A Region Growing Algorithm for InSAR Phase Unwrapping

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Abstract — In this paper, a region growing algorithm for InSAR Phase Unwrapping is presented. Initial experiments show that the region growing phase unwrapping algorithm can handle SAR interferograms which are more noisy than other unwrapping algorithms can handle. This algorithm also allows dense fringes caused by steep topography.

INTRODUCTION

A number of phase unwrapping algorithms for SAR interferogram have been proposed in recent years [1–4], However, none of them are very satisfactory when noisy and dense fringes occur.

BASIC CONCEPTS

The success of phase unwrapping depends upon the path chosen to perform the unwrapping, and choosing of the best path has been troublesome for many current algorithms. The region growing algorithm minimizes unwrapping errors by starting at pixels of high data quality, and proceeding along paths where unwrapping confidence is high. The algorithm is also able to correct unwrapping errors to a certain extent, and stop their propagation. Part of the basic concepts of this algorithm has been described in [5].

The unwrapping process can be considered as a state machine. At each step, the current state consists of some contiguous regions of unwrapped pixels. Surrounding each region, one pixel layer deep, is a ring of pixels which will be considered for unwrapping in the next step. Each pixel in the ring is called a growth pixel, as illustrated in Fig. 1, where each disc represents a pixel. The transparent discs represent pixels which have been unwrapped, and together they from an unwrapped region, shown dotted in Fig. 1. The gray and black discs represent pixels which have not yet been unwrapped. The gray discs represent the growth pixels. The black discs represent other pixels which will not be considered for unwrapping in the current iteration. The growth pixel marked "G" is the current pixel to be considered for unwrapping.

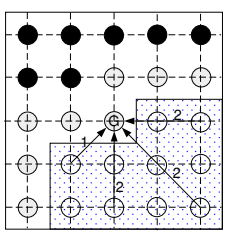

Figure 1 Growth pixel and its neighbours

How a Growth Pixel Is Unwrapped

Unwrapping of a growth pixel uses phase predictions. From each of the N_u unwrapped neighbour pixels of the growth pixel, an individual prediction of unwrapped phase value ${\phi^p}_k$ of the growth pixel is calculated based on the unwrapped phase or phase gradient along each line shown in Fig. 1. The subscript k is the prediction line number and the superscript p stands for prediction. The predictions are of 1st order or 0th order depending on the neighbour status. The composite prediction ϕ^p is a weighted average of these ${\phi^p}_k$:

$$\phi^p = \left(\sum_{k=1}^{N_u} w_k \phi_k^p\right) \Big/ \left(\sum_{k=1}^{N_u} w_k\right) \tag{1}$$

The weights w_k are given by the number of unwrapped pixels used in the prediction.

The phase prediction (1) is used to try to unwrap the growth pixel. The proposed unwrapped phase value ϕ_u at the growth pixel is computed as:

$$\phi_u = \phi_w + 2\pi m \tag{2}$$

where ϕ_w is the wrapped phase at the growth pixel, and the ambiguity number m is the integer closest to $(\phi^p - \phi_w)/(2\pi)$. As the unwrapping is based on the final prediction rather than any of its neighbours alone, a phase change larger than π between two adjacent pixels is then possible.

Control of Unwrapping Using Reliability Tests

The attempt at unwrapping the growth pixel is accepted only when a reliability test is passed. Let the measurement of reliability be r, and a tolerance threshold be t. The reliability test is passed when $r > t$. There may be various measurements of reliability. Three of them that have been used in our experiments are:

1.
$$r_p = 1 - d_p/(2\pi) > t_p \tag{3}$$
$$d_p = \left(\sum_{k=1}^{N_u} w_k |\phi_k^p - \phi^p|\right) \Big/ \left(\sum_{k=1}^{N_u} w_k\right). \tag{4}$$

2.
$$r_u = 1 - d_u/(2\pi) > t_u \tag{5}$$
$$d_u = |\phi_u - \phi^p| \tag{6}$$

3. r_c is the local coherence c of the interferogram [6]

$$r_c = c = \left|E\{a_m e^{j\phi_m} a_s e^{-j\phi_s}\}\right| / \sqrt{E\{a_m^2\}E\{a_s^2\}} \tag{7}$$

where (a_m, ϕ_m) and (a_s, ϕ_s) are the amplitude and phase of the master and slave SLC images, and $r_c > t_c$.

After running a number of experiments, it was found that the following combination of reliability tests worked the best: A fixed threshold test for measurement 1 and measurement 2 is added to the application of measurement 3, while t_c is gradually relaxed, and all of the three measurements must pass their respective tests.

The Process of Region Growing and Merging

Phase unwrapping is carried out concurrently but independently in a number of regions. Each region starts from a seed where reliability is high, as measured by the local coherence.

As each of the regions grows individually, two or more regions may develop an overlap area. As each growth pixel is processed in the current iteration, growth rings are established, as shown in Fig. 2. The gaps in the growth ring are pixels which have failed the reliability test. The regions before growing are dotted and the overlaps that occur in the growth rings are shaded in Fig. 2.

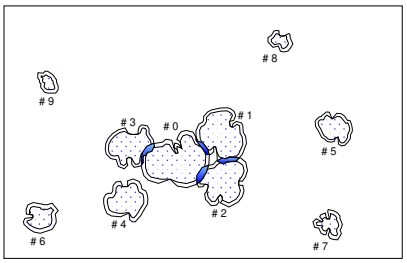

Figure 2 Regions, growth rings and overlaps

Suppose region i and region j have an overlap area of N pixels. The difference between the ambiguity number m_i for region i and the ambiguity number m_j for region j, caused by the different seed, is examined at each pixel k in the overlap area. Their average ambiguity number difference *dif* is then calculated:

$$dif = \frac{1}{N}\sum_{k=1}^{N}(m_j(k) - m_i(k)) \tag{8}$$

and *dif* is then rounded off to its closest integer *adif*.

