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Phase Unwrapping Based on Region Block[1)]

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Abstract Phase unwrapping for interferogram is the key and the most difficult step in the processing of Interferometric Synthetic Aperture Radar. By using the fringe lines of the interferometric phase image, we present one phase unwrapping algorithm based on region block. The image is first divided into distinct blocks. Blocks are delimitated by fringes lines and the border of the image such that there is no phase jump inside each of the blocks. Then phase unwrapping is performed block by block over the whole image. Finally, post-processing is applied to remove local error due to incorrect unwrapping. Results are shown on the real and simulated data. Comparison with one of the traditional methods demonstrates the efficiency and robustness of the approach.

Key words Interferometric phase image, phase unwrapping, synthetic aperture radar, fringe line

1 Introduction

In interferometric phase image the pixel value φ is called principal value ($-\pi<\varphi\leqslant\pi$), or wrapped phase value. The integer multiple of 2π in the absolute phase value can not be directly measured from the interferometric phase image, which is necessary for calculating the target height. We denote the absolute phase value (or unwrapped phase) as Φ, and we have:

$$W(\Phi)=\varphi, \quad -\pi<\varphi\leqslant\pi \tag{1}$$

where W is the wrap function. We refer to the procedure of resolving inverse function W^{-1} as phase unwrapping:

$$\Phi=W^{-1}(\varphi)=\varphi+n\cdot 2\pi, \quad n\in N \tag{2}$$

All generally existing phase unwrapping methods are based on the assumption that the pixel value in the interferogram is sampled in accordance with Nyquist sampling theorem, that is, the neighboring pixel differences are less than π in absolute value. On this assumption and in the ideal case in which no noise and no phase discontinuity are present in the data, the absolute phase could be recovered accurately by simply path-integration[1]. However, the presence of residuals (adjacent pixels with phase difference greater than π) in the actual interferometric phase image often makes the ideal case insufficient. Even the interferogram is filtered to reduce the noise, the residuals can not be completely removed.

Branch-cut method[2] and least square method[3] are the two representative algorithms in recent years[4]. The former was presented by Goldstein, whose basic idea is to link all residuals by appropriate branches first, and then avoid those branches in the subsequent integration. Since some small isolated areas are often formed when the phase image exhibits residuals and confusion, this method does not always work[5]. The least square method formulates the phase unwrapping problem as the minimization of a least square expression between the estimated and the unknown neighboring pixel differences of the unwrapped phase. It is very computationally efficient and robust when it makes use of fast Fourier

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transform technique, but the influence of residuals is not included. To overcome this problem a weighted least square method was derived[4,6]. However, the weighted least square algorithm proposed is iterative and not as efficient as the unweighted one. So many improving techniques for this method were presented[7]. Novel method presented by Costantini[8] and minimum weighted discontinuity method presented by Flynn[9] have the same lack as least square algorithms, the resultant accuracy of those methods depends on the weighting mask used.

The most particularly feature in the interferometric phase image is its fringe pattern, which comes from the phase value jumps. It is necessary to take full advantage of the fringe line information in phase unwrapping stage. Lin[10] described an edge-segment linking and curve-fitting approach for interferometric phase images. Yue[11] detected edges by wavelet functions and linked the fringe lines by active contour. This paper presents another robust phase unwrapping method, which is based on the basic idea of Lin. Also the fringe line image is detected in this new method. However, the linking technique, the limits for the fringe model of the interferometric phase image, and post-processing are different. This paper is organized as follows. In the next section the region division for interferometric phase image is described in detail. Then, the phase unwrapping based on region block is presented in section 3, comparison and analysis are given in section 4. We discuss the results and give some conclusions in section 5.

2 Region division for interferometric phase image

Fringe line image extracted from the filtered interferometric phase image is a black and white image, the line is of one-pixel width. When the fringe line image is superimposed on the original phase image, the lines and the border of the image exactly divide the image into blocks, inside which the pixel value is between $-\pi$ and π, that is, the phase unwrapping is completed inside the blocks. We choose Fig. 1 (a) as an example to illustrate the procedure. Fig. 1(a) has 256×256 pixels, which is provided by European Space Agency.

