UNWRAPPING METHOD FOR INTERFEROMETRIC IMAGES

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ABSTRACT

To analyze SAR interferometric data, an unwrapping process must be first performed. Most so far proposed solutions use either local or global methods. In this paper we propose a mixed method to solve this problem, based on a 3-step iterative process: a local unwrapping is first performed and then improved through a markovian segmentation, false unwrapped residues are finally detected and corrected. A deterministic algorithm is used for the relaxation process; wrong unwrapped areas are corrected by a backtracking mechanism. Some results obtained by this approach, which presents a lower computational cost compared to complex stochastic unwrapping methods, are also presented.

1. INTRODUCTION

Since 1986 [1], Interferometric Synthetic Aperture Radar (ISAR) observations provide measures to analyze terrain topography [2] and its small changes with a high accuracy [3, 4]. As for the stereoscopic method, two acquisitions are necessary; each interferogram pixel corresponds to the phase difference between the two radar signals backscattered by the same area. This difference $\Delta \phi$ is theoretically linked with the path length difference $\Delta R$ ($\Delta \phi (\mod 2\pi) \approx \frac{4\pi}{\lambda} \Delta R$) and is proportional to the elevation of the backscattering cell $h$ (as shown in figure 1).

Since $h$ can be estimated by the phase difference $\Delta \phi = \varphi$ with a modulo $2\pi$ ambiguity, unwrapping must be performed to remove it, i.e., to find the right order $k$ (label value) verifying $h \propto \Phi = 2\pi k + \varphi$.

There are three main types of unwrapping techniques. First proposed, local methods are based on unwrapping techniques of mono-dimensional signals extended to the bi-dimensional case; for each pixel the order value is chosen according with those of its previously observed neighbors [5, 6]. But with these methods, an error made at one pixel may corrupt the estimated phase values over a large surface. The second category of methods concerns the global approach. It looks for structures, such as edges, to characterize fringes and label them [7, 8]. Usually these methods are less subject to error propagation. Unfortunately these two approaches are very noise sensitive. So, a third approach has been introduced to locally analyze the data with a global effect of the result. Such a method has been proposed by Dupont and al. within a markovian framework [9, 10]. However the chosen relaxation algorithm led to a heavy computational cost. In this paper we propose a new method, with a low computational cost and present some associated results.

2. A MIXED GLOBAL-LOCAL METHOD

Our approach is based on an iterative process: an unwrapping image is first computed with a classical method (described below in step #1), this scene is then improved with a markovian segmentation (step #2), finally residual discontinuities are set as "not unwrapped" (step #3) and the process returns to step #1 until an end condition will be satisfied.

2.1. Step #1 – Initialization

The initialization is based on a local method proposed by H. Lim and al. [11] where the unwrapping process is performed iteratively:

- for each pixel, a confidence value is computed as the difference between a predicted phase $\Phi_p$ and the measured one $\Phi_s$:
Figure 2. The 3 steps process

- predicted phase: \( \Phi'_s = \sum_{r \in V_s} \frac{w_r \Phi_r}{\sum_{r \in V_s} w_r} \)

where \( V_s \) is the set of neighbors of the pixel \( s \) and \( w_r \) is a weight coefficient proportional to the distance between \( s \) and its neighbor \( r \);

- measured phase: \( \Phi_s = \varphi_s + 2k\pi \)

with \( k \) the integer closest to \( \frac{\Phi'_s - \varphi_s}{2\pi} \);

- a pixel with low a confidence value that is less than a given threshold is said reliable,

- areas with reliable data are unwrapped.

At each step of the iteration, the threshold increases in order to unwrap more pixels. The first lower values used ensure that only reliable unwrapped phase are accepted; the later higher ones, allow more pixels to be unwrapped. This method is fast because the order of each pixel is attributed as soon as the threshold condition is satisfied, and that pixel will never be again examined. However, this is the reason of the hazardous results appearing in case of a low Signal to Noise Ratio (SNR) interferogram. Moreover local errors are often propagated.