The reliability of this estimate is then checked by the following procedure. Suppose there are N_c pixels in the overlap area that agree with *adif*. The estimate of the difference between the ambiguity number for the two regions, *adif*, is considered as reliable as long as the following two threshold tests are passed:

$$N_c \geq t_{rn}, \qquad N_c/N \geq t_{rr} \tag{9}$$

If the estimation of the difference between the ambiguity number for the two regions is reliable, the two regions are then be merged. Otherwise, the two regions are kept separate and the whole overlap area is cleared. An example of merged regions and cleared overlaps is shown in Fig. 3.

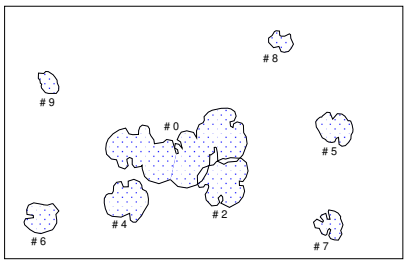

Figure 3 Merged regions and cleared overlaps

Whenever vacancies of region indices appear after region merging, additional regions can be started from newly-selected seeds.

PHASE UNWRAPPING EXPERIMENT

A portion of the phase image of an Sardegna ERS-1 interferogram is shown in Fig. 4, with the corresponding local coherence image shown in Fig. 5.

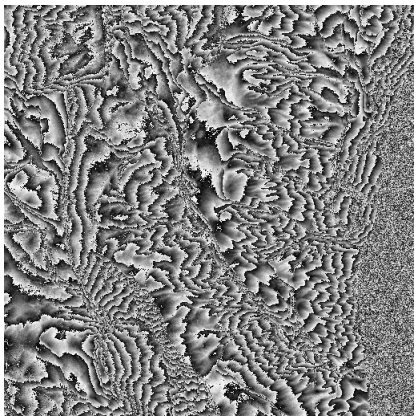

Figure 4 Phase of the interferogram, before unwrapping.

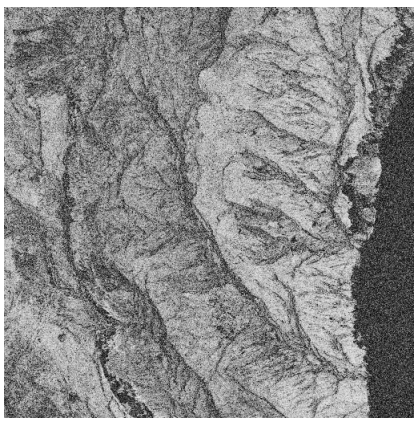

Figure 5 Coherence of the interferogram

This SAR interferogram is considered to be difficult to unwrap because of its many areas of low coherence caused by the local topography and vegetation. The distribution of the "residues" is shown in Fig. 6. This interferogram is too noisy for "residue linking" algorithms [1, 3] as they must correctly link the right pairs of "residues", which is difficult with such a high "residue" density [7]. The "edge detection" algorithm [2] faces the difficulty of detecting edges where edges join together and are fractured.

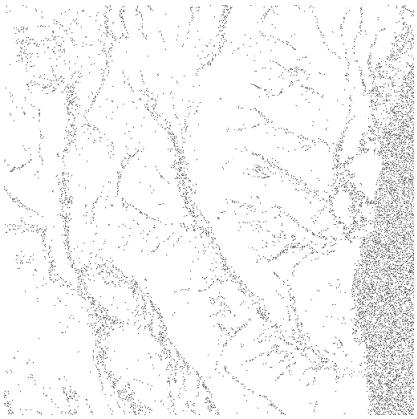

Figure 6 The "residues" distribution of the interferogram

The Sardegna interferogram was unwrapped using the region growing algorithm. A total of 255 initial seeds were selected based on regional diversity and highest coherence. Growth pixels were checked for unwrapping reliability using the thresholds: $t_p = 0.75$; $t_u = 0.75$; t_c starts from $200/256$ and is gradually relaxed to 0. Unwrapped regions are joined using the following reliability thresholds: $t_{rn} = 3$; $t_{rr} = 3/4$.

The unwrapped phase is shown in Fig. 7. The gray scale is reversed so that increasing heights as brighter. The displayed result is the region with index 0. The total number of pixels in this region is about 92% of the land area.

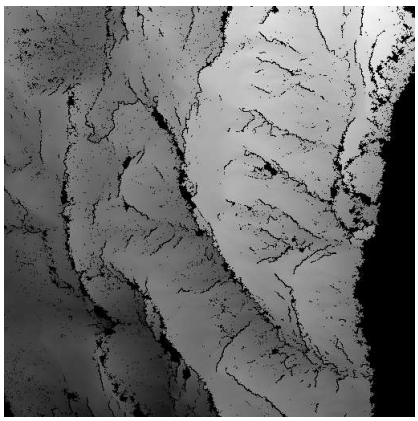

Figure 7 Unwrapped phase of the interferogram, region 0

CONCLUSIONS

We have developed a new phase unwrapping algorithm based on the following principles: using a prediction technique to estimate correct phase; using as much neighbourhood phase information as possible; applying a reliability check to the growth pixel unwrapping attempts; relaxing the reliability threshold gradually; carrying out unwrapping in regions which are allowed to grow with careful checking; merging and rearranging the growth regions properly.

With these principles, the region growing phase unwrapping algorithm can handle SAR interferograms which are more noisy than that other unwrapping algorithms can handle, as the Sardegna ERS-1 interferogram is commonly considered difficult for phase unwrapping. In addition, areas with steep topography where phase changes larger than π between two adjacent pixels are allowed by this algorithm.

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