Verification of Simple Calibration Method for Multi-baseline SAR Tomography

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Abstract – **SAR Tomography processing by using multiple SAR images can create a 3-D image including the height distribution of scatterers. The height estimation can be realized assuming that the multi-baseline observation data as an array data in the DOA (direction of arrival) estimation methods. Orbit error in observation might cause DOA/height errors in imaging results; therefore, calibration of orbits or equivalent phase compensation is necessary. In this report, we evaluate a simple calibration method by simple phase compensation for multi-baseline datasets and show experimental results by using the Pi-SAR2-X datasets.**

Index Terms — **SAR Tomography, TomoSAR, Calibration, Multi-baseline SAR, Pi-SAR2-X.**

1. Introduction

SAR interferometry [1] by using a slightly different flight-path dataset is commonly used 3-D imaging method in microwave remote sensing. However, it assumes that number of scatterers in each slant-range is only one; therefore, this assumption sometimes causes phase error when there is more than one scatterer such as layover. One of the solutions of this problem is SAR tomography, or TomoSAR [2-4]. In the SAR tomography processing, multi-baseline datasets, or multiple repeat-pass observation datasets, with slightly different flight-paths are regarded as an array data for elevation angle estimation in the Direction-of-Arrival (DOA) estimation with an array. For the elevation angle estimation, parallel flight-path is desired. However, using many SAR observation data, it is difficult to realize such an ideal dataset because the observations often arrayed out by repeat-pass flights. In this paper we propose a simple calibration technique for the multi-baseline SAR data and show experimental results by using the real airborne SAR datasets acquired by the Pi-SAR2-X. The conventional SAR tomography [2], each flight-path was roughly preprocessed to be parallel with the motion compensation in the SAR imaging processing. However such a processing can hardly realize by users. The SAR tomography in this report is processed without such a parallel preprocessing. That means we use conventional slant-range SAR images. The tomography is realized by the original flight path of each SAR image. This is also one of the features in this study.

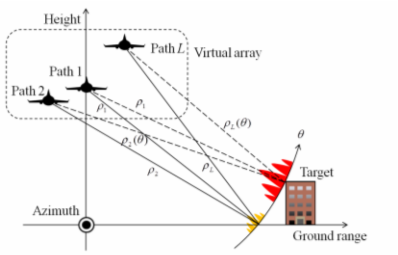


Fig. 1. Concept of SAR Tomography

2. SAR Tomography

The multi-baseline SAR datasets observing the same area can be regarded as array observation signals as shown in Fig. 1. By regarding each observing airborne antennas as array elements, we can apply the DOA estimation methods to them. The estimated elevation direction can be related to the height of scatterers. Then we can realize the 3-D imaging when there exist multiple scatterers in the same range.

3. Calibration Matrix

Mode-vectors in elevation angle estimation are calculated by using orbit information of the aircraft. These orbit information, however, do not often have enough accuracy for SAR tomography. Hence mode-vectors calibration for orbit error compensation is necessary. When the mode-vectors estimated by the orbit information is $\boldsymbol{a}$ and true mode-vectors is $\boldsymbol{a}_m$, the phase compensated calibration matrix $\boldsymbol{C}$ can be defined by

$$\boldsymbol{a}_m = \boldsymbol{C}\boldsymbol{a} \,. \tag{1}$$

To estimate the calibration matrix $\boldsymbol{C}$ we need K (> L) reference points whose altitude are known when we use L datasets (multi-baselines). Next, the phase shift correlation matrix $\boldsymbol{R}$ can be calculated by the following equation,

$$\boldsymbol{R} = (\boldsymbol{A} \circ \boldsymbol{A}_m^{\,*})(\boldsymbol{A} \circ \boldsymbol{A}_m^{\,*})^H \,, \tag{2}$$

where $\boldsymbol{A} = [\boldsymbol{a}_1, \ldots, \boldsymbol{a}_K]$ and $\boldsymbol{A}_m = [\boldsymbol{a}_{m1}, \ldots, \boldsymbol{a}_{mK}]$ are theoretical and measured mode-matrix which contain the theoretical and measured mode-vectors, respectively. Also $[\ ]^*$, $[\ ]^H$, and $\circ$ denote the complex conjugate, the Hermitian transpose, and the Hadamard product, respectively. After averaging $\boldsymbol{R}$ by using adjacent pixels as multi-look processing, then $\boldsymbol{e}_{max}$ can be estimated by the eigenvector corresponding to the maximum eigenvalue of $\boldsymbol{R}$. The vector $\boldsymbol{e}_{max}$ contains phase correction values of each path at the points. A local calibration matrix $\boldsymbol{C}_{local}$ can be defined as a diagonal matrix whose elements correspond to the phase of the elements in $\boldsymbol{e}_{max}$. Calculating the local calibration matrices $\boldsymbol{C}_{local}$ at several or many reference points in the image, then we can estimate the calibration matrix $\boldsymbol{C}$ for all area by using phase interpolation/extrapolation with adjacent local calibration matrices of reference points.

