ADVANCED MOTION COMPENSATION FOR AIRBORNE PLATFORMS: APPLICATION TO UAVSAR

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1. INTRODUCTION

The UAVSAR L-band synthetic aperture radar system has been designed for repeat track interferometry in support of Earth science applications that require high-precision measurements of small surface deformations over timescales from hours to years. Conventional motion compensation algorithms, which are based upon assumptions of a narrow beam and flat terrain, yield unacceptably large errors in areas with even moderate topographic relief, i.e., in most areas of interest. This often limits the ability to achieve sub-centimeter surface change detection over significant portions of an acquired scene. To reduce this source of error in the interferometric phase, we have implemented an advanced motion compensation algorithm that corrects for the scene topography and radar beam width. Here we discuss the algorithm used, its implementation in the UAVSAR data processor, and the improvement in interferometric phase and correlation achieved in areas with significant topographic relief. Examples of motion compensation applied to various UAVSAR data are examined.

2. UAVSAR OVERVIEW

UAVSAR is a synthetic aperture radar instrument with a quad-polarization, phased array, L-band radar antenna, deployed on a Gulfstream-3 aircraft. The UAVSAR instrument has been designed to monitor surface deformation to 3 mm accuracy with 10 m x 10 m surface area resolution, a scale unattainable with satellite-based SAR instruments. To achieve this level of accuracy in the derived surface deformation requires very accurate determination of the platform motion, attitude, and location, which is provided by a differential GPS system and a high-precision inertial navigation unit. The information about the platform parameters is used to minimize decorrelation between the acquired data sets by making real-time adjustments to the track position and the antenna beam steering angle during radar data collection in order to mitigate the error sources associated with changes in the look direction.

On different flights, the wind conditions can be totally altered, so that the aircraft flies with a different yaw, i.e., a different angle between the antenna axis and the flight direction, inducing a change in the look direction to a given location on the ground. The yaw is corrected by adjusting the phase of individual elements of the phased-array antenna to steer the beam to the desired squint direction. To reduce the repeat track baseline, the Gulfstream-3 platform has been modified to accept input from a precision autopilot system (PPA) designed to maintain the flight path with a tube of 10 m diameter about the planned flight track [1]. Information from the differential GPS system, which locates the platform position to submeter real-time accuracy, is fed to the PPA, which commands the Instrument Landing System to alter the platform control surfaces in order to maintain the desired track. In practice, the desired flight track is maintained within a 5 m diameter tube well over 90% of the time. Typical track error statistics collated over nearly 10 hours of radar data collection are shown in Figure 1.

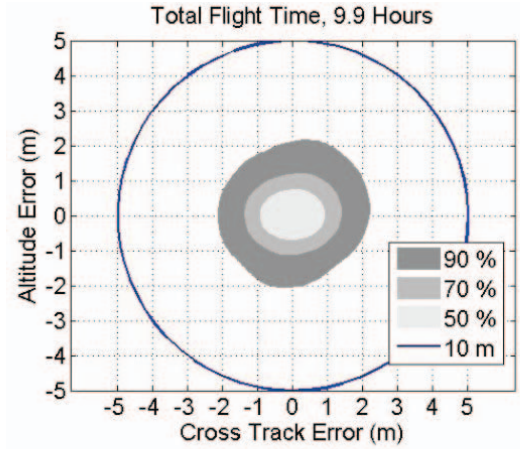

Fig. 1. *Statistics quantifying the ability of the Precision Autopilot control system to maintain the flight track of the UAVSAR Gulfstream-3 platform within a tube centered on the planned flight track. The flight track lies within a 4 m diameter tube approximately 90% of the time. The data is compiled over 9.9 hours of radar data acquisition.*

