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SMALL SATELLITE FORMATION DESIGN AND OPTIMIZATION FOR DISTRIBUTED SYNTHETIC APERTURE RADAR (SAR) DIGITAL BEAMFORMING CONCEPTS

Abstract

Synthetic aperture radar (SAR) is a well-established remote sensing technique offering unique information not obtainable through conventional optical remote sensing, and advantages such as imaging capability at day and night and the ability to image through clouds. However, traditional SAR faces a fundamental challenge: the trade-off between wide swath width and high spatial resolution. This constraint not only restricts the coverage capabilities of large platforms, but poses an even greater challenge for small platforms, which lack the resources to accommodate highly complex electronics. Extensive research has been conducted to overcome this limitation through digital beamforming (DBF) techniques that coherently combine data from distributed platforms flying at relatively close distances. Yet, such techniques impose several critical technical challenges, among which is the stringent baseline control. In this paper, we evaluate in detail the feasibility of spaceborne distributed SAR systems for high-resolution, wide-swath imaging with small platforms in terms of mission geometry, collision safety, and guidance, navigation, and control (GNC).

We propose formation-flying mission designs fulfilling the requirements for two distinct distributed SAR concepts: 1) Processing of samples acquired from multiple apertures positioned in the along-track direction allows for unambiguous recovery of the Doppler spectrum; 2) Processing samples from apertures uniformly aligned in the zero-doppler plane allows for the suppression of range ambiguities. Both cases require the satellites to follow specific relative trajectories with respect to the imaged area (i.e., in an Earth-Fixed geometry) with sub-meter baseline control accuracy, which depends on the used radar wavelength.

First, we define a spacecraft-centered frame, namely the zero-Doppler frame, in which the positioning requirements are defined, and characterize the degrees of freedom for the relative motion geometry of the formation. Then, we present a method to design relative motion models that conform to the ideal distributed payload geometries for limited fractions of the orbital period. In order to both compensate natural orbit disturbances and enhance the formation duty cycle, we propose relative motion control models utilizing on-board propulsion. We then present a method to characterize safety, evaluating the collision probability for spacecraft at close distances based on linearized relative motion models. Finally, we apply the developed formation design and safety evaluation methods to two test cases, one for ambiguity

suppression in azimuth and the other for ambiguity suppression in elevation, demonstrating the feasibility of these concepts with current technology in small spacecraft.