A Fast and Efficient Technique for SAR Interferogram Geocoding

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ABSTRACT

In the following paper a new efficient technique for SAR interferogram geocoding is presented. The method is based on the well-known geolocation approach which is used to relate the SAR signal domain to the geometric Euklidian space in which all geo-information is represented. In contrast to common approaches the geocoding problem is solved via an object-to-image transformation, hence allowing the user to precisely define the desired DEM sampling. The methodology appears to be extremely fast, yet highly accurate since supplementary interpolation of the DEM values can be avoided by proper oversampling of the interferogram data.

INTRODUCTION

The geocoding of SAR interferograms, defined as the conversion of the unwrapped interferometric phase into a terrain map in an earth-related coordinate frame, is an essential step in deriving rectified digital elevation maps from interferometric SAR data. It can principally be divided into two different steps: the conversion of the interferometric phase into terrain altitude and the transformation of the height information from the SAR range/azimuth coordinate frame into an earth-related reference frame. Both steps are intrinsically connected to each other since the concept of ”terrain height” already implies the definition of an earth's reference surface with zero altitude. Nevertheless, the geocoding procedure not necessarily needs to be performed in two parts, as will be proposed with the new technique.

Different approaches to solve the geocoding problem have been summarized in recent publications [1][2]. However, most of the techniques have been designed for small amounts of data, hence are reported to be rather time-consuming in the context of large area DEM generation. Furthermore, height accuracy often suffers from improper data interpolation especially in areas with steep terrain slopes.

In this paper a new efficient technique is presented which on the one hand reduces the processing time efficiently while on the other hand enables an easy adaption of the DEM sampling to the intrinsic sampling of the input (interferogram) data, therefore avoiding undesired interpolation. The method is based on the well-known geolocation approach which will be shortly recalled in the following section. Contrary to the forward solution that is applied in the common geolocation procedure an inverse object-to-image transformation constitutes the basis of the new algorithm and is subject of the main part of the publication. A final discussion on the applicability of the method concludes the paper.

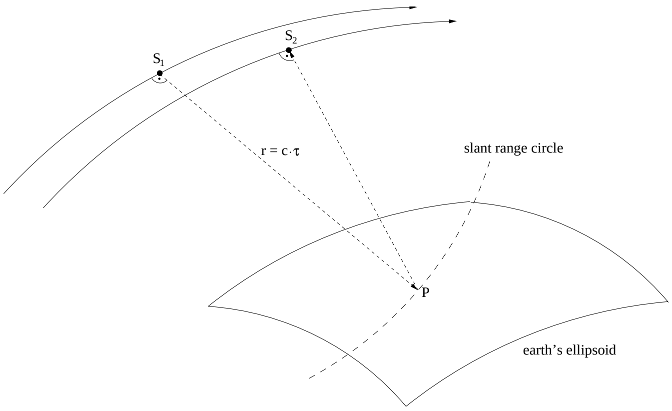

Figure 1: Geolocation approach with interferometric extension

GEOLOCATION APPROACH

The geolocation approach was originally developed to accomplish the geocoding of SAR magnitude images and is reported in detail e.g. in [3][4]. It marks the interface between the SAR signal domain, where the entire information is represented in range and azimuth time coordinates, and the real 3-dimensional Euklidian space to which all geophysical information has to be related to. The geolocation links each image pixel to its individual location in a terrestrial reference frame. Fig. 1 illustrates the basic idea of the method: starting from the sensor position S_1, which is accurately known through the orbit data information in combination with the azimuth time coordinate t, and exploiting the range distance r via the range delay measurement τ $(r = c \cdot \tau)$, the position P of the regarded pixel on the earth's surface can be estimated introducing two further assumptions:

- the shape of the earth's surface can be modeled, typically applying an ellipsoidal approximation for computational simplicity:

$$\frac{x^2+y^2}{a^2}+\frac{z^2}{b^2}=1 \qquad (1)$$

$$\text{with } a,b = semi-major\ and\ semi-minor\ axes$$

- the antenna squint angle of the observation is known with sufficient accuracy in order to introduce the proper orientation of the slant range circle

For interferometry purposes the common geolocation is extended by a subsequent orbit location, i.e. the second antenna's position S_2 (from which the same image pixel has been observed) is localized (see Fig. 1). Again the precise antenna squint angle has to be taken into account.

