 2010; Rödelsperger et al. 2010). Time domain reflectometry (TDR) for the detection of surface displacements in boreholes, reflectorless video tacheometry (VTPS) and a low cost GNSS sensor array for 3-D determination of surface movements were tested by researchers of the Chair of Engineering Geology and Chair of Geodesy of Munich University of Technology and the Institute of Geodesy of the University of Federal Armed Forces Munich (Thuro et al. 2010). At the Institute of Geodesy and Geophysics of the Vienna University of Technology and at the Geodetic Institute of the Darmstadt University of Technology an automatic tacheometer measurement system was used for landslide monitoring and an adaptive Kalman-filtering method was developed to predict displacements (Schmalz et al. 2010) with the aim to develop an early warning system.

All members carried out measurements at different types of landslide areas: in mountainous and hilly regions or on stream banks. This enables a better understanding of the general relationships between movements and geological, geomorphological, hydrological, meteorological, and other factors and their role in triggering landslides. The investigated test sites were: Steinlehnen test site in Austria (Northern Tyrol), Baota test site in China, the Aggenalm Landslide in the Bavarian Alps in Germany, Touzla overpass, Kristallopigi landslide, Basilikos landslide, Gkrika Cuts, Prinotopa site, Anthohori entrance, the Big Cut in Greece, the high loess banks of the river Danube at Dunaföldvár and Dunaszekcső in Hungary, and the Corvara test site in Italy. All participants collected their data in GIS (see e.g. Lakakis et al. 2009a; Mentes 2008a, b) and used these data to develop Spatial Decision Support Systems (SDSS) (e.g. Lakakis et al. 2009b) and early warning systems. To get reliable information about the landslide behaviour with the use of all available information, the Support Vector Machine (SVM) modelling was developed (Riedel and Heinert 2008). An Adaptive Kalman-Filtering method was developed for the Calibration of Finite Difference Models of Mass Movements and for prediction of displacements on the basis of real-time measurements (Schmalz et al. 2010).

In Hungary two characteristic landslide prone areas were investigated. Both test sites are stream banks along the river Danube. On the first test site in Dunaföldvár landslides occurred several times. Here continuous borehole tilt measurements have been carried out since 2002. Relationships between regional tectonics, subsurface structures and mass movements were investigated on the basis on remote sensing data, gravity and tilt measurements in a cooperation between the Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences and the Berlin University of Technology, Institute of Geosciences, Department of Hydrogeology and Bureau of Applied Geoscientific Remote Sensing (Mentes 2008a, b; Mentes et al. 2009; Újvári et al.

Fig. 1 Oblique aerial view of the Dunaszekcső landslide. Photo was taken by László Körmendy on February 17, 2008

2008). At this test site relationships between hydrological effects (water stage of the river Danube, ground water table and precipitation) and stream bank movements were also investigated in detail. The other test site at Dunaszekcső in Hungary gave a good opportunity to investigate the whole process of the landslide mechanism, since a large landslide occurred here on February 12, 2008. The high bank on this area was sliding slowly with increasing velocity from September 2007 till February 12, 2008. On this day there was an abrupt sliding. About 500,000 m^3 loess moved toward the river Danube (Fig. 1).

The movements before, during, and after the sliding process were monitored by GPS and borehole tilt measurements. Figure 2 shows the direction and magnitude of the horizontal movements (white arrows) during the development of the main factures (black lines) and after the sliding. Figure 3 shows tilt records made on the "stable" section of the high bank about 80 m far from the slid part of the stream bank before and after the sliding (+X tilt direction is to East and +Y tilt direction is to North) as an example, indicating that the high bank is still moving and a next slide event is expected to take place on the south part of the test site in the near future (see Fig. 4).

Studying the movement is a good opportunity to understand the kinematics and dynamics of the slope (Újvári et al. 2009) and therefore investigations are continued after the sliding event in 2008, to monitor the development of a new landslide on the south part of the test site.

