ANALYSIS OF THE GEOMETRIC PARAMETERS OF SAR INTERFEROMETRY FOR SPACEBORNE SYSTEMS

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ABSTRACT

Since SAR interferometry was first introduced for topographic mapping by Graham in 1974, the suitability of various applications of this technique has been investigated. The second main issue has been the reconstruction of digital elevation models (DEMs). By using differential interferometry a wide field of applications such as the monitoring of change detection, ice sheet motion, seismic events and volcanic hazards has been opened. The three different implementations of the geometry (along-track, across-track, and repeat-track interferometry) has been further investigated. Along-track interferometry is used on airborne systems for the observation of ocean currents. Across-track interferometry is the standard geometry used for airborne systems. Repeat-track interferometry is realised using data acquired by spaceborne systems from slightly different orbits. This paper focuses on spaceborne systems, because the available systems have a standard due to their equipment. This allows a comparison of the different systems which is not always possible with airborne systems. Some of these systems, for example, use a number of motion compensation systems which improves the quality of the data significantly. A complete review of the field of SAR interferometry is given by Gens and van Genderen (1996).
It has been part of the recent research in this subject to investigate suitable applications for SAR interferometry. This has especially included the investigation of the limitations of this technique. The quality of the results, in the form of coherence images as well as interferograms, depends on several parameters which have a complex influence on the geometry. These parameters are analysed in this paper in more detail.

KURZFASSUNG

Nach der ersten Anwendung von SAR Interferometrie zur Erstellung topographischer Karten durch Graham 1974 wurde die Eignung dieser Technik für verschiedene Anwendungen näher untersucht. Das zweite Hauptanliegen war die Rekonstruktion digitaler Höhenmodelle. Durch die differentielle Nutzung der Interferometrie hat sich ein weites Feld von Anwendungen, wie z.B. das Erfassen von Oberflächenveränderungen, die Bewegung von Eisflächen sowie die Untersuchung von Erdbeben und Vulkanausbrüchen, geöffnet. Es gibt drei verschiedene Umsetzungen der Geometrie (along-track, across-track und repeat-track Interferometrie), die grundlegend erforscht wurden. Along-track Interferometrie wird von Flugzeug getragenen Systemen zur Beobachtung der Meeresoberfläche benutzt. Across-track Interferometrie ist die Standardgeometrie von Flugzeugsystemen. Repeat-track Interferometrie wird durch Daten realisiert, die durch Satellitensysteme von zwei nebeneinander liegenden Orbits erfaßt worden sind. Dieser Artikel befaßt sich ausschließlich mit Satellitensystemen, da die verfügbaren Systeme einen gewissen Standard haben. Dies ermöglicht einen Vergleich dieser Systeme, was bei Flugzeugsysteme nicht möglich ist. Einige dieser Systeme nutzen z.B. Geräte zur Bewegungskompensation, die die Qualität der erfaßten Daten signifikant verbesssert. Ein vollständiger Überblick des Bereiches der Interferometrie ist bei Gens und van Genderen (1996) zu finden.
Ein Teil der derzeitigen Forschung in diesem Bereich konzentriert sich auf die Erforschung möglicher Anwendungen für die SAR Interferometrie. Dies schließt speziell die Erforschung der Grenzen dieser Technik bezüglich der Anwendung mit ein. Die Qualität der Ergebnisse in Form von Kohärenzbildern und Interferogrammen hängt von verschiedenen Faktoren ab, die einen komplexen Einfluß auf die Geometrie haben. Diese Faktoren werden in diesem Artikel im Detail analysiert.

1. GEOMETRIC PARAMETERS

The first error source for the geometry is the satellite system itself. All the available spaceborne systems are well calibrated, but, nevertheless, they have different characteristics, e.g. different incidence angles, different spatial resolution, etc. The calibration of the satellites has to be very precise to reach the expected accuracy, i.e., minor effects such as an internal clock drift which can cause phase artefacts (Massonnet and Vadon, 1995) have to be taken into account even at this stage. The system introduces a small amount of error caused by systematic effects such as system noise, image misregistration, etc.

The position of a satellite is described by its orbit. The main problem here is the accuracy of the determination of the orbit. The precision of tracking varies for different satellites. For example, with the launch of ERS-2, the Precise Range and Range-rate Equipment (PRARE) system is supposed to provide additional information for determining the antenna position more precisely during the data acquisition. The fact that the orbits are often not exactly parallel leads to range migrations which can be removed during the data processing. Another point is the time the satellite needs to repeat in a slightly different orbit. The accuracy needed for a specific application determines whether data e.g. from RADARSAT (24 days repeat phase) or only from the ERS-1/ERS-2 tandem mission (1 day apart) are suitable. This time difference between the data acquisitions leads to a temporal decorrelation, which among other factors depends on the weather conditions during the data acquisition. Until now, the simultaneous data acquisition to avoid the temporal decorrelation is only implemented on airborne systems; however, the concept of an implementation for satellites by means of a tethered system is given by Moccia and Vetrella (1992). Besides the derived phase difference which mainly depends directly on the topography of the observed site, the accuracy of the baseline estimation is an important influencing factor for the quality of the results.

