Super-Resolution SAR Tomography for Accurate Forest Height Mapping Using Spaceborne PolSAR Data

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Abstract:

This study employs advanced super-resolution techniques in SAR tomography to estimate backscatter power across forest height levels, enabling 3D forest structure reconstruction. It evaluates spectral estimation methods, including Fourier transform, beamforming, Capon, a new Capon-like algorithm, and fully polarimetric Capon, using Radarsat-2 and TerraSAR-X data from a teak forest in Haldwani, India. The Capon-like algorithm effectively captured height-specific backscatter variations, with X-band data outperforming C-band. Polarimetric extensions improved scatterer detection at lower heights. The fully polarimetric Capon algorithm achieved the best results, with an RMSE of 2.58 m and 88.64% accuracy, proving the most suitable for this application.

Methodology:

Figure 1 shows the processing chain of the tomographic processing of SAR data.

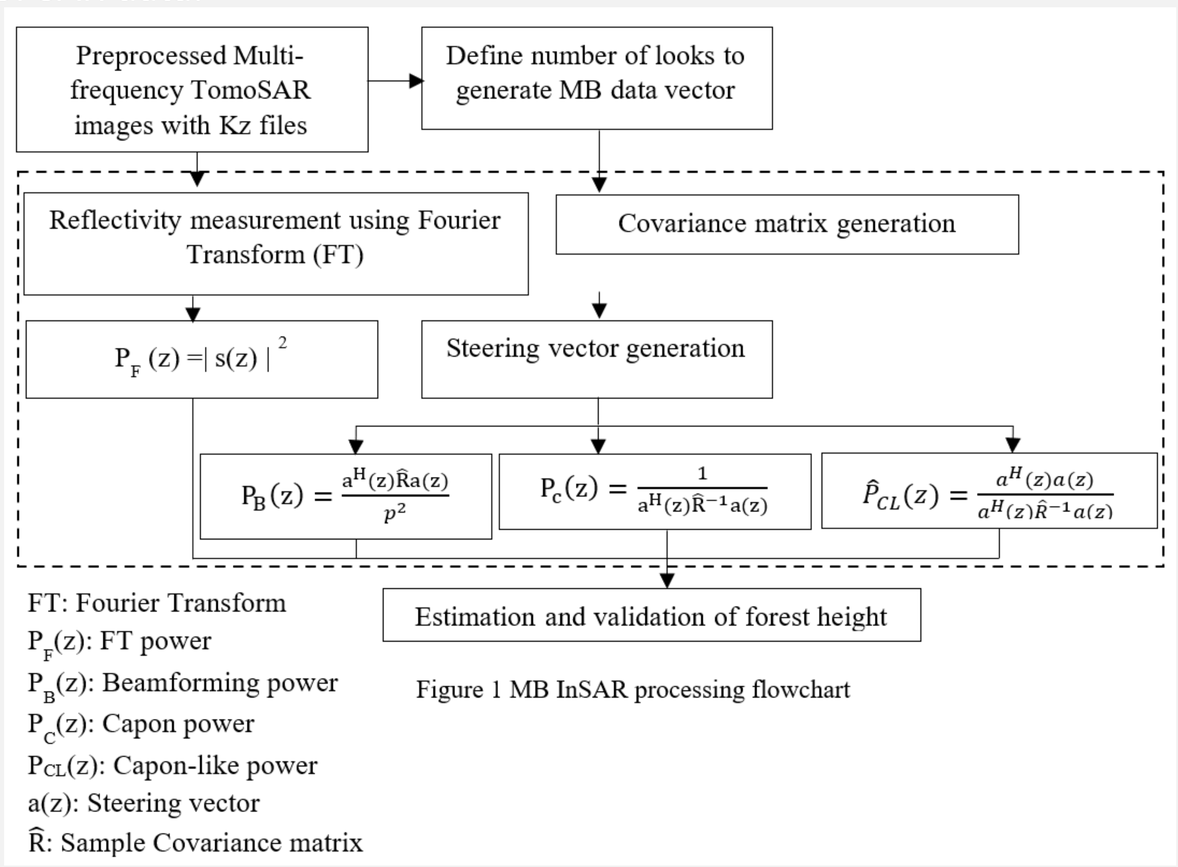

Figure 1 MB InSAR processing flowchart

Results:

Figure 3 illustrates the tomographic reconstruction using FP-Capon for the X-band, revealing notable insights. Two specific locations are highlighted in the figure. A comparison with Figure 2 shows that the tomogram in Figure 2 exhibits broad peaks and substantial leakage. FP-Capon effectively addresses these issues by enhancing the profile by significantly reducing sidelobes and narrowing the peaks. Additionally, FP-Capon successfully detects scatterers overlooked in SP-Capon, marking a key improvement.

