Decoding Light: Physics-Aware Self-Supervised AI for Low-Cost High-Fidelity Hyperspectral Imaging

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Hyperspectral imaging enables simultaneous acquisition of spatial and spectral information and has become indispensable in applications including material characterization, environmental engineering, biomedical imaging, etc. However, widespread adoption remains limited by the lack of cost-effective imaging hardware and accurate reconstruction methods that can reliably recover high-dimensional spectral data. To address this gap, I develop a low-cost Computed Tomography Imaging Spectrometer (CTIS) hardware system that captures the zero, first, and diagonal diffraction orders, together with a physics-aware self-supervised AI framework for high-fidelity hyperspectral reconstruction. The CTIS hardware simplification creates an under-determined inverse reconstruction problem with far fewer measurements than unknowns. I formulate its solution by combining physics-based backprojection with AI-based learning. To ensure physically plausible learning, I propose a novel Physics-Aware Spatial-Spectral (PASS) Transformer that embeds diffraction and point-spread function physics directly into its attention mechanisms to recover missing information in the null space of CTIS measurements. PASS also reconstructs overlapping spectral components inherent in CTIS by enforcing physical consistency, thus avoiding hallucinated structures and null-space ambiguities. By exploiting forward consistency with CTIS imaging physics during training, its self-supervision manner eliminates the need for costly ground-truth hyperspectral data. Experimental results demonstrate that my method outperforms state-of-the-art techniques in reconstruction fidelity. I apply and validate this integrated hardware-AI system in food allergy detection, plant stress monitoring, and environmental contamination analysis.

Awards Won:

First Award of $6,000

Association for Computing Machinery: Fourth Award of $500

Midjourney: Eight awards of $2,500