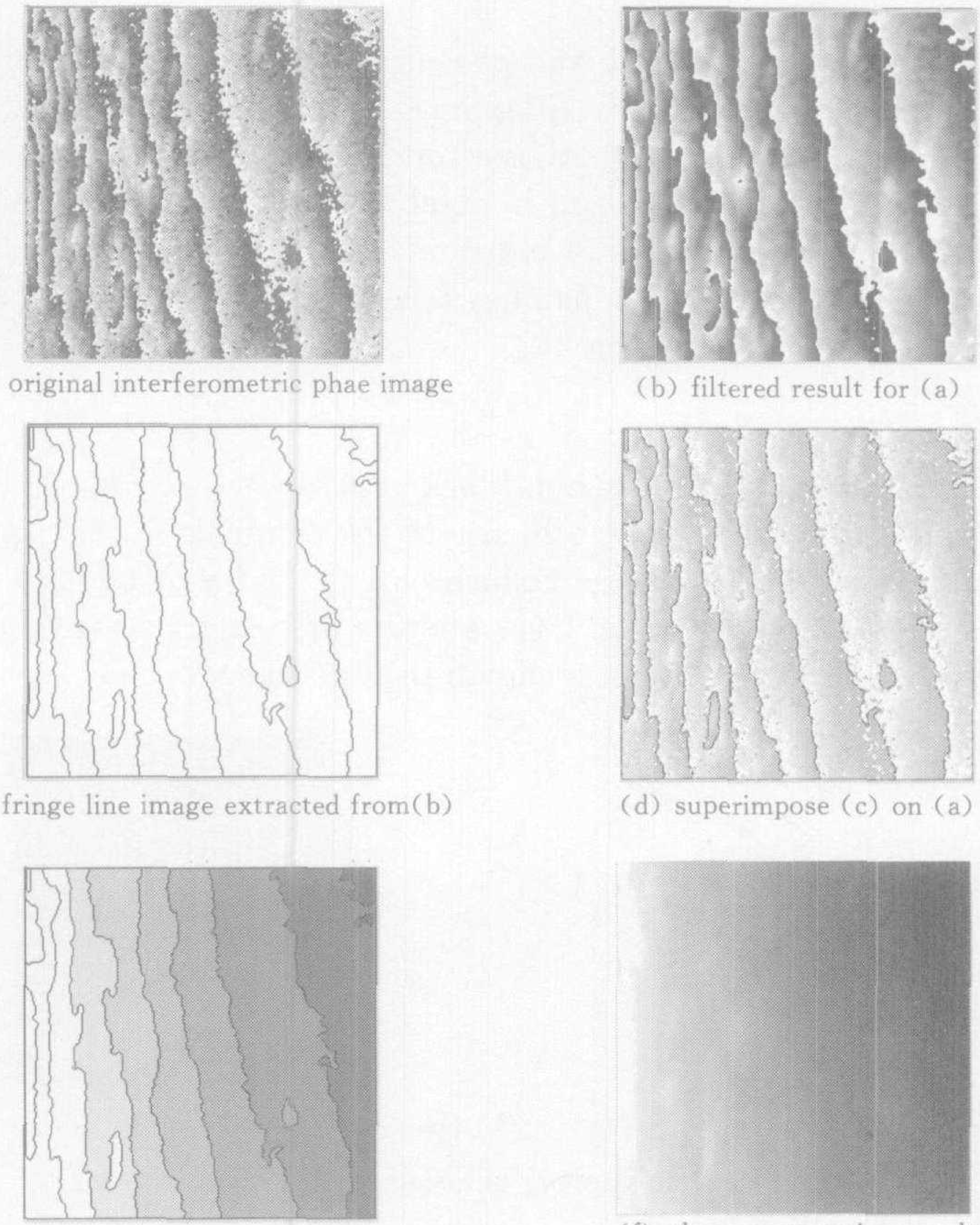
Fig. 1(b) is the filtered result for Fig. 1(a) by using vector filtering[12]. The fringe lines extraction from filtered interferogram includes several main steps as follows.

1) Edge points extraction roughly: Whether or not one pixel is on the fringe edge is decided by comparing the adjacent pixel difference with one given threshold. Those edge points are restored as one image.

2) Edge segments extraction: It is a refinement process to remove the false edge points from fringe point image. The width of the final edge segments should keep one pixel and the length should be longer than a given threshold. The threshold value depends on the images, it should be large enough to remove the edge pieces arising from noise, and it also should be small enough to keep the fringe line information.

3) Linking the segments into lines: This is the most important step, the edge segments must be connected into continuous and closed fringe lines. Directional searching algorithm[13] is used in this step. Finally, one fringe line image is obtained.

