Adaptive Filter in SAR Interferometry Derived DEM

XU Caijun  WANG Hua  WANG Jianglin  GE Linlin

ABSTRACT In this paper, the performance of median filter, elevation dependent adaptive sigma median filter, and directionally dependent adaptive sigma median filter are tested on both InSAR Tandem DEM and simulated high-level noisy DEM. Through the comparison, the directionally dependent adaptive sigma median filter is proved to be the most effective one not only in the noise removing but also in the boundary preserve.

KEYWORDS  InSAR; DEM; directionally dependent window; adaptive sigma median filter

CLC NUMBER  P225; TP793

Introduction

Radar interferometry (InSAR) has been successfully applied to measure the surface topography in the past two decades[1-4]. Since InSAR is a coherent technology, the most important constraint for the radar echo is coherence. However, decorrelation is always inevitably introduced by the thermal noise, geometric decorrelation, Doppler centroid decorrelation, volume scattering decorrelation, temporal decorrelation, orbit error, atmospheric delay, and data processing noise[5-6]. The decorrelation in the interferogram then has a significant effect on the accuracy of InSAR derived digital elevation model (DEM)[4]. Noise filtering has been commonly applied to the interferogram either in frequency domain or in spatial domain[7-8], but some noise will still remain in the DEM products. So low-pass filtering, e.g. median filtering, is also necessary for the InSAR DEM. In company with the removal of noise, median filter also tends to smooth out the details in the image. In addition, median filter is not effective for removing the clustered noise because of the use of fixed-size rectangular window in the filter[9]. In this paper, the directionally dependent adaptive sigma median filter is developed.

1 Selection of the directional window

In elevation dependent adaptive sigma median filter, the window size is determined on the assumption that standard deviation of the window pixels increases as the size of the window increases, due to the inclusion of height values that are either lower or higher than the central pixel value, and it decreases as the size of the filter window increases at the presence of noise[10]. However, the assumption is not always reasonable especially when the topographical undulation is not strong. In addition, as the rectangular window is used, the boundary can not be well preserved especially when the adaptive window size is large.

In this paper, directional window is used to...
smooth the noise. Sixteen directional windows with 9 by 9 rectangular window are plotted in Fig. 1. Only white pixels in the windows of Fig. 1 are used in the computation of the local median and standard deviation. Note that the pixel numbers in the sixteen windows are not equal, for example, the number in the first column in the first and third window is 27, and that in the second and fourth is 25. In the second and fourth columns, the number is 25, and in the third column, it is 23. The standard deviations in the sixteen windows can be calculated and the window with the minimum standard deviation is selected for the filtering. The use of directional window is more effective in noise smoothing than a square window because the pixels in the directional window have more homogeneous elevations and less noise.

![Fig. 1 Sixteen directional windows for InSAR DEM filter](image)

### 2 Modified sigma median filter

The sigma filter is based on the sigma probability of a Gaussian distribution\(^{[11]}\). It filters the noise by average of only those pixels whose values are within \(n\)-sigma range of the center pixel in the mask window. In the original sigma filter, the center value is given by the average. In this study, the median is preferred as the measurement of central tendency in determining the lower and upper limit. As compared with the average value which is often either overestimated or underestimated when noisy pixels are included in the mask window, the median is better in preserving the details in the DEM and less affected by the noisy pixels. So the modified sigma median filter can be written as:

\[
y(n) = \frac{1}{n_d} \sum_{i=1}^{n_d} x_i
\]

where \(n_d\) is the number of pixels in the selected directional window; \(x_i\) is the elevation value within \(n\)-sigma range of the median; \(y(n)\) is the output of filtered elevation value.

The \(n\)-sigma range is determined with the following formula:

\[
\begin{align*}
\bar{x} &= \text{med}(x_i) + n \cdot \sigma \\
\underline{x} &= \text{med}(x_i) - n \cdot \sigma
\end{align*}
\]

where \(\bar{x}\) and \(\underline{x}\) are the upper limit and lower limit respectively; \(\text{med}(x_i)\) is the median in the directional window; \(n\) is the sigma factor, e.g. 2 is used in the example of this paper; and \(\sigma\) is the standard deviation of the elevation value in the directional window.

