ITERATIVE CALIBRATION OF RELATIVE PLATFORM POSITION: A NEW METHOD FOR SAR BASELINE ESTIMATION

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1. INTRODUCTION

Synthetic Aperture Radar interferometry (InSAR) and differential interferometry (DInSAR) techniques have proven to successfully construct accurate Digital Elevation Model (DEM) and monitor terrain deformation. Advanced Land Observing Satellite (ALOS) launched in 2006, with Phased Array type L-band Synthetic Aperture Radar (PALSAR), overcomes the challenge of the low coherence over vegetation areas of Southeast Asia. Using PALSAR data and precise orbit information, a new approach for baseline correction is proposed based on a model of platform position from several acquisitions.

Baseline precision contributes significantly to the accuracy of SAR interferometry processing. The best estimation on baseline is required for most applications. Usually, the initial estimation is using orbital information, and extracted from the platform positions of a pair of SAR passes. Therefore, based on spaceborne properties, all the platform positions can be built under a coordinates system of several acquisitions at corresponding points. The error of the perpendicular baseline can be effectively reduced by using Ground Control Points (GCPs) [1] or a reference low resolution DEM [2]. However, without global constrain over every individual pair of images, the geometry of platform positions will not be representative of a realistic situation (see Fig. 1).

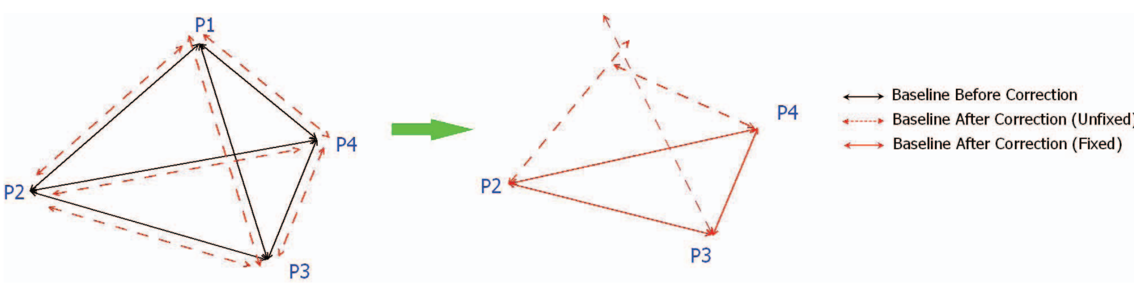


Fig. 1. 2D illustration of the problem between 4 passes. P1, P2, P3 and P4 represent the relative platform positions of passes. 6 baselines (4 sides and 2 diagonals) are displayed (black arrow). After the correction of baselines independently without constrain, the possible inaccurate reference DEM (or GCPs) and presence of atmospheric phase screen (random phase) affect the corrected baselines (red dashed arrow).

In Fig. 1, relative positions are reconstructed using corrected baselines. If 3 positions are fixed (red solid arrow), then the other 3 baselines will not end at a single 4^{th} point. This problem will become very complicated in 3D when more passes are used.

In this paper, an iterative optimization method is provided for baseline calibration, under constrain from relative platform positions over several acquisitions. A reference DEM is needed to calculate position displacement. The linear phase trend of 2-pass differential interferogram decreases during each iteration. The unique result from this method with respect to traditional techniques is the quantitative position calibration of any pass with inaccurate orbit information (offset error up to 10 m) along the direction of perpendicular baseline. The advantages of this method are global baseline correction, existence detection of reference DEM error as well as atmospheric effect, and processing without phase unwrapping (which can introduce unwrapping error [3]).

2. ALGORITHM

Modeling of the platform position requires a coherent coordinate system. Considering $K+1$ SAR images of the same area with no topographic change, and DEM is also available. Corresponding points can be found by precise registration of images using cross-correlation. The ideal system can be validated by TCN (Track, Cross-track and Normal) coordinates. Their unit vectors are defined as:

$$\hat{n} = \frac{-\vec{P}}{\mid P \mid} \qquad \hat{c} = \frac{\hat{n} \times \vec{V}}{\mid \hat{n} \times \vec{V} \mid} \qquad \hat{t} = \hat{c} \times \hat{n} \tag{1}$$

In Eq. (1), $\vec{P}$ is the platform position vector with respect to the Earth center, and $\vec{V}$ is the direction of velocity vector. In a first approximation, we assume that all of the platforms can have the same direction of $\vec{V}$ (in a second step, it can be easily corrected by a rotation matrix depending on baseline changing rate).

