A VECTOR FILTERING TECHNIQUE FOR SAR INTERFEROMETRIC PHASE IMAGE

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ABSTRACT

The interferometric phase image obtained directly from the co-registered synthetic aperture radar (SAR) images often exhibits much noise, which will destroy the following phase unwrapping result. This paper presents one filtering algorithm for this kind of image. The advantage of this filter is that the abundant fringe information of the phase image is saved when smoothing the noise. Using simulated and ERS-1/ERS-2 generated phase data sets, the effectiveness of this filter is demonstrated, including residue reduction, fringe enhancement, and its ability to filter areas with high fringe rates.

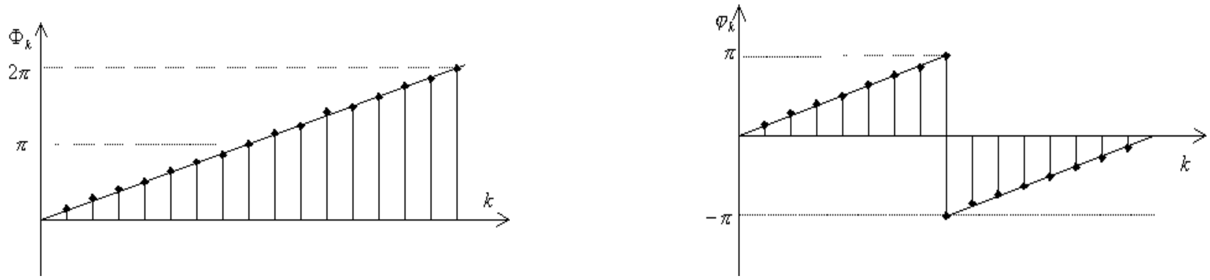
KEYWORDS interferometric phase image, synthetic aperture radar, filtering

1. INTRODUCTION

Image processing applied to remote sensing data becomes a more and more important topic. Interferometric Synthetic Aperture Radar (InSAR) is a new promising technique for extracting three-dimensional information of the Earth's surface. In this technique, two SAR images are acquired by two receiving antennas displaced a certain distance (the interferometer baseline) across the motion direction, or at two different times by one single antenna. When these two images are properly co-registered, an interferogram is produced by averaging the corresponding amplitudes and differencing the corresponding phases at each point in the images. The measured phases of the interferogram are known only the principal value between 0 and 2π (or wrapped phase); to calculate the elevation at each point in the image, the correct integer number of phase cycles (2π) must be added to each phase measurement, we refer to such procedure as phase unwrapping.

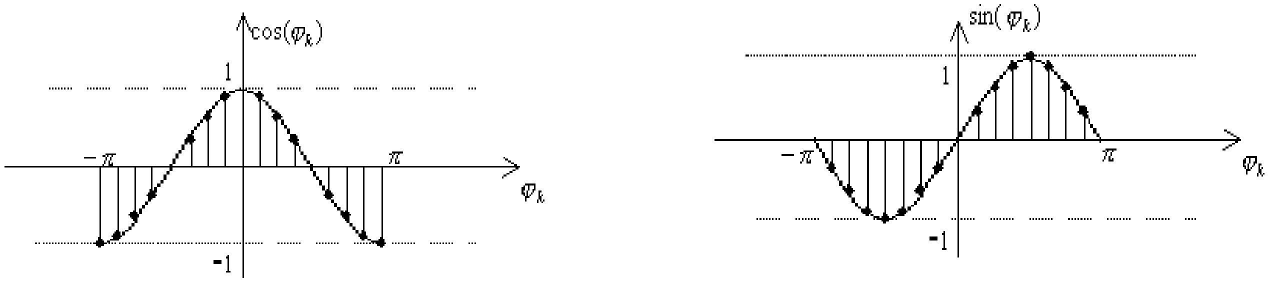
In an ideal case, the data of the phase image would be perfect, no noise is present, we can unwrap the phase difference precisely by integration method [1], but it should be noted that the interferogram obtained directly from complex images often exhibits much noise, which will destroy the phase unwrapping result, consequently noise filtering is commonly applied before phase unwrapping. Normally, there are three major sources of noise in the interferogram. They are receiver thermal noise, the "speckle" effect and an antenna effect. Multilook processing is the simple and common approach to mitigate these noises, but only at the expense of spatial resolution [1]. Jong-Sen Lee et al. proposed an adaptive filtering algorithm [2], they use directionally dependent windows to filter noise along the fringes, so this filter can preserve fringe pattern efficiently, but pixels in the operating window have to be phase-unwrapped before filtering and then be rewrapped after filtering, in addition, one has to do a lot of work to select the directional window. So if the image is large, the execution of this program will be very slow.