The fringe line image extracted from Fig. 1(b) is shown in Fig. 1 (c), which is superimposed on the original interferogram shown in Fig. 1 (d). We can find that the whole interferogram is exactly devided into closed region blocks by the fringe lines and the border of the image.



(a) original interferometric phae image (b) filtered result for (a)

(c) fringe line image extracted from(b) (d) superimpose (c) on (a)

(e) fill-flood result for(c) (f) phase unwrapping result

Fig. 1 Division and phase unwrapping for interferometric phase image

3 Phase unwrapping based on region block

Lets consider Equation (2). Our purpose is to recover Φ from known φ. Instead of the traditional methods which aim at recovering Φ directly, we will simply try to calculate n. Obviously, if n is known, Φ is known and the problem is solved. Our problem is then reduced to calculate n, which has the following characteristics: 1) n is an integer; 2) n is a constant value inside one region block; 3) between two neighboring blocks the difference value of n is $+1$ or -1.

Now each n corresponding to each block in the fringe line image should be computed by flood-fill method. Suppose that reference point is P_0, and that the corresponding integer is n_0. We fill the first block of P_0 with n_0. Then all the blocks are scanned to fill with corresponding n_i, which depends on n_{i-1} and the phase jump between the two blocks. The scanning is not over the border. Fig. 1 (e) is the flood-fill result for Fig. 1 (d), the reference point P_0 is (1,1), and the initial fill value n_0 is 100.

On the basis of the filled fringe line image, the phase unwrapping problem can be simplified by applying block integration. Set the actual phase value on the point P_0 is $\Phi(P_0)$:

1) For each pixel not on the fringe lines P, the unwrapped value is computed by the formula

$$\Phi(P) = \Phi(P_0) + (n_i - n_0) \cdot 2\pi + \varphi(P) \tag{3}$$

where n_i is the fill value of the block in which the point P is;

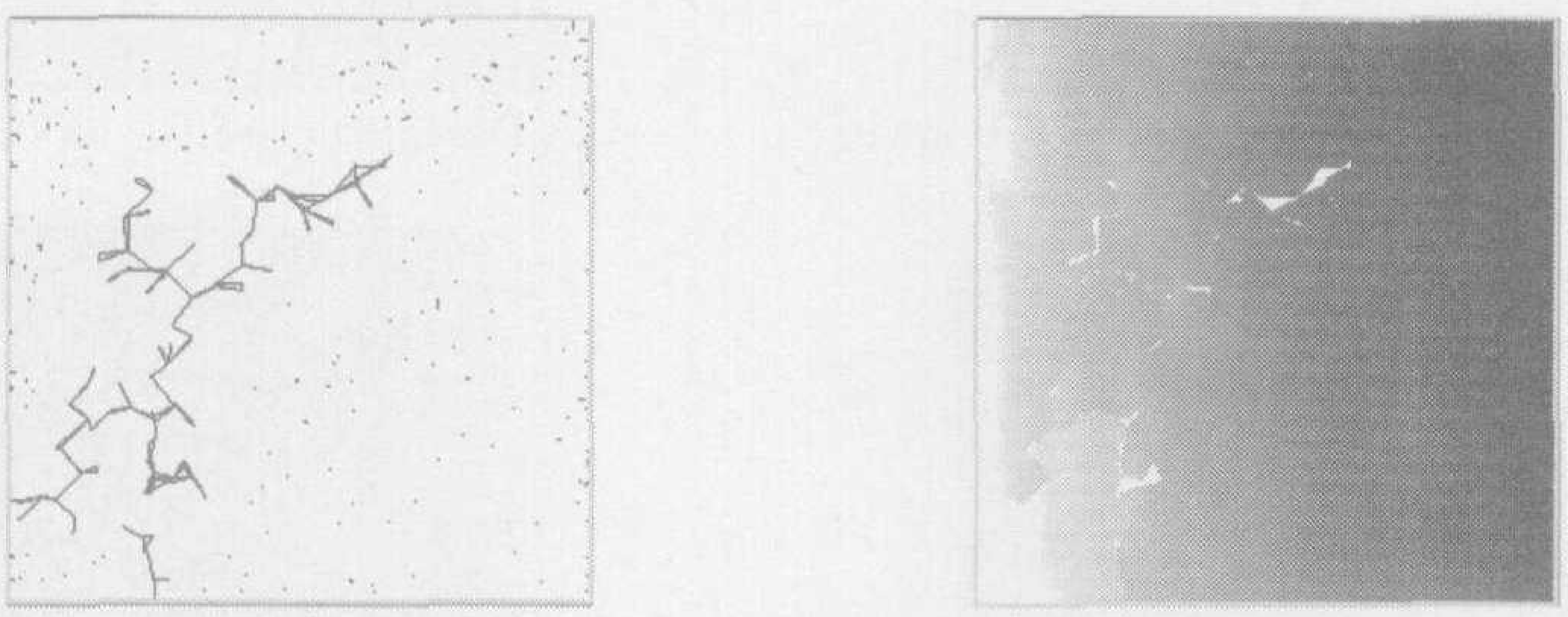
2) For those pixels on the fringe lines, the unwrapped value is substituted by the av-