The Institute of Geodesy and Geophysics of the Vienna University of Technology in cooperation with the Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences are developing measurement methods and their mathematical background for detecting very small displacements by accelerometers and borehole tiltmeters with very high resolution (1 nrad). These small movements are not detectable by geodetic methods but

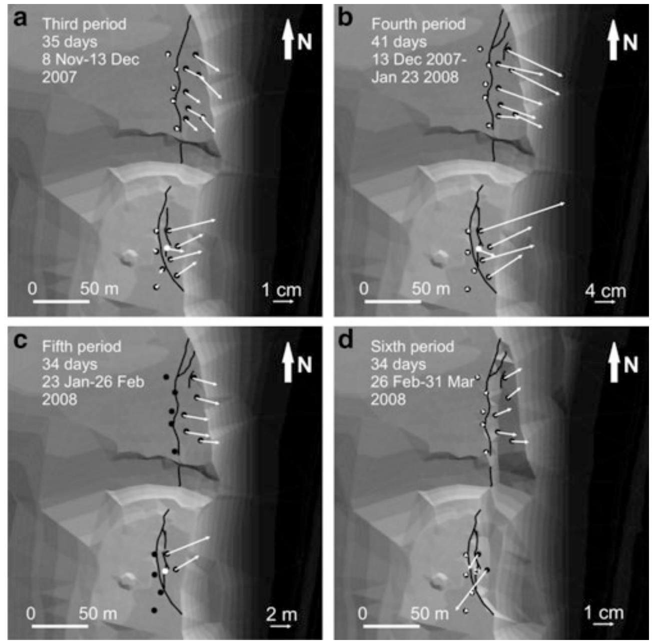

Fig. 2 GPS motion vectors and development of the fractures at the Dunaszekcső study area before, during and after the sliding event on February 12, 2008 (Újvári et al. 2009)

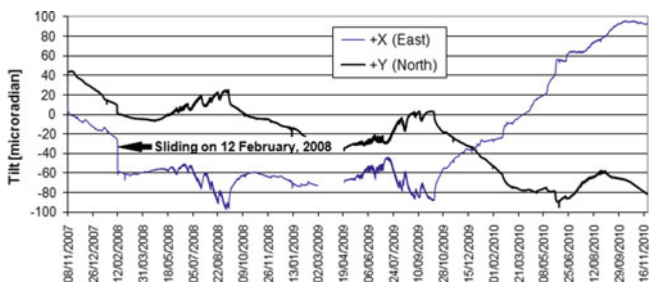

Fig. 3 Tilt record on the "stable" section of the high loess bank at Dunaszekcső, Hungary from 08.11.2007 till 30.11.2010

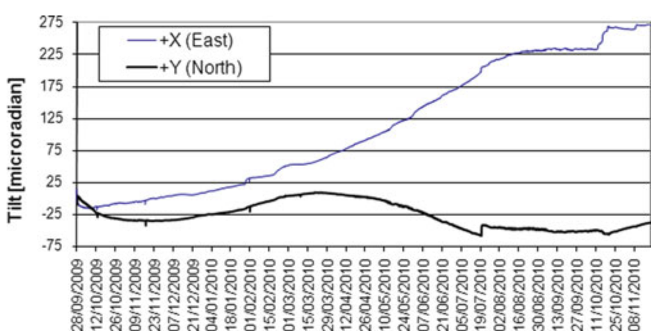

Fig. 4 Results of tilt measurements on the south part of the test site. The magnitude of the tilts are already much higher than during the first landslide

their early detection is very important for forecasting of a possible landslide. The most important issue of this research is how the small movements caused by the initial phase

