Night-time Satellite and Aerial Image Denoising with Online Complex Noise Modeling and Deep Learning

Sandeep Kumar Jangir, Reza Bahmanyar, Tobias Storch

At any given time, half of the Earth's surface experiences daytime, while the other half is in night-time. Most Earth observation missions focus on daytime imaging, overlooking the significant applications of night-time imagery. Artificial lighting has profoundly shaped human societies, enabling night-time activities and linking light emissions to social factors (e.g., wealth) and environmental impacts (e.g., light pollution). Night-time light imagery has been widely used to monitor conflict areas, assess the impacts of natural disasters, and detect damage to infrastructure such as roads, bridges, and buildings (1). Additionally, it has been employed to analyze urban changes during conflicts, monitor power outages in disaster-stricken regions, and evaluate humanitarian crises through changes in night-time illumination patterns.

Recent advances in instrumentation have driven rapid growth in night-time remote sensing research (2). However, progress remains constrained by the limited number of sensors and their shortcomings, including insufficient spatial resolution, spectral information, radiometric sensitivity, and revisit frequency. Furthermore, continuous operation of imaging sensors introduces noise artifacts such as dark current noise, fixed pattern noise, and hot pixels, which reduce the signal-to-noise ratio and hinder downstream applications such as classification, detection and more (4).

Traditional filtering methods struggle to address the diverse and complex noise types inherent to night-time imagery due to the ill-posed nature of the problem. Deep learning (DL) approaches (3) have emerged as a robust alternative, effectively learning noise patterns from data and handling complex degradations while preserving image details and colors, especially in low-light conditions. These models outperform traditional methods without requiring manual tuning and adapt to new noise profiles.

To address the scarcity of paired noisy and clean datasets for training night-time denoising models for satellite and aerial image, we propose a comprehensive noise modeling framework. By analyzing camera dark frames, we model a range of degradations, including stripe and pattern noise, hot pixels, dark current noise, and simpler noise types like RGB and black-and-white noise. During training, these degradations are injected into satellite and aerial images at various combinations and intensities, generating unique noise patterns in each mini-batch. This approach enables our DL-model to learn effective noise removal while preserving the fidelity of details.

Our trained model not only removes noise from raw images (8, 12, or 16-bit depths) but also strategically fills in missing information at noisy pixel locations. Comparative evaluations demonstrate that our approach outperforms state-of-the-art denoising methods. Furthermore, we highlight the practical benefits of denoising for a downstream night-time remote sensing application. This work provides a robust simulation model and training framework, advancing the utility of night-time imagery for both research and practical applications.

References

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