The error of TCN axis angle build by taking from image i to image j as reference (under above assumption) is:

$$\Delta\theta = \arctan \frac{\sqrt{\mid \vec{B}_{ij} \cdot \hat{c} \mid^2 + \mid \vec{B}_{ij} \cdot \hat{t} \mid^2}}{A_i + R} \tag{2}$$

where $\vec{B}_{ij}$ is the baseline vector between master image i and slave image j. A_i is the platform altitude of image i (691.65 km for ALOS) and R is the radius of the earth (6378.1 km). Usually the baseline component along $\hat{t}$ is small and error contribution can be neglected. Therefore, for baseline of 1 km along $\hat{c}$, the axis error is $0.0081°$ and the baseline error is $\vec{B}_{ij} \cdot \hat{c} \times \tan\Delta\theta \simeq 14$ cm for this system. In the following part, the same TCN coordinates system will be considered at corresponding point between all passes.

Starting points of the iteration is from the initial orbit-estimated baseline. Combination of the $K+1$ image is generated ($K(K+1)/2$ interferograms). Under the previous assumptions, the following results can be implied (in TCN coordinates):

$$\vec{B}_{ji} = -\vec{B}_{ij} \qquad \dot{\vec{B}}_{ji} = -\dot{\vec{B}}_{ij} \tag{3}$$

The iteration is processed with both baseline vector $\vec{B}_{ij}$ and baseline azimuth changing rate $\dot{\vec{B}}_{ij}$.

The following steps are shown for $\vec{B}_{ij}$:

1. Step 1: Taking image i ($i = 1$ at beginning of each iteration) as the master image, generate 2-pass differential interferograms without phase unwrapping (reference DEM available) by taking the other K images as slave images. Calculate the baseline error to be corrected by elimination of frequency centroid of Fast Fourier Transform (FFT) over a specific area. Average the result and estimate the standard deviation: $\Delta\vec{P}_i^{(n)} = \frac{1}{K} \times \sum_{j \neq i} \Delta\vec{B}_{ij}$, where $\Delta\vec{P}_i^{(n)}$ represents the displacement of platform position respect to image i, and n is the current iteration number.

2. Step 2: Update all the baseline vectors using the platform displacement.

$$\vec{B}_{ij} = \vec{B}_{ij} + \Delta\vec{P}_i^{(n)} \tag{4}$$

3. Step 3: Update the reversed baseline $\vec{B}_{ji}$ by using Eq. (3), take $i = i + 1$ and go back to Step 1, until all of the images have been taken once as master image (until $i = K + 1$).

4. Step 4: Iteration n is finished. Calculate the total displacement of all platform (absolute value) of iteration n: $\Delta\vec{P}^{(n)} = \sum_{i=1}^{K+1} \mid \Delta\vec{P}_i^{(n)} \mid$. Take $n = n + 1$ and go back to Step 1 for another iteration.

The algorithm for $\dot{\vec{B}}_{ij}$ is the same as $\vec{B}_{ij}$ by just replacing $\vec{B}_{ij}$ with $\dot{\vec{B}}_{ij}$.

Traditionally, all of the linear phase trends are removed by FFT method. However, some of them may not result from the inaccurate orbit. Atmospheric effect can also obviously affect the phase over a specific area of images [4]. Actually, this algorithm provides an optimized relative position to minimize the global linear phase trend. The main purpose is to average all the incoherence over interferograms to provide reliable information of platform position, and improve the overall quality of interferograms.