Both measurements together enable in principle the estimation of the signal path difference (hence the absolute interferometric phase) in case the terrain altitude is known. However, although in interferometric DEM generation particularly the height is the unknown quantity, the geolocation approach can be utilized for height derivation, e.g. by modeling the dependency $h = h(\Phi)$ via introduction of various terrain heights in (1), as described in [5][6].

A NEW INVERSE GEOCODING ALGORITHM

Principle

The basic idea of the newly developed geocoding procedure is to start with user-defined object coordinates (in a specified geo-projection) and directly calculate the terrain height values for this predefined coordinate grid. Accordingly, an object-to-image transformation rather than the common image-to-object transformation is carried out, hence rendering superfluous a further data interpolation.

The algorithm is based on the following two assumptions on the interferometric phase Φ:

1. For each image range line, the interferometric phase (including the *flat-earth* component) as a function of the range delay time has a monotonous (increasing or decreasing) behaviour. Although this is correct in theory, phase values in real interferograms are often corrupted by noise or are subject to phase aliasing (caused by undersampling of steep terrain slopes). Nevertheless, a monotonous curve can in general be restored by proper noise filtering.

2. For a given horizontal location on the earth's surface, the dependency of its height on the interferometric phase yields a monotonous curve, too. This is guaranteed by the nature of the imaging process (see Fig. 2): following the vertical straight line of increasing terrain heights, the different hyperbolas (each marking an isoline of constant Φ) are crossed. Since simultaneously, due to the side-looking geometry, the circles of constant range are passed through, a monotonous dependency between Φ and slant range r (respectively range delay τ) is implied.

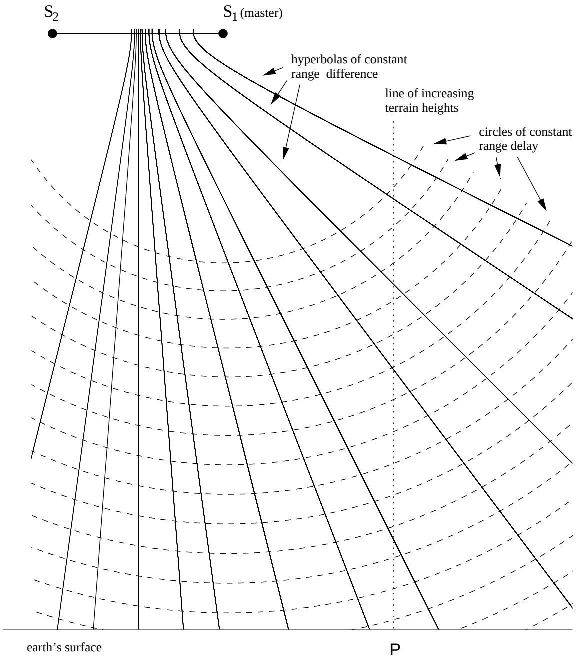

Figure 2: InSAR geometry: the terrain height depends monotonously on both the range delay and the range difference

Exploiting these conditions, the height value of a specific image pixel can be estimated by intersecting both phase functions.

Processing steps

Starting point of the geocoding procedure is the selection of the object coordinate frame, i.e. map projection, desired sampling, and boundaries of the final image extension, which defines all the coordinates for which the altitude has to be calculated. Processing then consists of a scanning of all these coordinate pairs that are within the selected boundaries. In the following one of those locations P on the earth's surface is considered.