The length of the baseline in connection with the time difference between the data acquisition determines the coherence which is a standard measure of quality of an interferogram. At the critical baseline length (e.g., about 1100 m for ERS-1) there is a complete loss of coherence. According to Schwäbisch and Winter (1995) there are several other factors which lead to a decreasing amount of coherence:

- thermal noise,
- different atmospheric conditions during the data acquisitions,
- phase errors due to the processing,
- changes in the object phase between the data acquisition,
- slightly different viewing positions.

Another problem is the influence of the topography and the weather conditions. Quantifying these parameters in SAR interferometry is a rather complex task. The topography and its backscattering behaviour directly cause changes in the phase difference contained in the interferogram. Besides the geometric distortions well known in any radar imagery such as layover, foreshortening and shadow, the slope angle has a direct impact on the quality of the phase unwrapping. In areas with steep slopes the 2π-ambiguity of the phase cannot be solved without introducing additional information. The volume scattering of any object leads to a time delay in the reflection of the signal. The result is a distortion in the geometry; i.e., the signal is received at another position. The direction of the slope has a direct impact on the angle of the phase gradient.

Wind, snow and temperature are parameters which have a direct impact on the topography as well as on the coherence of the images. The coherence is quite sensitive to temporal changes, e.g. the change of the soil moisture by freezing (Askne and Hagberg, 1993).

Finally, each sensor works with a signal which is determined by its frequency, polarisation and bandwidth. These parameters have a specific impact on the data depending on the conditions at the data acquisition such as atmosphere, acquisition time or weather. The frequency limits the depth of penetration of an object. While a sensor using X-band receives the backscattered signal from the top layer of a forest, the sensor which uses a wavelength in P-band is able to receive additional information from the ground. Depending on the structure of the surface, the response from the objects varies with the polarisation used by the system (e.g. VV for ERS-1/ERS-2). This is used as additional information for the interpretation of radar imagery; however, it has no direct influence on the geometry.

The atmosphere needs to be investigated because of its known influence on SAR interferometry (Tarayre and Massonnet, 1994). For radar imagery in general the influence of refraction in the ionosphere and effects caused by the troposphere might be negligible. However, for the accuracy requirements in SAR interferometry they have to be taken into account. The compensation for this effect is still a challenging task and part of the current research.

2. DATA PROCESSING

The data processing of interferometric imagery is another field which has a significant impact on the quality of the derived products such as coherence maps, interferograms and digital elevation models. The necessary steps of the data processing are well understood and implemented in several ways. However, it is still a challenging task to develop a software package for SAR interferometry to an operational status.

According to De Fazio and Vinelli (1993) the processing scheme for SAR interferometric data includes in general (1) the registration of the single look complex images, (2) the formation of the interferograms, (3) the phase unwrapping, and (4) the reconstruction of the digital elevation model. In this paper the first two steps of the data processing are analysed in more detail.

Assuming a sufficient accuracy of the used complex data sets, the quality of the interferometric results depends on the performance of each single processing step. For an accurate registration of the images a precise knowledge of the shift between the two scenes is needed. This is done by measuring control points in both scenes. After performing the coarse registration a first fringe image should be calculated to check the presence of a sufficient number of fringes. The coarse registration is already very sensitive to changes in the shifts.

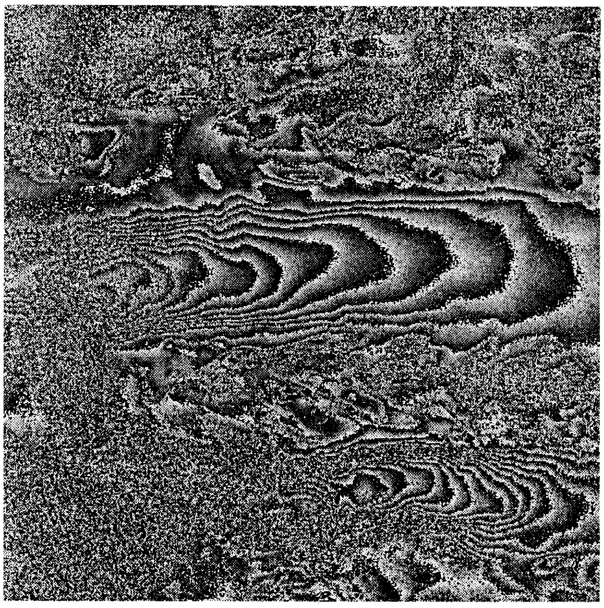

Figure 1: Interferogram with a shift of -3/-5 (Image courtesy of University Freiburg)

Figures 1 and 2 show an example from two ERS-1 scenes acquired on 3 and 6 March 1994 at the northern part of the McClary Glacier near the Argentinean station on the Antarctica peninsula. There has been a significant amount of surface changes between data acquisitions. This temporal decorrelation reduces the number of fringes rapidly. The variation between the images is caused by choosing shifts in range direction which differ by a single pixel.

