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A Survey Investigation of the Noise Performance in SAR

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ABSTRACT: The phase estimation of cross-track multibaseline synthetic aperture interferometric data is usually thought to be very efficiently achieved using the maximum likelihood (ML) method. The suitability of this method is investigated here as applied to airborne single pass multibaseline data. Experimental interferometric data acquired with a Ka-band sensor were processed using (a) a ML method that fuses the complex data from all receivers and (b) a coarse-to-fine method that only uses the intermediate baselines to unwrap the phase values from the longest baseline. The phase noise was analyzed for both methods: in most cases, a small improvement was found when the ML method was used.

Keywords: ML method, InSAR data, phase patterns, RADAR imaging.

I. INTRODUCTION

Multibaseline cross-track SAR interferometry is an extension of In SAR, whereby multiple baselines combine the advantages of shorter and longer baselines: simple phase unwrapping of interferograms from short baselines and lower sensitivity to phase noise from longer baselines (Rosen, 2000). Many different methods were developed to combine the data from the various baselines. The coarse-to-fine (C2F) phase unwrapping method (Magnard, 2014 and Essen, 2007) uses data from the shorter baselines to unwrap the interferogram based on the longest baseline. This method keeps the unwrapped phase information from the longest baseline, discarding information from the other baselines. The maximum likelihood (ML) method calculates a most-likely phase from arrays of focused SAR data (Single Look Complex data) according to a model (Lombardo, 1997). This allows use of all the data and should therefore improve the noise level and reliability. Several other methods such as least squares or weighted least squares can also be used to calculate the unwrapped phase; they were compared in (Lombardini, 2001), showing their advantages and shortcomings.

A lower phase noise is expected when using a model-based fusion of the complex data from all receiving channels such as that provided by the ML method. However, the effectiveness of the ML method with actual (non-simulated) high resolution single pass multibaseline airborne InSAR data has yet to be demonstrated. Such data have particularities such as dissimilar receiver properties, non-perfectly aligned phase centers, and imperfect motion compensation. On the other hand, issues such as temporal decorrelation or baseline lengths approaching criticality are not present. In this paper, we used data acquired with the Fraunhofer-FHR MEMPHIS Ka-band single pass multibaseline InSAR system (Table 1 and Fig. 1).

Table 1: MEMPHIS SAR system parameters.

Carrier frequency	35 GHz (Ka-band)
Bandwidth	900 MHz (stepped-frequency)
PRF	1500 Hz
Typical sensor velocity	77 m/s
Flight altitude	300 – 1000 m
Antenna tilt angle	20° – 35°
Theoretical rg. Resolution	0.167 m
Theoretical az. Resolution	0.082 m
Available baselines	0.055, 0.11, 0.165, 0.22, 0.275 m

The interferometric processing was achieved with a ML method fusing the data from all 4 receiving antennas as well as a C2F method only using the intermediate baselines to unwrap the InSAR data from the longest baseline. The investigated hypothesis that ML method results in a lower phase noise than C2F method was tested using flat verification areas.

II. INTERFEROMETRIC PROCESSING

The InSAR processing method starts from the 4 previously generated SLCs. An elevation angle dependent phase correction using antenna phase patterns is applied to correct for systematic

phase errors. Due to the short range distance and low flying altitude, the beam elevation varies significantly depending on the ground topography. An iterative processing method is therefore required: an approximate elevation angle is used in the first loop; the from the first iteration allows a more accurate calculation of the elevation angle that is used in the next loop. The InSAR processing chain using both ML and C2F methods is summarized .

III. MAXIMUM LIKELIHOOD METHOD

The maximum likelihood phase estimation uses the model presented in (Lombardo, 1997). This method assumes that all phase centers are perfectly aligned. The interferometric phase from pairs of MEMPHIS SAR data show constant phase offsets, contradicting this alignment assumption. Constant phase offsets

were therefore estimated from the data and corrected on the slave SLCs before performing the ML estimation. For each interferogram cell, the corresponding area is selected from each SLC, forming a vector of 4 matrices. The size of the matrices corresponds to the number of looks. This vector can be characterized as a complex Gaussian random vector with zero mean and covariance matrix C (Rodriguez, 1992). The covariance matrix is estimated from the data. The interferometric phase is then calculated as the position of the maximum of the logarithmic likelihood function.