Figure 5 illustrates the tomographic reconstruction using FP-Capon for the C-band RADARSAT-2 data. Firstly, FP-Capon demonstrates a significant reduction in spatial leakage compared to single-channel Capon, as highlighted in Figure 5 (Circle 2). Secondly, by integrating multiple polarization channels, FP-Capon successfully detects scatterers below 10 meters, allowing the wave to penetrate the forest canopy and reach the ground. This capability underscores the effectiveness of polarimetric Capon as a superior method for detecting scatterers

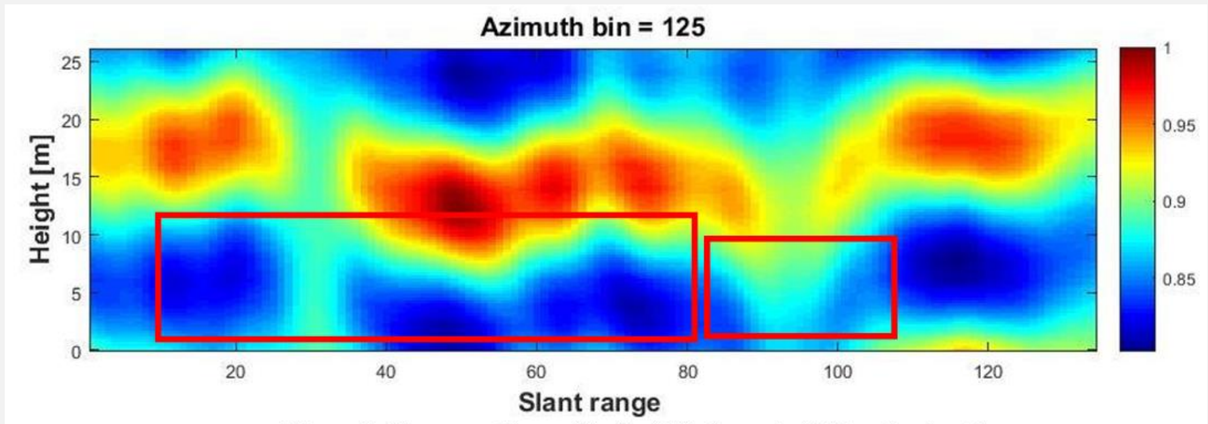

Figure 2. Tomographic profile for HH channel at X-band using Capon

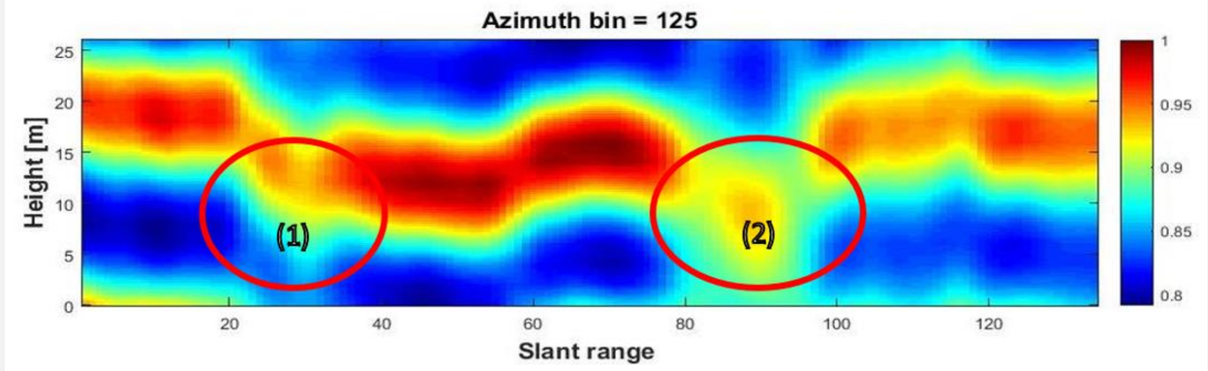

Figure 3. Tomographic profile of fully polarimetric Capon for X-band

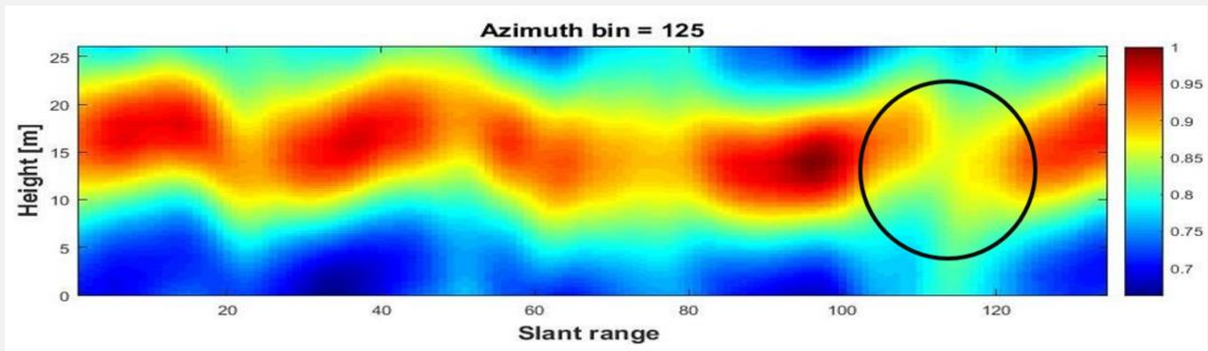

Figure 4. Tomographic profile for HH channel at C-band using Capon