In this paper we propose one algorithm that perform filtering for phase image. We will show that this is a simple but efficient method, the abundant fringe information of the interferogram is saved when smoothing the noise; especially in the high fringe rate area, this filtering algorithm can be successfully implemented. This algorithm will be described in the following section. Using simulated data and interferogram generated from European Remote Sensing Satellite ERS –1/2 data of Yangzi River in China, the



(a) (b)

Fig.1. Example of 1-dimensional phase values. (a) Unwrapped phase values (b) Wrapped phase values



(a) (b)

Fig.2. Cosine and sine curves between $[-\pi,\pi)$ corresponding to Fig.1. (a) Cosine values. (b) Sine values.

effectiveness of this filter will be demonstrated in section3, comparisons with averaging filter and adaptive filter are also made. Section 4 ends the paper with some concluding remarks.

2.VECTOR NOISE FILTER

The measured phase value of the interferogram φ is a discontinuous function given by:

$$\varphi_{i,j} = \varphi(x_i, y_j),$$
$$-\pi \le \varphi_{i,j} < \pi, \qquad i = 0,\cdots,m-1,\ j = 0,\cdots,n-1$$

Where m and n are the dimensions of the image and (x_i, y_j) the coordinates of a given point.

One main problem is encountered when filtering techniques are applied: phase jump. To avoid complexity, we choose 1-dimensional example to illustrate this problem (see Fig.1).

There Φ_k is the unwrapped phase function and φ_k is the wrapped phase function (measured phase function). We can note that φ_k shows continuous characteristic between $[-\pi,\pi)$, but when Φ_k are over than π, φ_k have phase jumps of 2π.

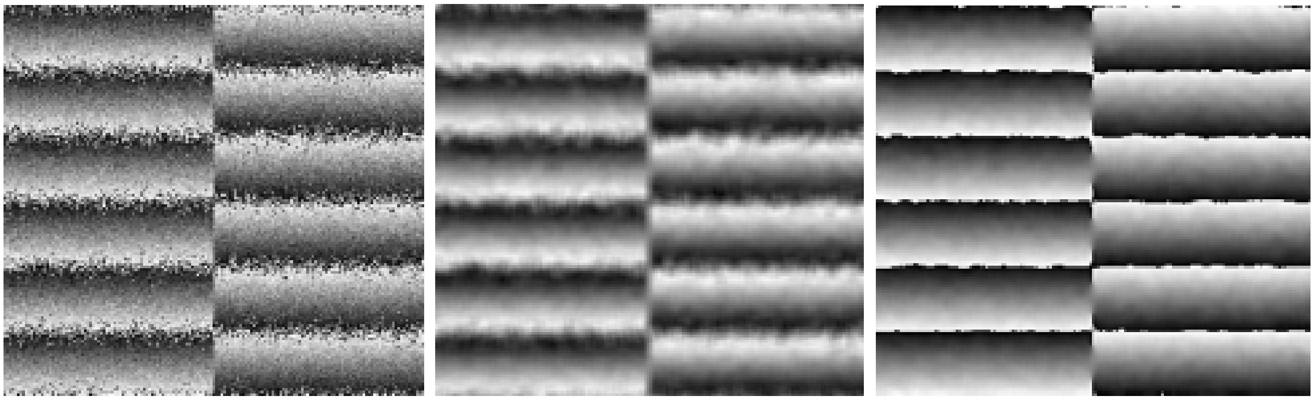
Now we do a map from the measured phase φ to its cosine and sine values:

$$\{(\varphi)\} \quad \longrightarrow \quad \{(\cos\varphi, \sin\varphi)\}$$

The result is that the phase has been transformed into one vector. The corresponding results to Fig.1 are shown in Fig.2.