4. Calibration and Imaging Specification

In this report, we apply the proposed calibration to Pi-SAR2-X datasets provided by NICT, Japan, and show imaging results by SAR tomography. The datasets used here are Toyanogata area in Niigata, Japan, which were taken in Aug.25, 2013. Center frequency and polarization of these datasets are 9.55 GHz and VV-pol., respectively, and the number of datasets L is 10 by 5 repeat-pass observations, including 5 single-pass interferometry channel datasets. Fig. 2 shows the power image of the area in this study, where TomoSAR area is shown by the red and blue lines in the image. In this area, we have an athletic truck on the left and a football stadium on the right. Reference points to calculate local calibration matrixes in this study are also shown by yellow markers which are located in azimuth and range directions in 15 pixel intervals in Fig. 2, and then we interpolate linearly the phases of these matrices to obtain the calibration matrix $\boldsymbol{C}$.

5. Results of Calibration and Imaging

The DOA estimation method used in this study is Beamformer method and imaging results shown here are expressed by ground-range and altitude. Fig. 3 (a) and (b) shows the height imaging results by SAR tomography along blue and red line in Fig. 2 without the calibration, where the Beamformer spectrums are normalized by the maximum power at each slant-range. The area shown in Fig. 3 has only one scattering point at the reference area shown in Fig. 2. However, we can see many height-distributed scatterers due to defocus by the path error. Fig. 4 (a) and (b) shows the imaging result by the proposed calibration technique. The result shown in Fig. 4 (a) corresponds to the height image

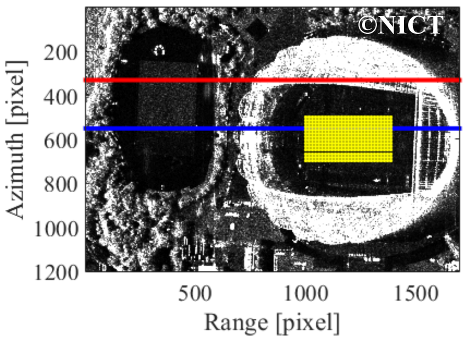
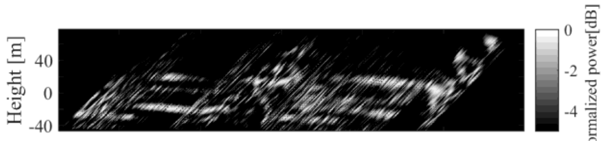
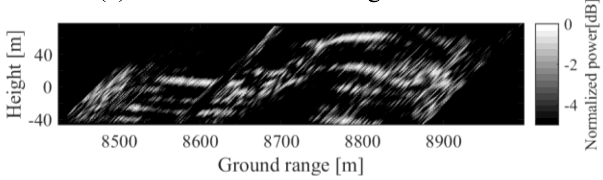


Fig. 2. Power image

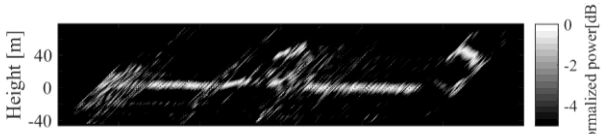


(a) TomoSAR result along the blue line

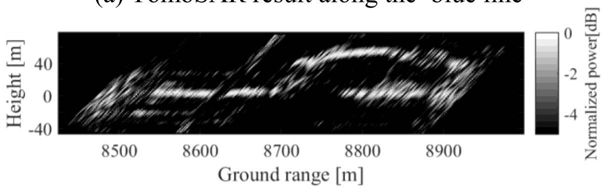


(b) TomoSAR result along the red line

Fig. 3. SAR Tomography results without calibration



(a) TomoSAR result along the blue line



(b) TomoSAR result along the red line

Fig. 4. SAR Tomography results with calibration

along the blue line in Fig. 3. The responses of the athletic-ground at around 8600 m and the dome roof at around 8900 m can be clearly focused. Similar responses can be confirmed in Fig 4 (b) for red line image. These results show that not only responses are well focused in the vicinity of reference points, but also well focused responses are obtained in other place.

6. Conclusion

In this paper, we proposed a simple phase calibration method for SAR tomography as a fundamental study on 3-D imaging. The method calculates the calibration matrices of the reference area by using phase interpolation/extrapolation. We assumed that calibration matrix $\boldsymbol{C}$ which compensates phases due to orbit errors varies smoothly in a processing area. Experimental results show that we can obtain clear images not only in the calibration area of reference points, but also the out of the calibration area.

References

[1] R.F. Hanssen, Radar Interferometry: Data Interpretation and Error Analysis, Remote Sensing and Digital Image Processing, Sprinter Netherlands, 2001.

[2] A. Reigber, A. Moreira, “First demonstration of airborne SAR tomography using Multibaseline L-band data,” IEEE Transactions on Geoscience and Remote Sensing, vol. 38, no. 5, pp. 2142-2152, Sep.2000.

[3] F. Lombardni, A. Reiger, “Adaptive spectral estimation for multibaseline SAR tomography with airborne L-band data,” Proc. IGARSS, no. 3, pp. 2014-2016, Toulouse, France, Jul. 2003.

[4] O. Frey, F. Morsdorf and E. Meier, “Tomographic processing of multi-baseline P-band SAR data for imaging of a forested area,” Proc.IGARSS, pp. 156-159, Barcelpna, Spain, Jul. 2007.