

Modified Polar Format Algorithm for Processing Spaceborne SAR Data

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Paper Summary:

We present a modified polar format algorithm for processing spaceborne synthetic aperture radar (SAR) data. The derivation of this algorithm is based upon the geometry of a spherical reference surface (i.e., a spherical Earth) and a platform flight trajectory that can include significant radial curvature, corresponding to the first-order curvature of an orbiting spacecraft. The algorithm may therefore be more accurate than the traditional polar format algorithm for situations in which the geometry of the sensor and the target scene of interest are described by a spherical model rather than a planar model.

The traditional polar format algorithm is well known for processing spotlight-mode SAR data. This algorithm involves the assumption that the spherical wavefronts of the radar pulses can be approximated by planar wavefronts around a central reference point in the imaged scene. The surface to which data are focused (i.e., the image plane) is also assumed to be flat when compensating for platform motion in the radial or vertical direction. These approximations are often reasonable for small target scenes imaged by airborne platforms, but for larger scenes, the approximations can lead to errors in parts of the scene far away from the central reference point. These errors may be of particular concern for applications such as interferometry, in which the image phase as well as the image magnitude must be faithfully reproduced during image-formation processing.

The modified polar format algorithm is based on the spherical-coordinate geometry of a spherical reference surface that locally approximates the curvature of the target scene. The platform motion is described in Earth-fixed (rotating) coordinates. The algorithm invokes a 3-D version of the Projection-Slice Theorem, which, loosely speaking, states that the 1-D Fourier transform of the integral of a 3-D volume over a set of parallel planes corresponds to the component of the 3-D Fourier transform of the volume along a line normal to the planes in the frequency or wavenumber domain. Note that geometrically, the intersection of two spheres is a circle that lies in a plane perpendicular to the line through the centers of the spheres. Therefore, the intersection of a spherical contour of constant range from the SAR platform and the spherical reference surface is contained in a plane normal to the platform position vector. Consequently, the signal data in a single range bin of a single radar pulse is the integral over part of a plane, assuming that the imaged area lies exclusively on the spherical reference surface. The orientation of a particular plane is determined by the platform location at the time of the pulse, and the distance of the plane from the origin is determined by the range. By mapping slant range into radial distance from the origin,

one can therefore recover the Fourier transform of the image intensity distribution, and hence the image itself, through the Projection-Slice Theorem.

The algorithm thus begins with a resampling of the range-compressed pulse data from slant range to radial distance from the origin. This step involves a uniform-to-nonuniform resampling in the time domain. The sample locations are chosen so that the frequency-domain samples of the 1-D discrete Fourier transforms of the resampled pulse data are aligned along one of the dimensions of a local Cartesian coordinate system. The resampled pulse data are then 1-D Fourier transformed. The resulting data represent the 2-D Fourier transform of the image, but sampled along radial lines. That is, the data are sampled nonuniformly in one dimension, in a manner akin to the 'keystone' of the intermediate resampling stage of the traditional polar format algorithm. A 1-D frequency-domain resampling thus brings the data onto a Cartesian grid, from which a final 2-D Fourier transform produces the final image. This image corresponds to the projection of the reference-surface brightness distribution onto a plane. The data can be projected back onto the spherical reference surface if desired.

We demonstrate results obtained with this algorithm on both simulated data and on data acquired by the NASA SIR-C instrument flown on the Space Shuttle in 1994. While the instrument was primarily designed for stripmap operation, it did acquire dual-polarized C-band and L-band data in spotlight mode.

Note that while this work was motivated by the desire for a processing algorithm with high phase fidelity, the phase behavior of the proposed algorithm was not examined in detail during this study; this topic is planned as the subject of future work.

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