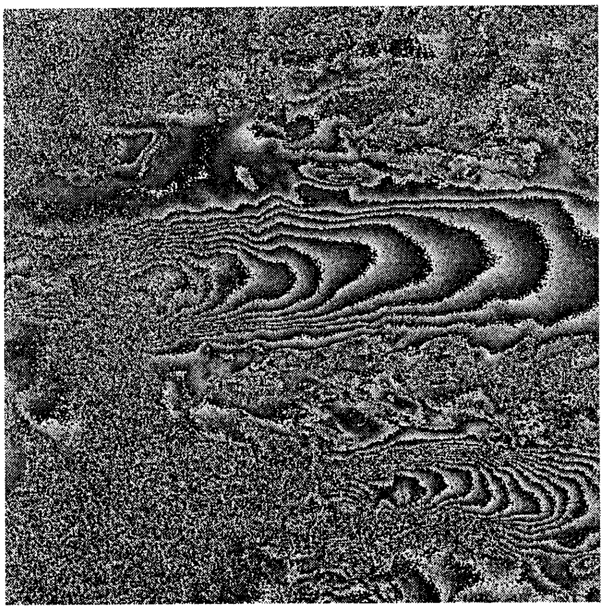

Figure 2: Interferogram with a shift -2/-5 (Image courtesy of University Freiburg)

Assuming a sufficient number of fringes, the fine registration can be performed. The accuracy of the fine registration depends mainly on a precise knowledge of orbital parameters. A further improvement can be achieved by deploying corner reflectors. These can be used as ground control points as well as other points which can be clearly identified. The use of ground control points becomes essential if data are used from systems with a low precision tracking (e.g. data from the shuttle mission SIR-C/X-SAR).

To reduce the amount of noise at each stage of the processing, filtering techniques can be applied. The use of any filter technique improves the images visually; however, it reduces the information content at the same time. Until now, only filtering techniques have been applied in SAR interferometry which were originally developed for other applications. This opens a new field for the development of new filtering techniques due to an optimal conservation of the phase information given by the complex imagery.

Based on the finely registered images the interferogram as well as the coherence image can be calculated. The quality of the coherence depends mainly on the way the resampling is performed. There are several implementations given in the literature (Lin et. al., 1992; Small et. al., 1993; Geudtner, 1995) which are based on different considerations due to the time required for the data processing.

3. IMPROVEMENTS

There are, in general, two possibilities to improve the quality of SAR interferometric products. The first aspect is the accuracy and amount of the data introduced into the data processing.

For the use of ERS-1/ERS-2 data, for example, precise orbit parameters are provided by ESA. Based on a better knowledge of the orbit, the geometry is more accurate, which leads to better results for the registration of the images.

Data from the SIR-C/X-SAR shuttle mission provide the user with data sets from different wavelengths. Because of the different backscattering behaviour of the surface topography due to the wavelength, data are obtained which could be used, e.g., as additional informaton for solving the ambiguity of the phase to improve the phase unwrapping.

The influence of atmosphere effects is assumed to decrease by averaging as many as possible data sets over the same area, which is the same approach used for reducing speckle.

The performance of the data processing itself is the other aspect to improve the quality of the results. For example, by using cubic splines instead of a bilinear interpolation during the resampling process, the signal-to-noise ratio can be increased. This leads to an improvement of 10 % of the coherence in the coherence image (Geudtner, 1995). The data processing is a complex task which is still on the way to reach an operational status. At present, there are no established commercial software packages for SAR interferometry on the market.

4. CONCLUSIONS

One of the most sufficient ways for a complete description of the complex structure of the influencing factors is an error propagation model. This needs to be further developed in order to estimate the influence of single parameters due to an interferometric product.

The influence of the atmosphere is assumed to be one of the most limiting factors due to the accuracy which can be reached by SAR interferometric techniques. The distortions caused by atmospheric effects appear locally and vary in time and are therefore difficult to correct. This aspect still needs to be further investigated.

At present, one of the main issues in the development in SAR interferometry is to reach an operational level for the different applications. The basic techniques are well studied and understood. However, there are several aspects in the data processing scheme to be optimised in terms of performance, accuracy and time. This includes especially the development of new filtering techniques.

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