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Comparison of several multi-look processing procedures in INSAR processing for ERS-1&2 tandem mode

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Abstract

Multi-look processing, as a traditional method to reduce phase noise in SAR processing, has been used in INSAR processing since the INSAR techniques developed in the late 1970's. In INSAR processing, there are several possibilities to insert multi-look processing into the processing chain. The first method is to form an interferogram after two multi-look images have been obtained from two single-look images. The second method is to obtain an interferogram by summing several multi-look processed interferograms. A third method is to produce an interferogram by filtering single-look interferometric image in the complex image domain. In this paper, we are aim to compare these multi-look processing procedures for ERS-1 and ERS-2 tandem mode data. The results will be evaluated by judging noise reduction in the interferogram and by the accuracy improvement in the 2-D phase unwrapping in INSAR processing.

Keywords: Multi-look processing, Phase noise.

Introduction

Topographic maps and DEM's over the global land obtained by interferometric SAR(INSAR) techniques have gained increasing interesting from scientists in a variety of research areas, such as geology, hydrology, geophysics, and so on, due to the fact that topographic maps produced by SAR interferometry have the advantages of all weather condition, high accuracy and automatic processing. INSAR techniques, which concentrate on the phase information included in two SAR complex images obtained from two antennas simultaneously or from repeat pass, have developed rapidly since the first concept proposed by Graham in 1974. General INSAR processing procedures, consisting of registration, baseline estimation, forming interferogram, filtering, flat area phase removal, 2-D phase unwrapping, etc., have been well investigated(Gens and Genderen, 1996). However, some technical details still remain controversial. Phase noise reduction is one of the troublesome topics needing to be solved in the near future since it directly influences the accuracy of DEM's produced by INSAR processing. Some papers have addressed this problem briefly and proposed some methods to solve it. In 1988, Goldstein indicated that multi-look processing can reduce speckle noise of interferograms and improve the accuracy of 2-D phase unwrapping. Since then, multi-look processing for interferometry has been included in INSAR processing. In 1990, Li established a complete model for INSAR, in which speckle noise and thermal noise are considered. He proposed an *ad hoc* method to simply sum up the interferometric images over the multiply looks in the complex vector domain so as to obtain a complex vector with interferometric phase information. The expected height uncertainties due to phase errors caused by speckle noise was estimated by his simulation results. Afterwards, Lee(1994) presented his results on a statistical model of interferometric and polarization SAR images. He also demonstrated the results of the relationship between phase standard deviation and the number of looks. From another point of view, Lin(1992) pointed out that the median filter was helpful for speckle reduction of interferograms.

In order to make further research on the influence of phase noise in INSAR imagery, our approach has been to investigate, as a first step, several multi-look processing procedures and analyze the test results. In the following sections, we first summarize the sources of noise in INSAR. The second part presents three noise reduction procedures used in INSAR processing. Part three compares the results obtained with these three procedures and evaluates the results by visualization procedures.

Summary of Phase Sources

Phase noise forms an obstacle to interpret interferogram or to generate DEM from an interferogram. If the phase noise is too strong, some fringes will be completely lost which will result in errors in the DEM. Phase noise(Zebker, 1992 and 1994; Huang, 1996) is mainly caused by radar thermal noise, speckle noise due to coherent SAR processing, decorrelation, sampling, processing artifacts, interpolation noise, defocusing, registration noise, etc. There are briefly explained below:

Thermal noise, regarded as an additive noise, is caused by the radar system itself. Increasing the signal-to-noise ratio(SNR) of the radar system can reduce thermal noise to the quality requirement of a SAR image. It is not a crucial noise source in a normal SAR image since the SNR of the radar receiver and coherent SAR processing ensues that the final image possessed a large enough SNR to omit the effect of thermal noise. However, it is an important noise source in INSAR due to the combination of two SAR images enhancing the intensity of the thermal noise to a certain extent. Especially, in the dark areas, the SNR is quite low in an INSAR image.

Registration noise, caused by not properly registering two SAR images, will lead to the fringe pattern of the interferogram being smeared and sometimes even completely lost. The interferogram generated from misregistration becomes drastically noisier. This noise cannot be remedied by post processing such as filtering. It can only be reduced by a fine registration operation. Thus, image co-registration is a crucial step in INSAR processing.