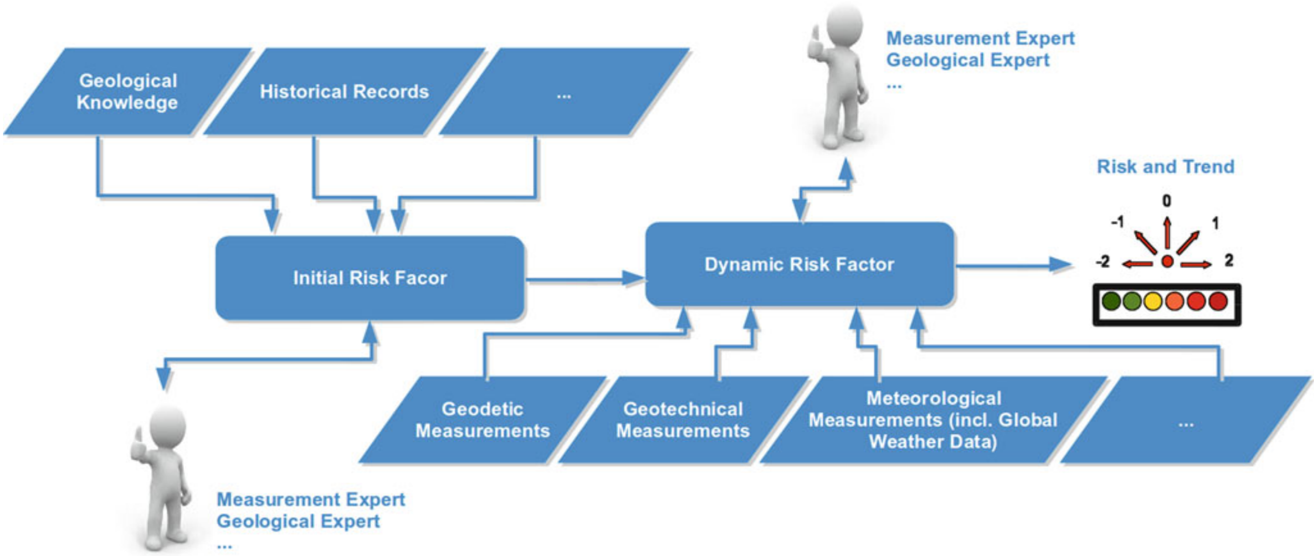

Fig. 5 Simplified architecture of a knowledge-based geo-risk assessment system

of a landslide can be separated from the background noise (Kahmen et al. 2007; Mentes 2008b, c).

During the 4-year period the inactive members of the working group were replaced by other members who were active in landslide research. Members of the working group actively cooperated with each other and achieved new scientific results.

3 Application of Artificial Intelligence (AI) in Engineering Geodesy

Artificial Intelligence (AI), in general, is the study and design of intelligent agents, where an intelligent agent is a system that perceives its environment and takes actions to maximize its chances of success. Many real-world problems require the agent to operate with incomplete or uncertain information. Methods used for uncertain reasoning are probabilistic in nature, such as Bayesian networks, which represent a general tool that can be used for a large number of problems, for example, reasoning (using the Bayesian inference algorithm), learning (using the expectation-maximization algorithm), planning (using decision networks), and perception (using dynamic Bayesian networks). Probabilistic algorithms can also be used for filtering, prediction, smoothing and finding explanations for streams of data, helping perception systems to analyze processes that occur over time. AI techniques also include classifiers and statistical learning methods.

AI has become an essential technique for solving complex problems in Engineering Geodesy. Current applications using AI methodologies in engineering geodesy are: geodetic data analysis, deformation analysis, navigation, deformation network adjustment, and optimization of complex measurement procedures (Chmelina 2008; Chmelina and Grossauer 2010; Grejner-Brzezinska 2008; Reiterer and Egly 2008).

Currently the interdisciplinary research project *i-MeaS* ("An Intelligent Image-Based Measurement System for Geo-Hazard Monitoring") is focused on the development and implementation of an interpretation tool for geo-risk objects. Using knowledge-based techniques the system evaluates information coming from different sources (e.g. geodetic measurements, meteorological data, geological knowledge about the object, etc.) to detect the risk of the object deformation behaviour. The challenging problem in developing such an alerting system is (1) to identify relevant factors and (2) to subsequently capture the interlinkage of these influence factors. The risk assessment has been divided into a two-step decision/evaluation process: (1) the evaluation of the object at the beginning of inspection/monitoring ("*Initial Risk Fac*tor") and (2) the evaluation of the risk during inspection/monitoring (*"Dynamic Risk Factor")*. The first step estimates data sets from former monitoring periods, from historical records, knowledge about the object (geological, geophysical, etc.) and facts captured by a filed inspection (driven by a questioner). The second step evaluates the risk during the monitoring—geodetic and geotechnical measurements, meteorological data, updated facts/knowledge about the objects, and other parameters build the basis for this decision process. Finally, the system calculates a risk factor and a trend of risk, both updated regularly. Figure 5 shows a simplified overview of the system architecture (Lehmann and Reiterer 2008; Vicovac et al. 2010).

4 Conclusions and Outlook

In this paper the achievements of the two working groups "Investigation of Kinematic and Dynamic Behaviour of Landslides and System Analysis" (WG 4.2.4) and "Application of Artificial Intelligence (AI) in Engineering Geodesy" (WG 4.2.3) of Sub-Commission 4.2 in the last 4 years have been summarized. It can be seen that the development of alert systems employing AI technologies is very important nowadays and therefore an increased use of AI techniques in geodesy is expected, mainly because tools become more available. The integration of AI techniques into the development of geodetic applications greatly simplifies system creation (see Reiterer et al. 2010a, b). The work of the two WGs shall be continued in the next period. Additionally, a new Study Group SG 4.1 on "New Technologies for Disaster Monitoring and Management" was established in 2011. This new SG will be interlinked with the two WGs.

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