# Height Reconstruction Techniques for Synthetic Aperture Lidar Systems

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The data-processing techniques and acquisition modes of a synthetic aperture lidar (SAL) instrument operating at optical wavelengths are closely related to the analogous modes of a synthetic aperture radar (SAR) instrument operating at microwave frequencies. It is consequently natural to explore the applicability of SAR processing techniques to SAL sensors. In this paper, we examine the feasibility of adopting SAR height-reconstruction techniques with SAL sensors to obtain high-resolution 3-D imagery at optical wavelengths.

Interferometric SAR (InSAR or IFSAR) techniques are commonly used to obtain very accurate digital elevation models of land surfaces, and such techniques could in principle be used in the context of SAL instruments as well. It is unlikely that a SAL system could feasibly meet the stringent requirements on phase accuracy and stability required for interferometry, however. In particular, because of the short wavelengths of SAL sensors, interferometric SAL measurements would be highly sensitive to errors arising from uncompensated phase-center motion, atmospheric turbulence, target decorrelation, and target motion or vibration. A SAL interferometer would also require multiple phase centers, which might be costly to implement because of the need for dual optical chains in the receive system.

A more practicable option for SAL height reconstruction might be the use of techniques related to amplitude-comparison monopulse processing. Assuming that the SAL receiver utilizes a (coherent) focal-plane detector array in elevation, the output of each detector corresponds to a different receive beam pattern. This scenario is analogous to the microwave case of a reflector antenna with multiple offset feeds. The data streams from the SAL detector channels can therefore be processed jointly or in pairs to estimate the elevation angle from which the dominant energy for a particular range-azimuth pixel arrives. With only trivial processing, the elevation angle could be estimated from the real-beam SAL image; the accuracy of these elevation angle estimates would be the diffraction-limited beamwidth $\lambda/D$, where $\lambda$ is the wavelength and $D$ is the diameter of the real receive aperture.

By comparing the amplitudes of pixels from adjacent detector channels in the range- and azimuth-compressed images, the elevation angle can be estimated to a fraction of the diffraction-limited beamwidth with an accuracy determined by the CNR. The elevation angle estimates from such processing will exhibit a bias when the CNR is low, however. We give expressions for the theoretical performance of this amplitude-monopulse estimator and verify our expressions with Monte Carlo simulations.

The bias arising from the amplitude-monopulse estimator can be avoided for the most part by processing all of the detector channels jointly. We derive a scheme for doing so and show that it corresponds to the maximum likelihood (ML) estimator for the elevation angle. We demonstrate the performance of the ML estimator with simulations.

Because of their ability to provide elevation angle estimates beyond the diffraction limit, their relative robustness to errors, and their ease of implementation, we

conclude that amplitude-based height reconstruction techniques are most suitable for foreseeable SAL systems. Note that phase-comparison monopulse processing is unattractive because it requires multiple phase centers and is thus characterized by the same drawbacks as SAL interferometry.