The height standard deviation depends directly on the range distance, and is related to the local ambiguity height. The heights were first converted back into phase values to aggregate the data from various range distances. Histograms of the phase were generated and normal distribution curves were fit to these histograms.

RADAR imaging and interferometry are applicable in many tasks of remote sensing and monitoring of various constructions. One of the promising applications is ground based SAR and differential interferometry. SAR systems preserve phase information about the scattered signals.

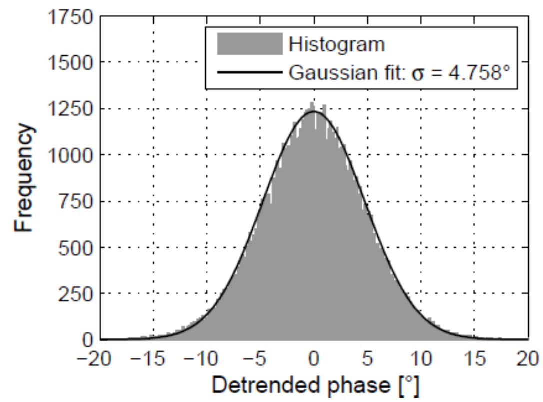

Fig. 1. Distribution of the detrended phase for 3 range and 12 azimuth looks (0.5 x 0.621 m sample interval), using the ML method. All verification areas were combined to produce the figure. The histogram used a 0.2° bin width.

RADAR imaging and interferometry are applicable in many tasks of remote sensing and monitoring of various constructions. One of the promising applications is ground based SAR and differential interferometry. SAR systems preserve phase information about the scattered signals. The obtained images are coherent which means that each image element contains phase information along the amplitude one. This phase information is used in inteferometry to visualize difference between coherent images obtained under different conditions. Differential interferometry is based upon comparison of two coherent images of the same scene made from

the same aperture but at different time. If the scene and the equipment don't change between two measurements, the phase difference between coherent images is expected to be equal to zero. If certain changes occur in the scene during the time between taking images, they can be detected in the interferogram as phase shift assigned to the corresponding image pixels. But if the equipment performance or even position has changed with time, some phase shifts can occur in the radio holograms obtained. Such phase shift can impede detection of changes in the object. Sources of instabilities in equipment can be split into two groups: mechanical and electronic ones. Mechanical instabilities have been investigated theoretically in previous works [2]. Current work is devoted to experimental investigation of electronic instabilities in specific SAR – namely, Ka-band Ground Based Noise Waveform SAR (GB NW SAR) [1].

This SAR uses noise signals for sounding and coherent reception of radar returns [3]. We describe the equipment, experimental setup and present the results of NW SAR stability investigation.

IV. NOISE WAVEFORM SAR

Coherent images were formed using a Ka-band GB NW SAR operating in bistatic configuration. Tape scanner antennas with synthetic aperture were used for scanning [4]. For the antenna beam forming and scanning in these antennas we use the principle similar to that used in 1D Antenna Array (1D-AA), but realizing transmit/receive of electromagnetic signals at each position of a single radiating element moving along the aperture rather than simultaneous transmit/receive by all its elements. In other words, we use the concept of synthetic aperture radar being applied in the situation of a 1D-AA having a real aperture and implementing sequential radiation of radar signals by its elements. Generally, this

approach enables application of both various types of radiating element and methods for implementing of its motion along the antenna aperture. In the antenna suggested, the overall beam width is defined by the antenna real aperture, while the number of beam positions is defined by that of measurement positions for the radiating slot. The sidelobes level depends on the phase-amplitude distribution (weighting function) along the real aperture of the antenna. Technically this approach was realized as follows: As a real aperture antenna, we used a waveguide with a non-radiating half-wavelength longitudinal slot in its wider wall. When covering this wall with a metallic tape having a half-wavelength transverse resonant slot one provides a good condition for resonant radiation of the wave traveling inside the above waveguide. In order to enhance its efficiency we placed a sliding plunger tied to the tape at the proper distance from the radiating slot. The tapes were moved forward and back in step-like manner which simplifies realization of the required synchronous motion of radiating slots in Tx and Rx antennas for the case of bistatic radar configuration. Transmission and reception are done when both antennas are not moving. The tape moves along precise guides. Position of the slot is controlled by angle sensor. Length of synthetic aperture for both antennas equals to 0.7 m. Frequency modulation technique was applied for sounding noise signal forming: amplified avalanche discharge noise was used as a modulating signal for Ka-band VCO in the noise radar transmitter. The generated signal may have either Gaussian or close to rectangular power spectral density.