Speckle noise, regarded as a multiplicative noise, is generated from coherent processing formation of a SAR image. It is a dominate noise source in a SAR image. Eventually, it exists in an INSAR product due to the speckle characteristics of two SAR images used to form an interferometric image being not entirely identical. Incoherent summation helpful to reduce speckle noise has been proven by many research reports (Huang, 1996).

Decorrelation noise, regarded as a complicated noise, is caused by two SAR images which are used to form an interferometric image being not exactly the same, since they are observed from a slightly different antenna viewing angle, at a different time and during varying terrain condition. It is dependent on the antenna separation, antenna rotation, bandwidth of the radar, time interval between the two images obtained, variation of terrain, etc.

Processing artifact noise , such as quantization noise, interpolation noise, sidelobe noise, defocusing noise, Doppler Certroid estimating error, etc., lead to an unexpected random noise added in an interferometric image. To minmize these noise sources, a highly precise processing algorithm is required to improve the quality of SAR processing and increase the creditability of INSAR processing.

Description of Several Multi-look Processing Procedures

Multi-look processing in INSAR processing, introduced from original SAR processing, is used as an efficient algorithm to reduce phase noise in an interferometric image since it is the optimal estimator in a maximum likelihood sense for an interferometric image. There are three main methods to insert multi-look processing in a normal INSAR processing chain. Fig.1 shows three processing chains including multi-look processing.

Method I

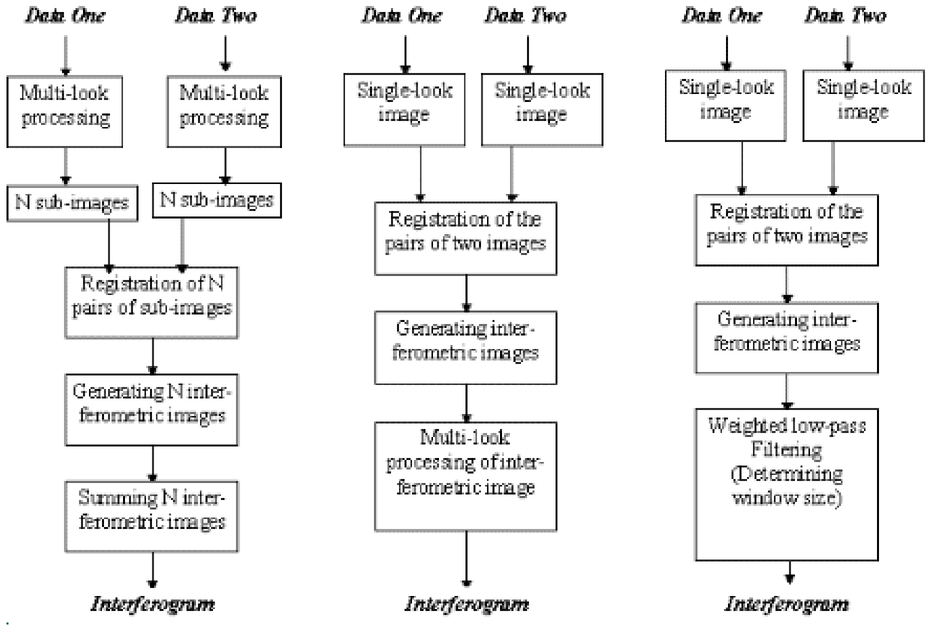
Mutli-look processing is performed in both SAR images. Several multi-look processed image pairs are used to form several interferometric images. Then, these interferometric images can be summed to achieve a final interferometric image. The interferogram is extracted from the phase of the interferometric image.

Method II

Multi-look processing is performed after the single-look interferometric image has been generated. Then, the averaging operation is implemented in this single-look interferometric image to form the multi-look interferogram.

Method III

After the single-look interferometric image is formed, a weighted low pass filter is used in the interferometric image. The filtered interferometric image can form the final interferogram. Window size determination is a crucial step in the filtering process. Actually, Method II is similar to Method III. But, Method III is more flexible to filter the interferometric images.



Method I Method II M ethod III

Fig.1 Three processing chains for multi-look processing

Comparison of Three Multi-look processing Methods with ERS-1 and ERS-2 Tandem Data

The area selected for testing the three methods described above is a subset of an Italian test site, using ERS-1 and ERS-2 single-look complex imagery consisting of 512 slant range pixels and 2048 azimuth pixels.The image covering this area is shown in Fig.2. In order to match the size of azimuth to the range, the image has been averaged four times in azimuth. The data set obtained from ERS-2 is one day delay to ERS-1 on Sept.5, 1995. The baseline of data set is estimated about 50m in cross-track.