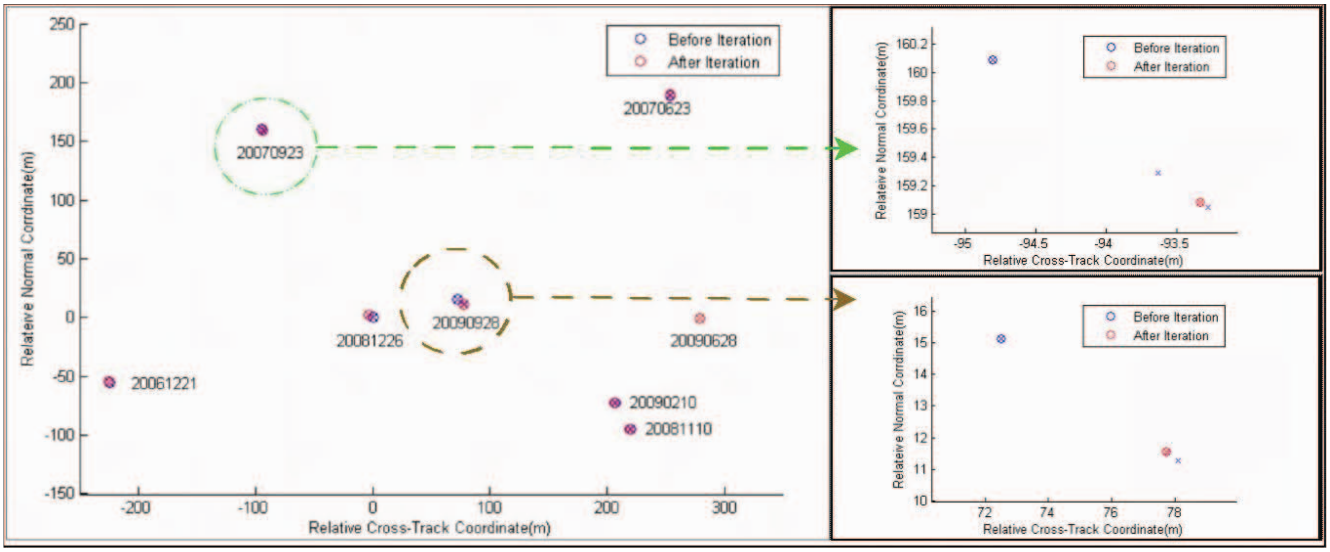


Fig. 2. Relative position iteration of Singapore passes and zoom-in passes (20070923 and 20090928). Only cross-track ($\hat{c}$) and normal ($\hat{n}$) coordinates are illustrated ($\hat{t}$ component is usually small and not clearly observed in 3D). The position of 20081226 before iterations is taken as reference origin of coordinates (we are only interested in relative position). Blue and red $\circ$ represent the position before and after all iterations respectively. $\times$ represents the position of each iteration. The 8 positions are translated back every time after Step 4 by minimizing global displacement.

3. VALIDATION USING DATA OVER SINGAPORE

The area is centered on the island of Singapore in South East Asia. The area is rather flat except for one mountain in the Northwest of the image. Most of the area in Singapore is urban while the part of Malaysia (north of the image) is mostly palm tree plantations. The data are 8 passes of PALSAR over the same area in interferometric conditions between December 2006 and September 2009. Only the HH polarization is used for the processing here. SRTM is used as reference DEM.

10 iterations are processed on the passes. The displacements of each platform position are clearly shown in Fig. 2. The maximum $\hat{c}$ component of baseline is about 300 m. From Eq. (2), the estimated system error is 4 cm. Two obvious calibrated passes can be detected (20081226 and 20090928). Details are shown for selected small calibrated pass (20070923) and large calibrated pass (20090928). The displacements are 1.78 m and 6.35 m respectively. The displacement follows almost a straight line along the direction of perpendicular baseline in TCN system.

Fig. 3 shows the plotting of displacement during iterations. The total displacement $\Delta\vec{P}^{(n)}$ is an indication about how much of the linear phase trend is left during n^{th} iteration. The convergence does not go to zero verifies that some of the linear phase trend cannot be removed under constrain (both inaccuracy of SRTM and atmospheric phase screen can induce this result). Therefore, the converged value of $\Delta\vec{P}^{(n)}$ shows existence of DEM error and atmospheric effect. Furthermore, the standard deviation supports the argument in Fig. 1. It shows that the displacements provided by the other K passes are different with about 1 m standard deviation. The reason is the contribution of some random phases (existence of atmospheric phase screen).

