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Improved navigation-based motion compensation for LFMCW synthetic aperture radar imaging

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Abstract In this paper, a new motion compensation algorithm using navigation data is proposed for frequency domain algorithm of synthetic aperture radar (SAR) imaging. SAR processing method assumes that the sensor is moving in a straight line at a constant speed; however in reality, a SAR platform will deviate from this ideal. This non-ideal motion can seriously degrade the SAR image quality. In this study, the linear frequency-modulated continuous wave SAR signal model is presented. The effects of non-ideal motion during the SAR signal modeling are investigated, and new method for motion correction is developed. This new motion compensation algorithm is verified with simulated data and with actual data collected using FMCW mode SAR dataset.

Keywords Synthetic aperture radar · Motion compensation · Frequency-modulated continuous wave · Strip-map

1 Introduction

Synthetic aperture radar (SAR) processing algorithms (without any phase error correction or motion compensation step) assume that the radar platform moves at a constant speed in a straight trajectory. Nevertheless, this is not true as the platform experiences a variety of deviations from the ideal path in actual data collection. These deviations happen when the platform changes its attitude, speed, or is subjected to turbulence in the atmosphere. Variations in along-track ground speed result in non-uniform spacing of the radar pulses on the ground. This non-uniform sampling of the Doppler spectrum results in erroneous calculations of the Doppler phase history. Changes in pitch, roll, and yaw introduce errors of a different kind. The pitching displaces the antenna footprint on the ground, the roll changes the antenna gain pattern over the target area, and the yaw introduces a squint. Pitch and yaw shift the Doppler centroid, with the shift being range dependent in the yaw case. Translational motion causes platform displacement from the nominal, ideal path. This results in the target scene changing in range during data collection. This range shift also causes inconsistencies in the target phase history. These deviations introduce errors in the stored data, which lower SAR image quality.

In this paper, we have only considered translational motion error in the SAR signal modeling. Coherent processing of SAR data requires precise knowledge of the relative geometric between the flight trajectory and the scene being imaged. This geometry information is typically acquired using navigation systems such as inertial measurement units (IMUs) [1] and global positioning system (GPS) receivers [2]. In a typical SAR system, navigation data are employed for motion compensation (MC) [3,4].

Constructions of very small SAR systems are possible by using a linear frequency-modulated continuous wave (LFMCW) signal in the radar transmitter [5–10]. Combined with an analog de-chirp in the receiver, these systems can be made with hardware which is simpler, cheaper, and consumes less power than conventional pulsed SAR systems. This enables the use of low cost SARs on small unmanned aircraft systems (UAS) [8]. The motion error problem is particularly apparent to the UAS SAR, because it is easily disturbed by the atmospheric turbulence due to its small size

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