A Rotating Synthetic Aperture Radar Imaging Concept for Robot Navigation. In this paper introduces a concept for robot navigation based on a rotating synthetic aperture short-range radar scanner. It uses an innovative broadband holographic reconstruction algorithm, which overcomes the typical problem of residual phase errors caused by an imprecisely measured aperture position and moving targets. Thus, it is no longer necessary to know the exact trajectory of the synthetic aperture radar to get a high-resolution image, which is a major advantage over the classical holographic reconstruction algorithm. However, the developed algorithm is not only used to compute a high-resolution 360 2-D image after each turn of the radar platform while the robot is moving, but also to calculate the relative residual radial velocity between the moving radar scanner system and all targets in the environment. This allows us to determine the exact velocity of the robotic system on which the radar scanner is mounted, and thus to obtain the exact radar trajectory, if there are stationary targets like walls in the environment.

Improved synthetic aperture radar micro Doppler jamming method based on phase-switched screen, In this paper target micro-motions such as rotation and vibration introduce phase modulation, termed as micro-Doppler (m-D) effect, onto synthetic aperture radar (SAR) signals. This causes ghost targets in the reconstructed SAR images. Inspired by this unique characteristic, a passive-jamming method based on m-D was developed for SAR. The m-D jamming method utilised a rotating reflector to intentionally generate ghost targets as jamming strips on the SAR image so as to protect certain areas. The m-D jamming method based on a single rotating reflector can only generate a long jamming strip along the azimuth direction but located in a finite number of range cells, which restricts the region of protected scene. In this study, an improved m-D jamming method based on phase-switched screen (PSS) is proposed, which combines the advantage induced by the PSS modulation and the usefulness of the m-D jamming. By controlling the modulating frequency and waveform of the PSS, the jamming strip is enlarged along the range direction.

Synthetic Aperture Radar Processing of Kaguya Lunar Radar Sounder Data for Lunar Subsurface Imaging, In this paper Synthetic aperture radar (SAR) processing was applied to the observation data of Lunar Radar Sounder (LRS), which is an HF sounder which was installed onboard a Japanese lunar exploration orbiter, Kaguya, for the purpose of imaging lunar subsurface structure. A two-media model was introduced to the LRS SAR algorithm to define the reference function of the LRS SAR processing. The LRS SAR algorithm has two free parameters, i.e., dielectric constant of the subsurface medium and synthetic aperture.

The effect of these free parameters on LRS SAR imaging was studied by simulation and was verified by actual LRS observation data. A practical guideline for LRS SAR processing was drawn. The dielectric constant of the subsurface medium may be ignored in practice so far as the synthetic aperture is smaller than 10 km. For a larger synthetic aperture case, assumption of a moderate dielectric constant of the subsurface medium is effective in realizing good focusing of deep targets. Finally, taking full advantage of ground processing, advanced processing was attempted. Off-nadir focusing SAR processing proved to be effective in imaging oblique objects whose dominant scattering angle was not the angle toward zenith. Changing the dielectric constant of the two-media model proved to be effective in focusing/defocusing small objects, thus enabling us to localize the object's position as surface or subsurface.

Synthetic aperture radar target configuration recognition using locality-preserving property and the Gamma distribution, In this paper Taking the inevitable speckle noise in synthetic aperture radar (SAR) images into account, a feature extraction algorithm is proposed by combining the locality-preserving property and the Gamma distribution for SAR target configuration recognition in this study. To describe the essential characteristics of SAR images, the authors model the speckle noise by the Gamma distribution. Moreover, the locality-preserving property which is of great importance for recognition is fused into the statistical model to preserve the local structure of the datasets. Besides, they modify the affinity matrix that is used in the locality-preserving property to capture both the local and global structures of the datasets for configuration recognition. The coordinate descent method is carried out for parameter estimation, in which a decomposition method is presented to obtain the transformation matrix. The on the moving andstationary target acquisition and recognition database validate the effectiveness.

