Abstract

The determination of the ground deformation can be realised by applying various measurement methods such as levelling, gravimetry, photogrammetry, laser scanning, satellite navigation systems, Synthetic Aperture Radar (SAR), and many others. To ensure a continuous service for monitoring large-scale displacements, at least one of the geodetic measurement methods has to be implemented in the subsidence area. However, providing sufficient spatio-temporal resolution of three-dimensional (3-D) deformation with high accuracy can be challenging using only one method. Therefore, the application of multiple complementary methods allows the establishment of an overall system for the determination of three-dimensional displacement values and rates. The presented thesis concentrates towards exploiting strengths and reducing weaknesses of Global Navigation Satellite System (GNSS) and Interferometric Synthetic Aperture Radar (InSAR) techniques by providing a new methodology of integration involving Kalman filter algorithms for non-linear strong ground displacements.

An unquestionable advantage of GNSS technology is the possibility of continuous monitoring of deformations in 3-D space. Moreover, the evolution of GNSS estimation methods allows for obtaining a highly precise position determination with a relatively low latency (ranging from a few seconds to less than one hour). The limitation of satellite navigation technology is the spatial range of the measurements. Ground deformations can only be observed at the point where the GNSS antenna is located. Additionally, acquisition, installation, and maintenance of equipment may also involve high costs. At least several dozen GNSS receivers are needed to acquire a ground system to monitor horizontal and vertical movements across an area of interest. Moreover, some technical issues related to, e.g., power loss may introduce significant interruptions in the time series of observations.

In contrast to the GNSS technique, the InSAR methods enable the detection of large-scale subsidence areas with the possibility to use free products and software (e.g., Sentinel-1 and SNAP). Large-scale InSAR investigations provide a better overview of local landform changes. The radar imagery coverage ranges from 5 to 250 km with a ground resolution of 0.5 to 20 m. Unfortunately, InSAR methods also have some limitations related to data acquisition technology. The data are available in one line-of-sight (LOS) dimension with a few-day latency in acquiring new products. Due to the nearly north-south trajectory of the SAR satellites, the system has limited sensitivity to ground movements in this direction. Furthermore, the InSAR time series of displacements can be affected by outlier values related to the limitations of the technique, e.g., decorrelation in vegetated areas, local atmospheric effects, or other phase unwrapping problems.

The main goal of the thesis is to determine a novel integration method between the data acquired by the InSAR and GNSS techniques regarding the capabilities and limitations of these two technologies. The presented methodology is suitable for the non-linear dynamic ground deformations, conducted for areas affected by underground mining works. The fusion process is based on the Kalman filter approach, which is capable of ingesting the time series of GNSS topocentric coordinates with significant gaps and noisy time series of InSAR ascending and descending LOS velocities affected by troposphere artefacts and improper SAR phase unwrapping errors.

Keywords: GNSS, InSAR, Kalman filter integration, ground deformation, displacement monitoring