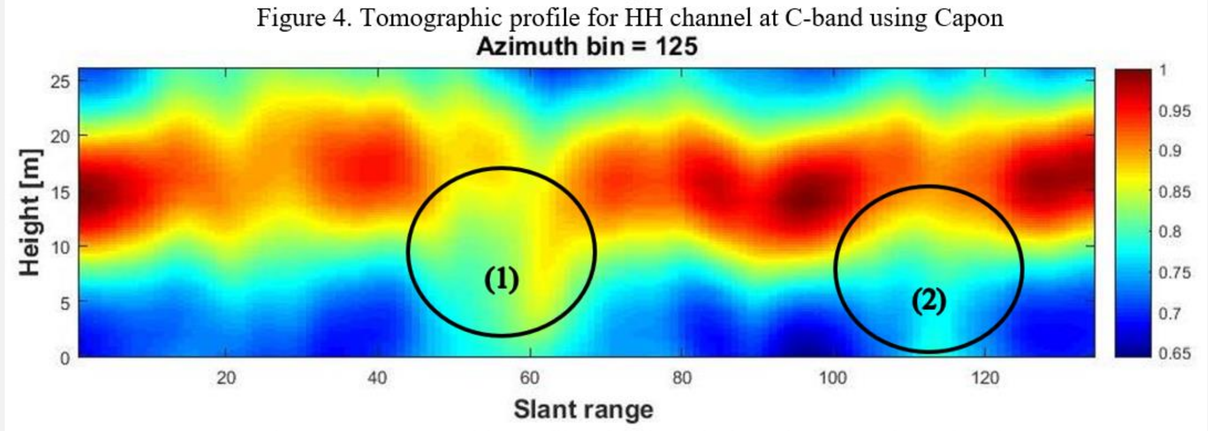

Figure 5. Tomographic profile of fully polarimetric Capon for C-band

Conclusions:

Fourier transform, a foundational SAR tomography technique, is limited by high sidelobes and height ambiguities due to baseline sparseness. Super-resolution methods like beamforming, Capon, and the Capon-like algorithm address these issues, enhancing vertical profiles and suppressing sidelobes but with a trade-off in radiometric accuracy. Among the tested methods, Capon and fully polarimetric Capon for C-band, and Fourier transform for X-band, showed superior performance. FP-Capon emerged as the most effective, achieving an RMSE of 2.58 m and an accuracy of 88.64%, with height distributions following a normal curve and flat sample plot distributions.

References:

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