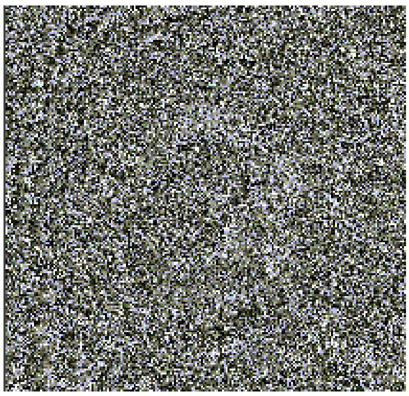


Fig.4 Interferogram with flat phase removal.

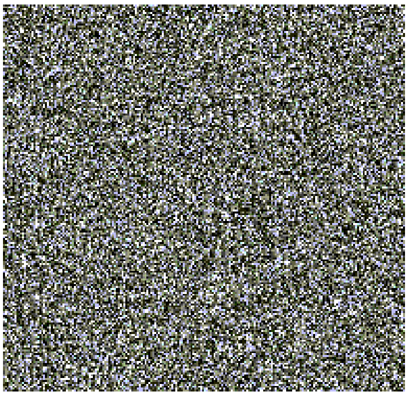


Fig.3 Interferogram of test area

The first step of INSARprocessing is registration. Registration of two SAR images consists of two steps. The first step is called coarse registration, by which two images can be registered to the accuracy of one pixel space in both directions.The second step is called fine registrat-ion, by which two images will be registered to the accuracy of sub-pixel space. The registration criteria we used in our processing is to searchthe maxi-mum of value of the coherence co-efficient proposed by Li in 1990.After the step of fine registration, the interferogram is generated by multiplying the first image with the conjugate of the second image. The result of the single-look interferogram is shown in Fig.3. Due to the size in azimuth being four times in range, the result is decimated by four times.Fig.4 shows the interferogram after we roughly remove the phase term of a spherical earth at a constant terrain height by shifting the spectrum of the interferometric image in range. The fine removal is not implemented due to lack of enough accurate satellite data as required. However, the fringe pattern image in Fig.4 is sufficient to illustrate the noise reduction by multi-look processing in the following part.

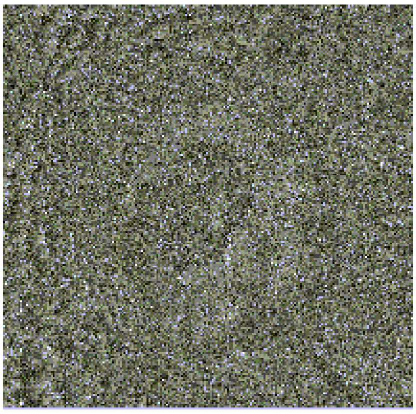


Fig.5 Multi-look processed Interferogram(Method two)

Both Fig.3 and Fig.4 appear to contain too much noisier to recognize the fringe pattern. Hence, we use multi-look processing(Method II) to reduce the phase noise. The result is shown in Fig.5. In Fig.5, the interferometric image is averaged by four times in azimuth and then the phase difference is extract from the interferometric image to form interferogram. Compared with single-look interferogram in Fig.4, the multi-look processed interferogram looks much better and the fringe pattern is clearer in Fig.5.

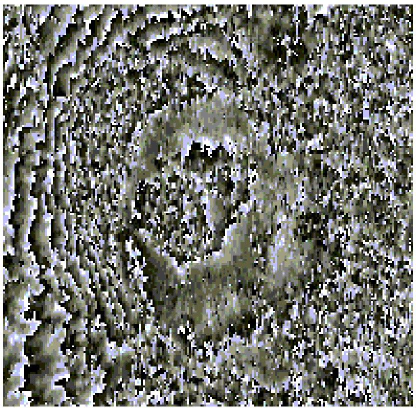


Fig.6 Multi-look processed Interferogram(Method one)

