Analysis of the influence of radar interferogram combination on digital elevation and movement models accuracy

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Ph.D. Thesis

Abstract

Radar interferometry is a relatively new technique, which can be used to obtain high resolution Earth surface data from satellite or airborne images. Its most promising application fields are production of digital elevation models and observation of surface movements, especially in areas not well covered with ``classical" methods. In digital elevation model production accuracy of approximately ten meters in horizontal and a few meters in vertical direction can be obtained. Differential interferometry is another useful technique, which enables detection of surface movements in the scale of used wavelength that is approximately half a centimetre for ERS satellites.

In interferometric processing complex radar satellite or airborne images are used. These contain both amplitude and phase of reflected microwaves. Value of complex phase depends on surface electromagnetic properties and distance from the emitting antenna to target and back to receiving antenna. When we have two images of the same area that were made from slightly different orbits, we can relate the interferogram - phase difference of the two images - to elevation on the ground. However, for obtaining good results the viewing geometry and interferometric conditions have to be considered with special care. Images have to be made from almost the same orbits and phase reflectance between image acquisitions must not change considerably.

In differential interferometry three images can be used to detect small surface movements. With three images two interferograms can be produced and from them one differential interferogram can be computed. The later should be non-zero only if phase reflectivity changed between image acquisitions or if surface moved uniformly. The first factor represents an inconvenience and should be avoided while the second one allows accurate displacement determination.

Theoretical background of interferometry is known for more than twenty years and there has been more than fifteen years from the first successful interferometric processing. The breakthrough of interferometry occurred after the year 1991 when the first European remote sensing satellite ERS-1 was launched. Since then the technique was used in numerous studies, ranging from hydrology and volcanology to seismology, glaciology and ecology. Nonetheless, interferometry is still not an operational technique. There are several reasons for that, most notably lack of standardized processing procedures, but also complicated software and problematic interferogram combination.

The thesis starts with theoretical background of interferometry, its historical development and radar remote sensing in general. Special attention is paid to sensitivity of the technique to various parameters. One chapter is devoted to digital elevation model production and quality control. Further on, thesis describes the entire process of interferometric processing. Detailed instructions for image pair selection, image co-registration and preparation of external digital elevation model are given. The existing external lower-quality model is used to improve accuracy and to simplify processing. Interferogram computing is described as well, but special attention is given to its enhancement since it can considerably simplify further processing. The study describes in more detail phase unwrapping - the process of solving phase ambiguity - and conversion of interferometric phase to digital elevation and displacement models. Extensive description and some advanced suggestions regarding geocoding of interferometric results are also given.

The main part of the thesis is devoted to interferogram combination. Combination of several interferograms can be used to create models of larger areas and improve the accuracy in certain regions. Techniques for merging both ordinary and differential interferograms were developed. Digital elevation models were improved with coherence weighted averaging and by using external elevation models. Weighted averaging increased the accuracy statistically by emphasizing ``good'' data while external models were used to eliminate large errors of partial models. The problem is more complicated in the case of movement models. When steady long-term changes were observed, for example surface subsidence due to underground activity, coherence weighted averaging was used as well. In observation of instantaneous displacements caused by an earthquake for example, interferograms were combined in a controlled way taking into consideration the interdependence of interferograms.

Several case studies are presented in the thesis. First, a digital elevation model of Slovenia and its surroundings with resolution of 25 by 25 m was produced. Analysis of the results showed that interferogram combination reduced total elevation error from approximately 10 m to 3 m. Further on, movements caused by the earthquake in the upper Posočje and surface subsidence in the area of Velenje were also analysed. In the surroundings of Bovec average deflation between 0,5 cm and 2 cm has been detected, while near Velenje subsidence rate of up to 2 cm/year was observed.

Keywords

synthetic aperture radar, interferometry, differential interferometry, digital elevation model, digital image processing, satellite images

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