As first step a transformation into the Cartesic coordinates of the orbit data's system is carried out, using an approximate first guess height value. Thereafter an orbit location in the master orbit is performed, as described above. This leads on the one hand to a certain azimuth time t in the master image (actually the time at which this pixel was, respectively would have been illuminated), which in turn provides a range line i of the unwrapped phase image, yielding a monotonous curve of phase values of which one may correspond to the correct height of the point (precondition 1). Since fractal positions of i are possible, nearest neighbour interpolation has to take place. Adequate oversampling of the original interferogram may improve the determination accuracy. However, care has to be taken with the estimation of i since it is slightly dependent on the actual terrain height of P especially if no zero Doppler SAR processing was applied. In that case the phase curvature as a function

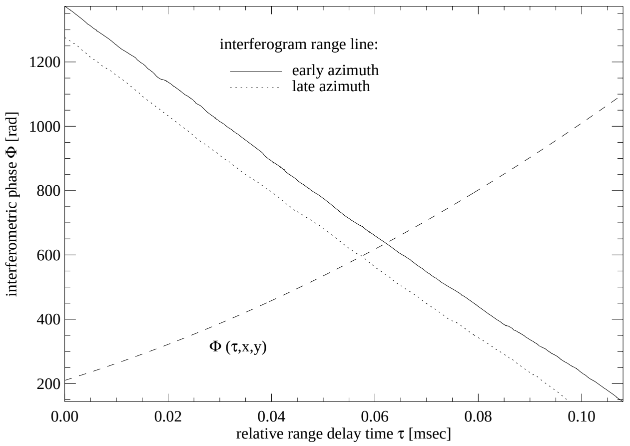

Figure 3: Intersecting phase curves (example from an ERS Tandem interferogram)

of h migrates over several range lines, hence cannot be easily represented by a single i.

In addition to this phase curve a further functional relationship between Φ (emerging from the two signal path lengths) and h can be established by introducing various terrain heights and performing orbit locations in both orbits. Now, since Φ depends on τ at the same time, the relationship $\Phi = \Phi\left(\tau\right)$ can be set up instead, having in mind that it is still related to one specific location on the earth's surface. In more detail, coefficients of a 2nd-degree polynomial

$$\Phi\left(\tau, x, y\right) = k_0\left(x, y\right) + k_1\left(x, y\right) \cdot \tau + k_2\left(x, y\right) \cdot \tau^2 \qquad (2)$$

are computed, where x, y denote the horizontal coordinates of P. Herewith, precondition 2 is exploited.

The requested terrain height now can be obtained in a look-up procedure which in turn is realized via intersection of the two phase curves: the one of the image range line corresponding to azimuth time t and the one described by (2). Again, it is useful to have oversampled the original phase image in the range direction as well so that the intersection can be estimated more precisely and higher accuracy subsequently can be achieved. Fig. 3 gives a typical example of the phase curves intersecting each other.

In this way the height values can be obtained for each desired coordinate location. However, in order to save computation time the setup of (2) is done only for a grid of 10×10 original coordinates that span the entire image. The calculated coefficients k_j are then interpolated for the intermediate coordinates, using a biquadratic least squares fit. A sufficient accuracy is guaranteed since only small variations of the coefficients across a typical scene extension (up to $100 \times 100\,km^2$) are present.

Performance

The method was applied on ERS full frame interferograms ($\simeq 5000 \times 5000$ samples). Interferogram-to-DEM conversion for an output pixel spacing of $25\,m$ takes about $12\,min.$ on a PC with Pentium Pro 200 MHz CPU. Results were compared to a solution of a common approach [5] and yielded no significant deviations.

CONCLUSIONS

A new efficient technique for SAR interferogram geocoding was presented. Phase-to-height conversion and map coordinate estimation is performed simultaneously with an object-to-image transformation, which marks the main advantage of the approach compared to common solutions that need additional, often extremely time-consuming resampling of the data. However, monotonous behaviour of the interferometric phase along range is a basic requirement for high accuracy achievement, but is not necessarily guaranteed in real interferograms. Furthermore, efficient computation requests zero Doppler SAR processing as well as a precise first guess height value for each pixel. To this purpose it is recommended to include coarse elevation information, originating e.g. from ETOPO5 data.

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