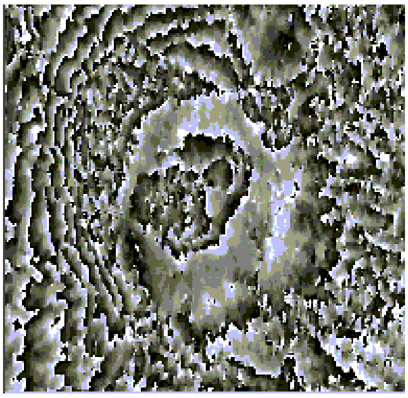


Fig.7 Multi-look processed Interferogram(Method three)

We also tested Method I and Method III with the same data set according to the diagram of multi-look processing illustrated in Fig.1. There are several key points which need to be mentioned here: In Method I, the two SAR single-look images ought to be processed into multi-look images of 512 by 512 pixels with the same Doppler certroid frequency so as not to lose coherence in every pair of multi-look processed images. Each pair forms an interferometric image with amplitude and phase. Then, a complex summation operation is performed to obtain a final interferometric image. The interferogram is shown in Fig.6. Due to registration errors existing on the registration of each pair, the result obtained from Method I is not as good as that from Method II. In Method III, two single-look images are registered first and the complex interferometric image is formed based on the registered images. We can design different low-pass filters to filter it and reduce phase noise as less as possible. Filtering can be implemented in the frequency domain by FFT operation or in the time domain by convoluting a filter kernel with the interfermetric images in range and azimuth dimensions. Different weighting functions can be used in the filter design. Here we tested various ones,such as the rectangular function, exponential weighting function, Sinc weighting function, etc. One crucial point in filter design is to know how to select bandwidths of range and azimuth in two dimensions or to determine the window size of range and azimuth in the time domain. For cross-track interferometric SAR, the fringe pattern is oriented along-track so that the bandwidth in azimuth can be much smaller than that in range. That means the fringe pattern in range is more sensitive to the filter bandwidth than that in azimuth. In addition to these above reasons, the choice of the filter bandwidth is influenced by terrain slope, coherence coefficient, baseline,etc. If the bandwidth of the filter is too large, the filter is less efficient to remove phase noise. If it is too small, it will smooth the fringe and demage the subtle details of the interferogram.

After several tests, the quasi-optimal filter window size we selected for our test image is 5 in range by 35 in azimuth. The filtered result is shown in Fig.7. We also tested the Sinc weighting filter and the Exponential weighting function filter. These results are shown in Fig.8 and Fig.9. Test results indicate that the Method III is more flexible to reduce noise as well as preserving the fringe pattern by adjusting filter bandwidth. Fig.8 and Fig.9 show that weighting filters are more efficient to remove phase noise whilst keeping the subtle details of the fringe pattern. The Sinc weighting filter appears slightly better than Exponential one.

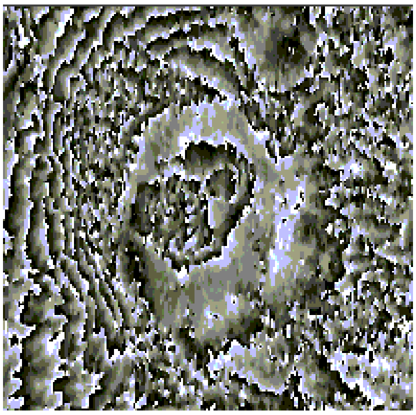


Fig.9 Filtered Interferogram with Sinc Weighting Filter

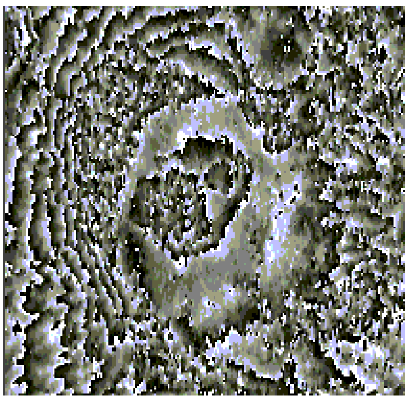


Fig.8 Filtered Interferogram with Exponential Weighting Filter

Conclusions

In this paper, three multi-look processing methods have been investigated both in terms of theory, and in practice by experiments. The test results show that Method III is the best one to filter phase noise as well as preserving fringe patterns of the interferogram. Our further research will focus on designing an adaptive filter dependent on the characteristics of phase noise to make further improvement to the interferogram.

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