erage of unwrapped neighboring pixels.

Fig. 1 (f) is the phase unwrapping and post-processing result by combining unfiltered interferometric phase image (a) and the filled image (e). Post-processing is one technique of rectification deviation. Generally, there are some white or black patches near the fringe lines after phase unwrapping. The reason is pixel false segmentation which leads to false computation of n and therefore results in more or less 2π to be added on those pixels. In post-processing stage, we find out the patches according to Nyquist theorem and then correct the value by adding or subtracting 2π.

4 Comparison and analysis

The phase unwrapping based on region block actually belongs to the integration-based category. We compare and analyze the influence of the residuals in this section. One of the traditional integration-based methods——Branch-cut method will be applied. As in Fig. 2 (a), the residuals are selected from Fig. 1 (a) and the branches are also set. The phase unwrapping result by Branch-cut method is shown in Fig. 2 (b).

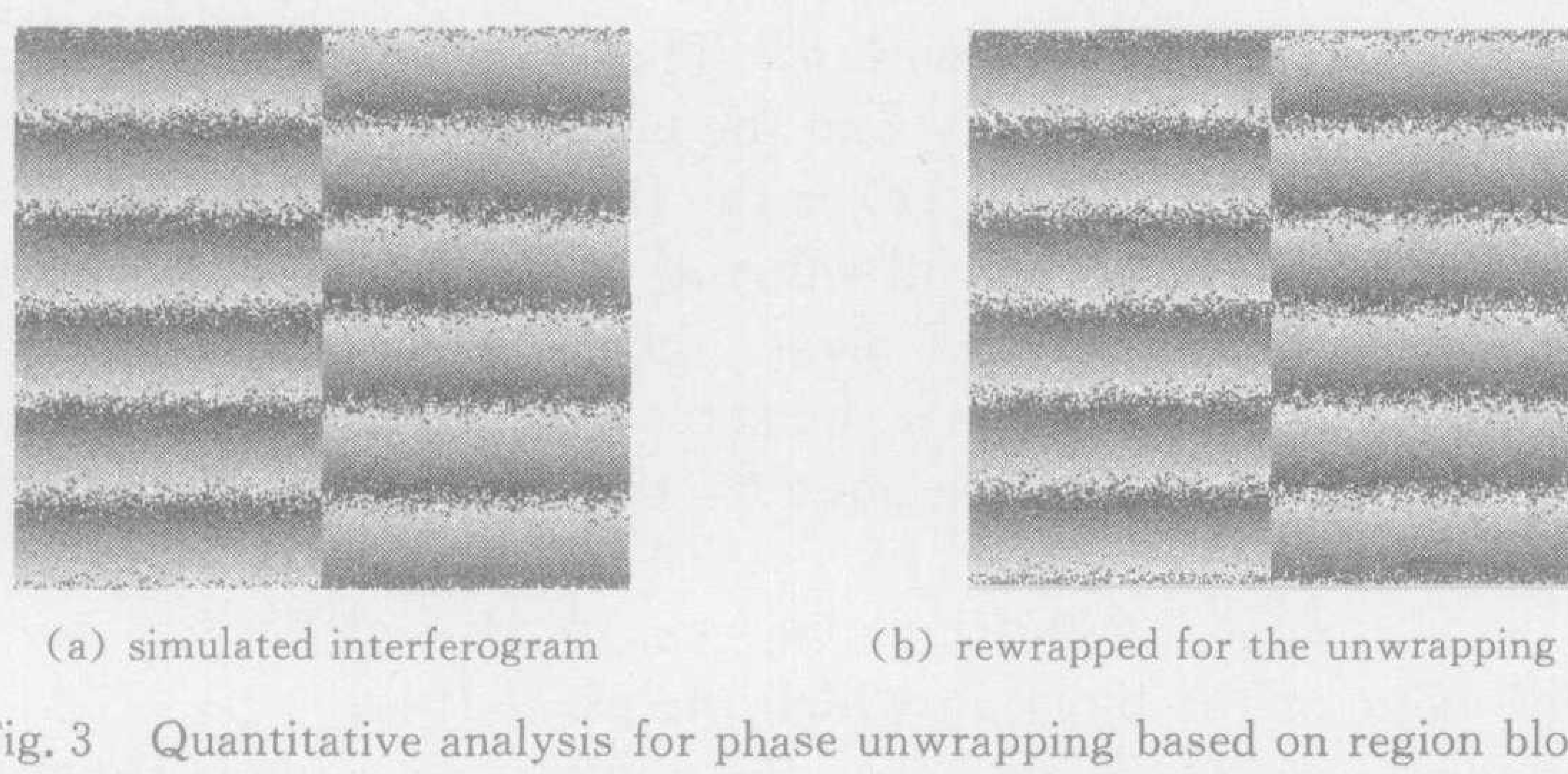


(a) branches from Fig. 1 (a) (b) phase unwrapping result by Branch-cut method

Fig. 2 Phase unwrapping by using Branch-cut algorithm

We note that the interferometric phase image is not unwrapped completely in Fig. 2 (b), there are several small incorrect areas in the unwrapping result. This is because of the isolated areas formed by the branches. Our method can avoid this problem (see Fig. 1 (d)). The main difference between the branch-cut method and ours is that the former is based on pixels and the latter is based on blocks. The method based on blocks is much more robust, without error propagation and without isolated area, that is, each pixel in the image can be unwrapped.

For quantitative analysis, we use one simulated data shown in the Fig. 3 (a) (http://ftp.wiley.com/public), the image size is 257×257 pixels. The unwrapping result by block-based method is rewrapped again, shown in Fig. 3 (b). The non-zero difference pixels are mainly distributed near the fringe lines, totally 2.6 percent.



(a) simulated interferogram (b) rewrapped for the unwrapping result

Fig. 3 Quantitative analysis for phase unwrapping based on region block