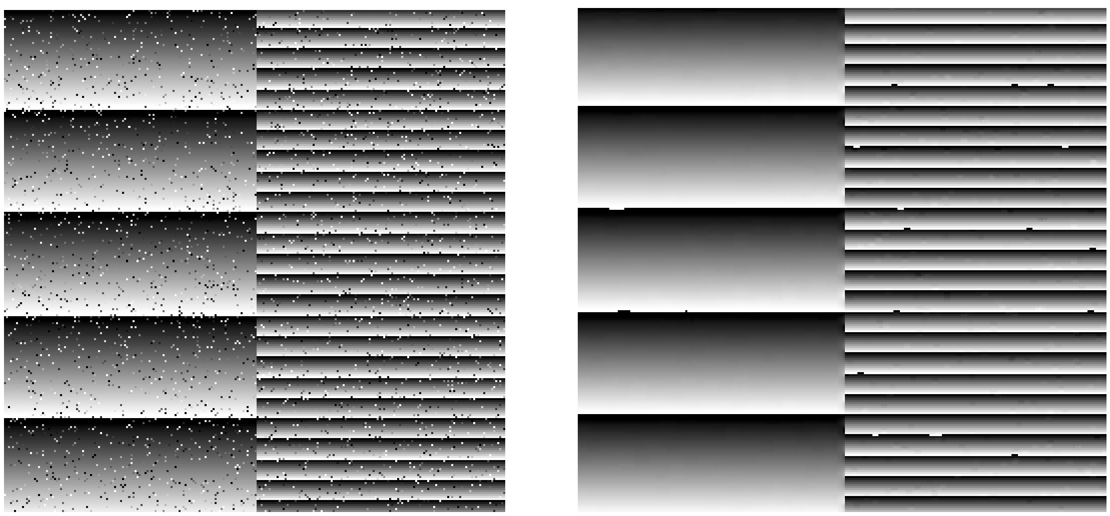
It is obviously that there are no jumps over π, that is the discontinuous variable has been transformed into two continuous ones for the periodicity of cosine and sine functions.

Let $t_1 = \cos\varphi, \qquad t_2 = \sin\varphi$



(a) (b) (c)

Fig.3. Residue reduction and fringe enhancement are shown with simulated data, images have a dimension of 257x257 pixels. (a) The original noise phase pattern. (b) The result of averaging filter. (c) The result of vector filter.



(a) (b)

Fig.4. Flexible in choosing filter window size is shown with simulated data, images have a dimension of 257x257 pixels. (a) The original noise phase pattern. (b) The result of filter, the window size is 7 on the left part and 3 on the right part for the high rate fringes.

The next step is to filter the cosine and sine images, respectively, by any smoothing filter. Here we choose averaging filter for its simple and easy implement, the formula is:

$$T_1(i,j) = \frac{1}{t^2} \sum_{(i,j \in w)} t_1(i,j)$$

$$T_2(i,j) = \frac{1}{t^2} \sum_{(i,j \in w)} t_2(i,j)$$

Here T_1 and T_2 are the filtered result of cosine and sine images respectively, t refers to the size of filter window w centered on pixel (i, j).

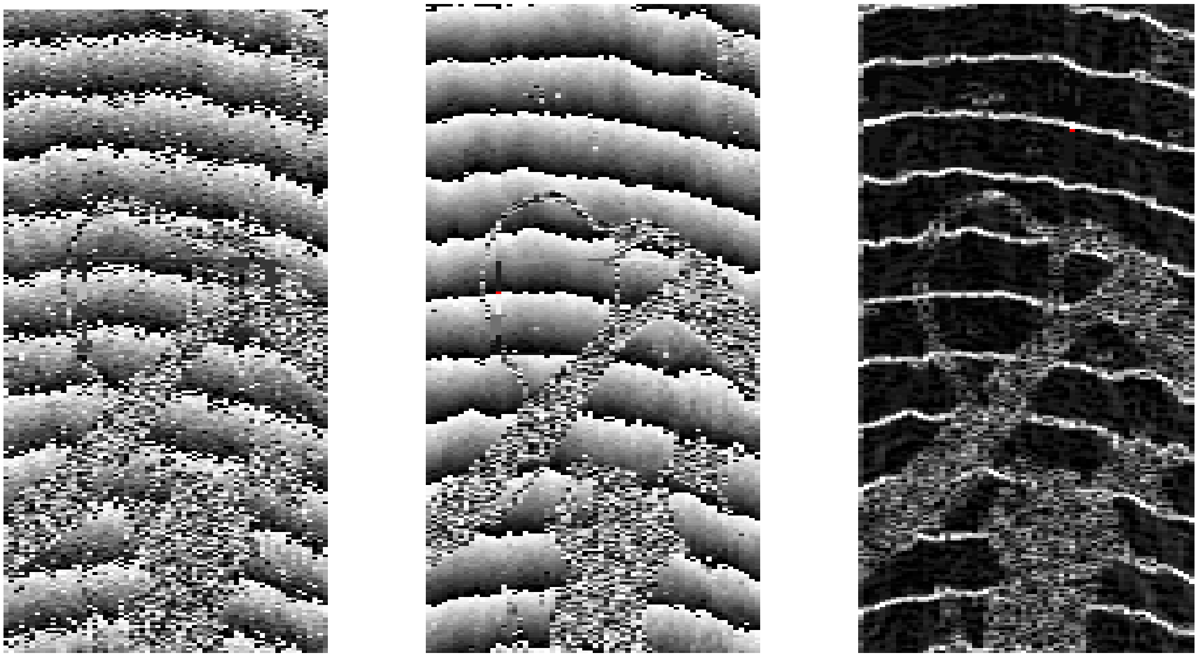
Finally we obtain the filtered interferometric phase image using inverse map:

$$\{(T_1, T_2)\} \longrightarrow \{\phi\}$$

Here $\phi = arctg(T_1 / T_2)$. In this step, we have to take more care of the sign.

The vector filtering algorithm is summarized as following:

1. Perform the map from phase image to it's cosine image and sine image.
2. Filter the cosine image and the sine image respectively by average filtering.



(a) (b) (c)

Fig.5. Wrapped interferometric phase image obtained from a pair of ERS-1 and ERS-2 images of a region along YangZi River in China. (a) The original noisy phase image. (b) The filtered result of vector filtering algorithm. (c) The fringe lines detected from (b).

3. Perform the inverse map from vector to single variable.

The selection of filter window size depends on the noise level. The phase noise level varies across the phase image. Areas with high noise level should be filtered more, so larger window size is needed. Areas with low noise level should be filtered less to preserve original information.

The selection of filter window size also depends on the density of the fringe lines. When the fringe density is large, a smaller window size (like 3x3) needs to be used, because large window may span more than one fringe, which will destroy the continuity of fringes.

3. EXPERIMENTAL RESULTS

In this section, we have tested our algorithm on simulated and real SAR interferometric phases. All images depicting here are scaled between black and white for display. Intensity level at each point represents phase value, one complete cycle of phase (2π) corresponds to one revolution from black to white.

First we will show the vector filter's capability of reducing the number of residues (adjacent pixels with phase difference greater than π) and enhancing fringes. A two-side ramp structure is shown in Fig.3 (a), the dimensions are 257x257 pixels. The result of vector filtering is shown in Fig.3 (c). The residue reduction is significant and the fringes are much better enhanced. The comparison with average algorithm is done here, we show the result in Fig.3 (b). We use the same window size 7x7 as in vector filtering.

We also show the flexible of the vector filter in choosing filter window size here. As shown in Fig.4, the filter window size is 7 on the left part and 3 on the right part for the high rate fringes.

In the third example, the quality of the filter demonstrated on very big image, we use real data obtained from a pair of ERS-1 and ERS-2 tandem SAR images of a region along YangZi River in China. This interferometric phase data consists of 1024 x 4096 pixels in the cross and along-track directions in Fig.5 (a). There is water area in the middle of image, which would be avoided in phase unwrapping procedure. Fig.5 (b) shows the result of vector filtering method, and the fringe lines is shown in Fig.5 (c).

4.CONCLUSION

A vector filtering technique for interferometric phase image has been developed. It's a great modification of the average filter. The algorithm works well when fringe lines are clearly separated, It is especially suitable for high rate fringe areas, even there are only a few pixels between adjacent fringe lines. The effectiveness of this algorithm has been demonstrated using simulated and real data. We believe its simplicity and convenience will be helpful for phase unwrapping.

Actually we can also show the flexible of the vector filter in choosing filtering window size in the different parts on one image. In addition, the fringe-line detection phase unwrapping can get great benefits from noise removal and the reduced number of phase residues [3].

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