Joint approach of translational and rotational phase error corrections for high-resolution inverse synthetic aperture radar imaging using minimum-entropy this paper In high-resolution inverse synthetic aperture radar (ISAR) imaging, the rotational motion of the targets tends to introduce the time-variant Doppler modulation in the echo, which acts as the range-variant phase errors in the phase history. Moreover, the performance of translational phase error correction may be dramatically degraded without properly considering the range-variant phase errors. In this study, a joint approach of translational and rotational phase error corrections is introduced into high-resolution ISAR imaging. In the procedure, the joint phase error correction is modelled as that of range-invariant and range-variant phase errors using a metric of minimum entropy. Then, the minimum-entropy optimisation is solved by employing a coordinate descend method based on quasi-Newton solver. In comparison of the conventional methods, the proposed approach in this study promises a better performance of phase error correction with a higher efficiency. Finally, experiments based on simulated and measured data are performed to confirm the effectiveness.

Amplitudes Estimation of Large Internal Solitary Waves in the Mid-Atlantic Bight Using Synthetic Aperture Radar and Marine X-Band Radar Images, In this paper the accurate estimation of internal solitary waves' (ISWs') amplitudes from radar images is important for understanding the ISW evolution, energy dissipation, and mixing processes. The *in situ* data from the Non-Linear Internal Wave Initiative experiment in the Mid-Atlantic Bight show many ISWs with amplitudes of 10 m or more in a shallow water depth of 80 m or less. Therefore, the higher order Korteweg–de Vries (KdV) equation in a two-layer system is needed to describe these large-amplitude ISWs instead of the classic KdV equation. Based on a simple theoretical radar imaging model, we develop a method to estimate large ISW amplitudes from distances between the positive and negative peaks of ISW signatures in radar images and a selection rule from the two possible amplitude solutions. Two groups of ISWs with large amplitudes, determined from the temperature records from nearby moorings, are observed in a RADARSAT synthetic-aperture-radar image and in marine X-band radar data collected during the experiment. We validate the method using the ISW signatures taken from these two cases. We find the estimated amplitudes to agree well with those determined from the moorings. The proposed method provides a relatively simple and accurate way to estimate large ISW amplitudes from radar images.

V. CONCLUSION

Although they are commonly used, standard performance measures such as MSE and PSNR are not appropriate measures for SAR image compression algorithms. This follows from the fact that these metrics are noise measures and assume signal independent noise which is not a valid assumption in image compression algorithms. In this work we propose a new framework for evaluating the distortion introduced by compression. We measure the linear distortion by modeling the compression-decompression procedure as a linear filtering operation followed by the addition of uncorrelated noise. Both the linear distortion measure and the noise quality measure can be weighted in frequency domain depending on the application.

We use the contrast sensitivity function, which is based on a linear model of the human visual system, to weight these measures assuming the decompressed images are consumed by humans. With high compression ratios, however, the additive noise approximation is invalid and the noise measures are inappropriate. In this case we use the correlation of edge information, which gives us a better measure of the nonlinear distortion, since the distortion is primarily a high frequency effect. We have tested the metrics on several SAR images and conclude that these metrics give more consistent results compared to the commonly applied metrics. A model for the distribution of the estimated look cross spectrum, which has the coherence as a key parameter. The model provides pdfs for the phase, magnitude as well as the real and imaginary part of the cross spectrum depending on the amount of smoothing applied in the estimation. The coherence was factored into two components with the first one describing ML phase estimation was demonstrated to be appropriate for In SAR processing of single pass high resolution multi baseline airborne data. Careful calibration steps were necessary to make the data fit the ML model assumptions. For example, an elevation angle dependent phase correction was applied for each slave channel. ML method. These were found to be statistically significant, confirming the hypothesis stated in the introduction that ML method results in a lower phase noise than method. Outliers were discarded from the data to compute the phase standard deviation. They were mostly found when using low numbers of looks. These outliers will be further studied, including their distribution and their dependency on the Processing method, the local coherence, and the number of looks.

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