Below is a brief explanation of the influence of residuals for the block-based method. As mentioned, the division for the interferogram is starting from the filtered interferogram. Most of the random residuals are removed after filtering, the remaining residuals are scattered and can not influence the block division (seen from the generation of the fringe line image) and therefore can not influence the unwrapping result. The influence of residual for our method is in two cases. One is the actual topography discontinuity is very near to the fringe line, and several phase cycles maybe exist. The other one is two or more fringe lines are mixed together. The block-based method does not work under the two cases. Actually, there is no efficient policy presented for these situations up to now.

5 Conclusions

The existing phase unwrapping algorithms and their shortcomings were analyzed. Considering the edge feature of the interferometric phase image, the phase unwrapping based on region block method was presented. There are obvious grey break near the phase jumps, we make use of this feature to extract the fringe line image from filtered interferogram. The fringe line also divides the interferogram into blocks, in which there is no phase jump. On the basis of the block segmentation, phase unwrapping is implemented by block and block. We avoid to recover the unwrapped phase directly from wrapped phase, and turn to consider the equivalent problem "to recover the ambiguous integer number n". This problem is much easier resolved on the basis of block division. The false patches are rectified in post-processing according to Nyquist theorem. Comparison with Branch-cut method demonstrates the efficiency and robustness of the new method, which provides a useful addition to the algorithm ensemble of phase unwrapping.

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基于分块技术的相位展开算法

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摘　要　对干涉相位图的相位展开是干涉合成孔径雷达处理过程中的重要步骤,也是干涉合成孔径雷达理论与应用研究的难点所在.在充分利用干涉相位图中的干涉条纹信息的基础上,提出了一种基于分块技术的相位展开算法.首先对干涉相位图做了分块处理,块是由干涉条纹线和图像边界线组成的一个封闭的区域,在一个块内不存在相位跳跃,即在块内的相位展开已经完成.在下一步对全图做相位展开时,再逐块进行.最后通过后处理技术进行错误校正.通过对真实数据的实验和与传统方法的比较,证实了算法的有效性和稳定性.

关键词　干涉相位图,相位展开,合成孔径雷达,干涉条纹

中图分类号　O235; TP391