

On-Board Real-Time Atmospheric Correction for Hyperspectral Remote Sensing: Algorithm Optimization, FPGA Implementation, and Resource-Accuracy Tradeoff Analysis

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Hyperspectral remote sensing is highly valuable for time-sensitive applications, such as disaster monitoring and environmental assessment. However, the high computational complexity of atmospheric correction algorithms poses a fundamental challenge for real-time on-board processing under the severe resource constraints of spaceborne platforms^[1]. Building upon our previously introduced Advanced Synchronization Monitoring Atmospheric Corrector (ASMAC), this study presents a comprehensive hardware-software co-design framework enabling real-time, on-orbit atmospheric correction^[2].

To address the prohibitive storage demands of full-dimensional lookup tables (LUTs), we apply a Sobol-based global sensitivity analysis to quantify the impact of each input parameter on the final correction accuracy, including aerosol optical depth (AOD), columnar water vapor (CWV), and observation geometry. By eliminating or reducing non-sensitive variables, the LUT is successfully compressed from gigabyte (GB) to megabyte (MB) scales while preserving correction fidelity for quantitative applications. Furthermore, to reduce computational load during atmospheric parameter retrieval, a spectral-prior-guided fast aerosol inversion method and a band-ratio-based water vapor retrieval module are developed.

The entire correction pipeline is mapped onto a high-performance, aerospace-grade FPGA (Fudan Micro JFM7K325T) utilizing a dataflow-driven heterogeneous parallel architecture. To maximize throughput under limited logic resources, fine-grained operator pipelining, fixed-point bit-width optimization, and ping-pong buffering strategies are employed. Experimental results demonstrate that the proposed approach achieves real-time processing capabilities with acceptable precision loss. Finally, a systematic resource-accuracy tradeoff analysis provides quantitative guidance for configuration selection across diverse mission scenarios, offering a practical pathway toward agile and autonomous hyperspectral data exploitation.

References

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