### 3 Results and comparison of different filters

ERS-1 and ERS-2 tandem pair in Appin mining area is used to generate InSAR DEM with EV-InSAR software (Fig. 2 (a)). In the image, isolated and cluster noise can be seen. To evaluate the performance of the directionally dependent adaptive sigma median filter, other two filters, median filter and elevation dependent adaptive filter\(^{[1]}\), are also applied. In median filter, 5 by 5 mask window is used (Fig. 2 (b)). In elevation dependent adaptive filter (Fig. 2 (c)), the minimum mask window size is 3 by 3, and the maximum size is 13 by 13, and the adaptive window size within the minimum and maximum size is determined by the standard deviation of the window pixels, described in Section 1. The sigma factor is 2. In directionally dependent adaptive filter (Fig. 2 (d)), the square mask window size is 9 by 9, and the directional window illustrated in Fig. 1 is determined by the standard deviation of the window pixels, described in Section 1. The sigma factor is the same with elevation dependent adaptive filter. The mean value and root mean square error (RMS) of the DEMs relative to the one-second reference DEM with the accuracy of 3 m are listed in Table 1.
It can be seen that the result filtered by elevation dependent adaptive filter is more smoothly than those by the other two methods, as large mask window size is often used for this filter compared with the others. From the areas closed by the ellipses in Fig. 2(c) and Fig. 2(d), we can find that the bright speckle still remained in Fig. 2(c), but it does not exists in Fig. 2(d). So the directionally dependent adaptive filter is more effective for removing the cluster noise than the elevation dependent one. The results by median filter and directionally dependent adaptive filter are very similar, and the latter is slightly better than the former. This is by reason that the tandem InSAR DEM is used for the analysis, and the DEM itself is not much noisy, so the priority of the latter filter is not obvious. Even though, we still can see that the directionally dependent adaptive filter is more effective in filtering the noise than the median filter from the image in the rectangular areas in Fig. 2(b) and Fig. 2(d).

In Table 1, the mean value of difference between original InSAR DEM and 1'' DEM is negative. The reason is that some noises in original DEM are so large and negative (up to $-28.68$) to the reference DEM that takes a great part of contribution to the mean value. After these noises have been removed, the mean value of difference between filtered DEM and reference DEM becomes positive, with a tendency being closer to the true value and the mean value of difference between real DEM and reference DEM as the effectiveness of the filter increases, seen in Table 1.

![Fig. 2](image)

**Table 1** Mean and RMS of difference between InSAR DEM and 1'' DEM

| DEM                      | Mean 'm | RMS 'm | CPU time 's |
|-------------------------|---------|--------|-------------|
| InSAR DEM               | -28.68  | 68.57  |             |
| Median filtered DEM     | 28.15   | 25.50  | 51.0        |
| Elevation dependent filtered DEM | 28.66   | 25.36  | 1040        |
| Directionally dependent filtered DEM | 28.70   | 25.21  | 877         |

To test the performance of the directional dependent adaptive sigma median filter when the noises in DEM are more complicated, we simulated a DEM of slope, which contains not a very strong topographical undulation with maximum height of 895.2 m and minimum height of 27.5 m, as indicated in Fig. 3(a). Thereafter high-level noises comprised of normal distributed error and gross errors are added to the original simulated DEM (Fig. 3(b)). The members of median filter and directional dependent adaptive sigma median filter are the same as of the ones used above. The minimum and maximum window size used in elevation dependent adaptive sigma median filter is 9 by 9 and 17 by 17 respectively, and the sigma factor is 2. Fig. 3 shows the filtered results by the three filters. The mean value and root mean square error (RMS) of the DEMs relative to the simulated original DEM are tabulated in Table 2. From the areas closed with rectangles and ellipses and Table 2, it can be shown that the directional dependent adaptive sigma median filter is more effective than the other two filters. Furthermore this simulated case implies that the performance of the directional dependent adaptive sigma median filter in high-level noisy DEM filtering is even better than the performance in low-level noisy DEM filtering, compared with median filter and elevation dependent adaptive sigma median fil-
The time consumption of the three filters are listed in Table 1 and Table 2 and show that it takes shortest time for the median filter to do filtering due to its simple algorithm and the directional dependent adaptive sigma median filter is more cost-effective than the elevation dependent adaptive sigma median filter.

### Table 2 Residue mean, RMS and CPU time in simulated test

| DEM                              | Mean/m | RMS/m  | CPU time/s |
|----------------------------------|--------|--------|------------|
| Noisy simulated DEM              | 1.58   | 20.77  | -          |
| Median filtered DEM              | 0.26   | 4.63   | 25.8       |
| Elevation dependent filtered DEM | 0.51   | 4.28   | 782.5      |
| Directionally dependent filtered DEM | -0.04 | 3.01   | 483.4      |

### 4 Conclusions

Because of the decorrelation in SAR interferometry, the interferogram is always noisy, which will affect the accuracy of DEM and also make it noisy. Low-pass filter is useful for noise removal. A directionally dependent adaptive sigma median filter is developed for noise removal in InSAR derived DEM. In this filter, the directionally dependent window with the minimum standard deviation is used as the filter window. In this window, a modified sigma filter is used. Median is preferred as the measurement of central tendency for determining the lower and upper limit. From the results of real DEM filtering and simulated DEM filtering we can conclude that the directionally dependent adaptive sigma median filter is more effective both in noise removal and in boundary preserve, especially in high-level noisy DEM filtering.

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