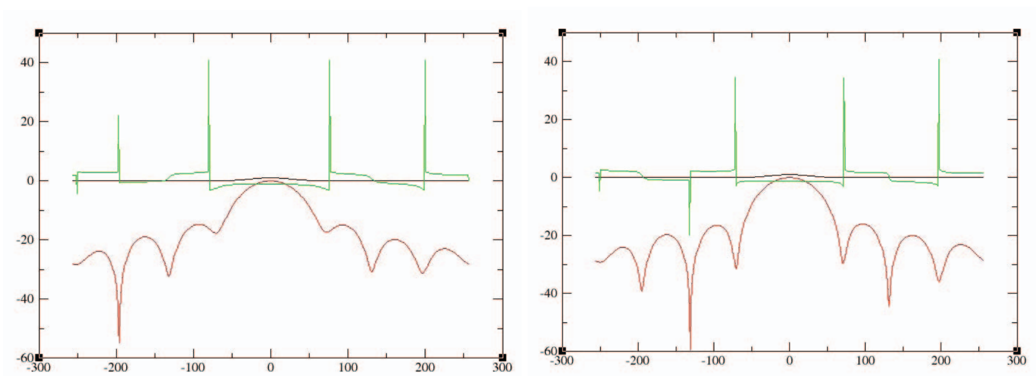

Fig. 2. *Azimuth impulse response for a point target with convention motion compensation (upper plot) and the advanced motion compensation (lower plot). The red curve is the amplitude and the green the phase of the response. In this instance the simulation for the point target included no topographic error, so the plot reflects the improved azimuth resolution from the aperture-dependent correction only.*

3. MOTION COMPENSATION

The highly accurate ephemeris and attitude information used for real-time flight path control and antenna beam steering is essential for post processing of the SAR image data. Data from the differential GPS and INU are blended post-flight in the ground data system to generate the position and attitude data used to process the SAR data. At this stage, the platform position is determined to 2-3 cm accuracy. To achieve subcentimeter level accuracy in the surface deformation derived from the interferometric phase requires appropriate motion compensation to remove the platform-induced phase changes.

During processing, the range-compressed signal is resampled to a uniform spacing in the along-track direction (presum) and the phase of the range-compressed signal is corrected for the baseline offset, i.e., the difference between the actual platform position and the position at which a target at the same slant range would be imaged on an ideal reference track. For repeat pass processing, both tracks are processed to the same reference track, which is chosen to maximize the spectral overlap of the signals from the two tracks. Conventional motion compensation algorithms correct for the baseline based upon two inaccurate assumptions: (1) The terrain imaged is all at the same height, the ”reference height,” which is taken to be the average height across the synthetic aperture; and (2) the azimuth beam width is neglected in considering the radar return to originate entirely from beam center, the direction of peak antenna power. These assumptions lead to phase errors that mask the surface change

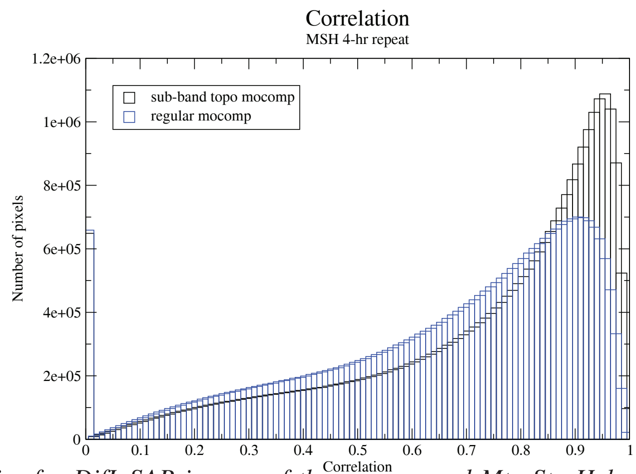

Fig. 3. *Correlation statistics for DifInSAR images of the area around Mt. St. Helens. The blue indicates the statistics for conventional motion compensation and the black for the new motion compensation that accounts for the topography and beam width.*

signal in areas with even moderate surface height changes and lead to defocussing and a relative shift between the final processed image from the two different passes.