From observation, 5 iterations are enough for the platform positions to converge. Therefore, processing time can be further reduced, which depends on how many passes are used. Fig. 4 and Fig. 5 show the 2-pass differential interferogram of the most inaccurate pass 20090928 with some other passes before and after iteration.

4. CONCLUSION AND FUTURE WORK

An iterative optimization of baseline with constrain of relative platform position is presented in this abstract. The PALSAR passes which gives inaccurate platform position is successfully detected and calibrated using this algorithm. After processing, new estimated baseline improves the quality of interferogram (Fig. 4 and Fig. 5). Existence of reference DEM error and atmospheric phase screen can also be detected. Satellite orbit correction and DEM generation will benefit from this method, and there will be modifications to improve the performance.

Expression of Eq. (4) still need improvement, because iteration may converge too fast and be trapped by local minimum.

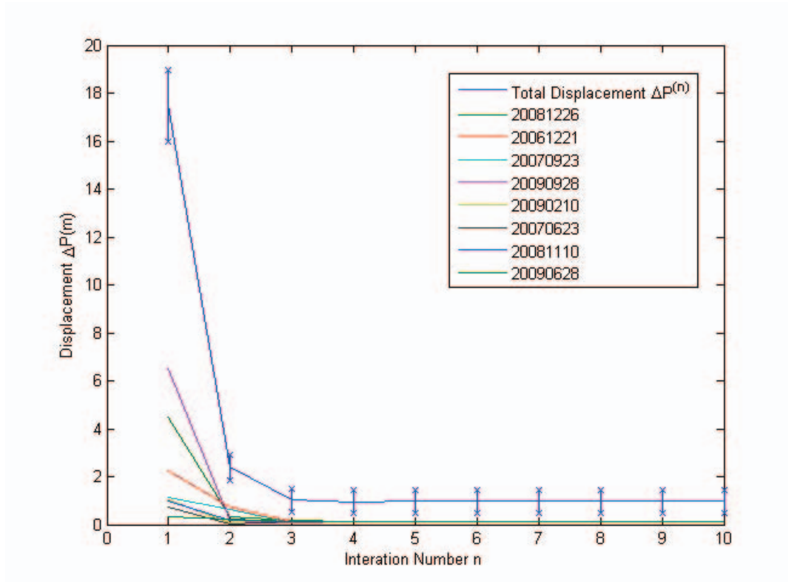
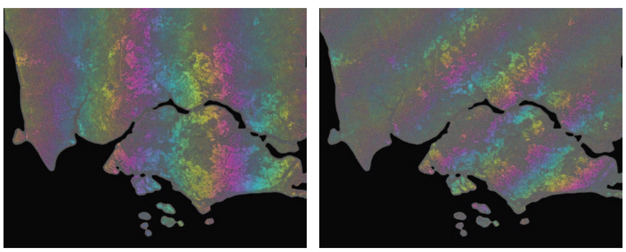
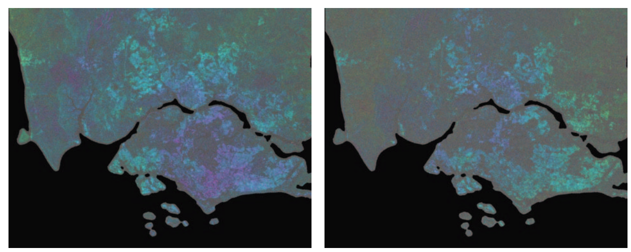


Fig. 3. Plot of the displacement for each pass $\Delta\vec{P}_i^{(n)}$ and the total displacement $\Delta\vec{P}^{(n)}$ during n^{th} iteration. The total standard deviation is indicated together with $\Delta\vec{P}^{(n)}$



(a) M: 20090928 S: 20090628 (b) M: 20090928 S: 20081110

Fig. 4. 2-pass DInSAR before baseline correction.



(a) M: 20090928 S: 20090628 (b) M: 20090928 S: 20081110

Fig. 5. 2-pass DInSAR after baseline correction.

The updated expression is already proposed with weight coefficient, and the result is still under evaluation. FFT is the first method we have tried for baseline calibration. Now other methods of baseline estimation is under evaluation to improve the result (iteration converge at smaller $\Delta\vec{P}^{(n)}$ with smaller standard deviation). These updates will be shown in the full paper.

5. REFERENCES

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