2.2. Step #2 – Markovian Segmentation

The second step is a segmentation algorithm performed with a markovian model [12]. The previously unwrapped interferogram is considered like a system, and an energy function is defined on a neighborhood system with associated potential functions. The system solution is reached when the energy is minimum.

Let:

- \( S \) be the set of image pixels,

- \( K = (K_s)_{s \in S} \in \Omega = \{1..k_{max}\}^{[S]} \) the segmentation process corresponding to the order,

Figure 3. Up: Mount Etna interferogram. Center: Unwrapped phase after one iteration of the process (step #1 and #2). Down: Residue image (step #3).
• \( \Psi = (\Psi_s)_{s \in S} \in \Delta = [0, 2\pi]^{[S]} \) is the random variable used to describe the phase, corresponding to the grey level value of the interferogram,

• \( k = (k_s)_{s \in S} \) and \( \varphi = (\varphi_s)_{s \in S} \) are respectively the values of the random variables \( K \) and \( \Psi \).

We are given a Markov Random Field on these pixel sites, defined by a neighborhood system \( V = \{ V_s, s \in S \} \), where \( V_s \) is the set of neighbors of the pixel \( s \), and by clique potentials.

Like most models we use a first energy term based on a membrane model:

\[
U_1(\varphi, k) = \sum_{s \in S} \sum_{r \in V_s} |(\varphi_s + 2k_s \pi) - (\varphi_r + 2k_r \pi)|
\]

\( U_1 \) measures the reconstructed surface regularity.

We add a second term based on the local homogeneity within a fringe according to a small neighborhood (a pixel tends to have the same order than its neighbor with the closest grey level value):

\[
U_2(\varphi, k) = \sum_{s \in S} \left( \sum_{r \in V_s \setminus k} \chi(k_s = k_r) \right)
\]

where \( \chi(k_s = k_r) = 1 \) if \( k_s = k_r \) and 0 otherwise. \( U_2 \) measures the local phase homogeneity.

The optimal labeling is obtained with a deterministic optimization method (Iterated Conditional Mode). The result of step #1 is used to start this relaxation algorithm.

2.3. Step #3 – Residues

Due to the deterministic relaxation, the result often corresponds to a local minimum, presenting discontinuities, ie regions where the phase difference between two neighbors is greater than \( \pi \). To reduce these discontinuities, we classify them as "residues" labeled to "not even unwrapped".

Then we iterate the global unwrapping process and return to step #1.

The global iteration process ends when the energy value becomes stable in step #2 (see figure 4).

3. RESULTS

The data interferogram and the result of the method with one iteration of the global unwrapping process are displayed in figure 3. The result after eight iterations may be seen on figure 5.

The main advantage of this method is the use of the local properties of the markovian approach without its usual heavy computational cost. The result is obtained the with about 10 iterations of the global unwrapping process and less than 200 iterations for each ICM (step #2), versus 2,000 to 100,000 iterations in the stochastic optimization case. As the gray arrows shows in figure 5, this method allows some true discontinuities (the pointed one is due to

Figure 5. The final unwrapped image and the reconstructed DEM.

the radar incidence). Furthermore, all pixels are always unwrapped, ie no pixel will be labeled as unwrappable. This can be interesting for areas with a low SNR, like the top of mount Etna. However, in areas with no coherence, the obtained labels will be meaningless: the ionic sea surface pointed by the black arrow on figure 5 should be a flat area.

4. PERSPECTIVES

Two types of discontinuities may occur within the unwrapping process: discontinuities caused by initialization errors or true ground discontinuities. The first one must be corrected but the second must be kept. This could be achieved by classifying the true and false discontinuities. For example we could make use of a segmentation technique like that proposed by E. Trouvé and al. [13] where unwrapping obstacles are detected through a classification merging several measures performed over the phase, coherence and amplitude data. An alternative could be the use of these coherence and amplitude images to compute another potential function allowing true discontinuities.
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REFERENCES


