Synthetic Aperture Radar Image Formation with Uncertainty Quantification

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Abstract

Synthetic aperture radar (SAR) is a day or night any-weather imaging modality that is an important tool in remote sensing. Most existing SAR image formation methods result in a maximum a posteriori image estimate which approximates the reflectivity function of an unknown ground scene. This single image provides no quantification of the certainty with which the features in the estimate should be trusted. In addition, finding the mode is generally not the best way to interrogate a posterior. Therefore, we introduce a sampling approach to SAR image formation. A hierarchical Bayesian model is constructed using conjugate priors that directly incorporate coherent imaging and the problematic speckle phenomenon which is known to degrade image quality. A Gibbs sampler is used to sample the resulting posterior, obtaining samples of the image as well as the parameters governing speckle and noise. Utilizing a non-uniform fast Fourier transform, $\sim 5 \times 10^5$ latent variables are efficiently sampled. The resulting samples are used to compute estimates, as well as to derive other statistics such as confidence images which aid in uncertainty quantification. The latter information is particularly important in SAR, where ground truth images even for synthetically-created examples are typically unknown. Examples are performed using the GOTCHA Volumetric SAR data set from the Air Force Research Laboratory. Our results and analysis show that a sampling-based approach to SAR image formation provides parameter-free estimates with improved contrast and significantly reduced speckle, as well as unprecedented uncertainty quantification information.