PHYSICS-BASED NOISE MODELING FOR MSFA IMAGE DENOISING WITH DECOUPLED NETWORKS

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Abstract

Multispectral Filter Array (MSFA) imaging has emerged as a compact and cost-effective solution for acquiring spectral information in a single shot. Unlike traditional multispectral systems that rely on beam splitters or multiple sensors, MSFA sensors capture different spectral bands using a mosaic pattern similar to Bayer sampling in RGB cameras. However, the mosaic acquisition process makes MSFA images highly sensitive to complex noise sources, including photon shot noise, read noise, and spectral crosstalk. These noise components are signal-dependent and spatially variant, making conventional denoising approaches inadequate. To address these challenges, this work proposes a physics-guided MSFA image denoising framework that integrates a realistic camera noise formation model with a noise-decoupled deep neural network.The proposed approach first models sensor noise using a physics-based formulation that simulates photon shot noise through Poisson statistics, additive Gaussian read noise from electronic circuitry, and optional spectral crosstalk between adjacent bands. This modeling ensures that the training data closely resemble real sensor measurements under varying exposure and gain conditions. The denoising network adopts a noise-decoupled architecture with dual prediction branches: one branch reconstructs the clean mosaic signal, while the second branch estimates the residual noise component. A physics-consistency constraint enforces that the sum of predicted clean signal and noise residual approximates the observed noisy measurement, thereby improving interpretability and stability.