Advanced motion compensation algorithms that take into account topography and beam width have been developed. A review and comparison of several Fourier-based motion compensation algorithms is given in [2]. We have implemented a similar algorithm that uses a digital elevation model (DEM) in latitude/longitude/height to determine the look direction to the ground associated with a given platform position, slant range, and azimuth angle, then corrects the phase for the component of the baseline in the look direction. The topography- and aperture-dependent motion compensation is implemented instead of the conventional motion compensation following the presum processing step and before range migration and azimuth compression. The data in a patch is divided into blocks and transformed to the azimuth frequency domain. The azimuth angle θ_a for the signal in a particular subaperture is determined from the azimuth frequency, f_a, of the subaperture and the radar wavelength, λ, as

$$\theta_a = \sin^{-1}\left(\frac{f_a \lambda}{2}\right) \quad (1)$$

The look vector $\hat{\rho}$ for a given slant range ρ and azimuth angle θ_a is determined by iterating to find the intersection of the doppler cone, the slant range sphere, and the DEM elliposoid.

Once the look vector, $\rho\hat{\rho}$, is determined, the signal is corrected for the baseline, $\vec{b}$, by a phase shift of $\Delta\Phi = \vec{b} \cdot \hat{\rho}$ and a corresponding range shift to register the data relative to the reference track. Each element in the block is corrected to the look direction for its particular slant range and azimuth direction, which corrects for topography and the beam aperture at the same time.

Following formation of the single-look complex images from the two repeat track in an interferometric pair, the range and azimuth offsets between the two images are used to estimate centimeter-level residual motion that was undetected by the differential GPS and inertial navigation units in the radar system. The track motion files are corrected based upon these estimations and the data is reprocessed to obtain the final differential interferogram.

4. APPLICATION TO UAVSAR DATA

The beam aperture correction should improve the image focus in the azimuth direction. This was verified in analysis of simulated point target data. The improvement is shown in Figure 2, where the top figure shows the azimuth impulse response with

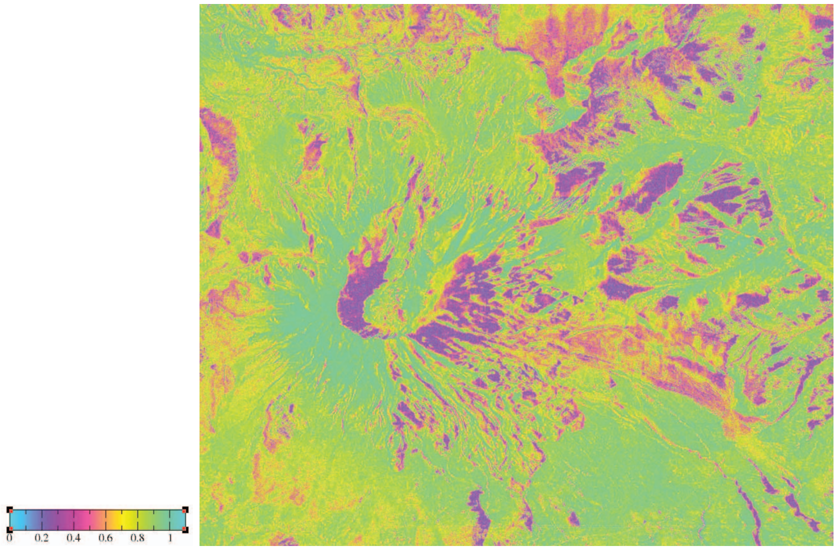

Fig. 4. *Correlation in the vicinity of the peak of Mt. St. Helens between the images collected on two passes separated by four hours.*

convention motion compensation and the bottom figures includes the aperture correction in the advanced motion compensation (no topography correction). The first null is deeper, the phase flatter, and the PSLR increased with the new algorithm, as expected for the UAVSAR azimuth beam width of 8°.

The advanced motion compensation has been applied to UAVSAR data collected over Mt. St. Helens, Washington, on two passes separated in time by four hours. The area processed extends for approximately 30 km north and south of the peak, with a swath width of 17 km. The advanced motion compensation algorithm significantly improves the correlation between the images collected on the two passes over this area, which has significant topographic relief. The improvement in the correlation is shown in Figure 3, which shows the correlation statistics. There is a significant shift towards higher correlation with the advanced algorithm. The correlation in the vicinity of the mountain peak, shown in Figure 4, is consistently high where the terrain is not in shadow.

5. ACKNOWLEDGMENT

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6. REFERENCES

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