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

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ESA - LIVING PLANET SYMPOSIUM

Significance of Night-time Imagery

Global Relevance: At any moment, half of Earth's surface is in night-time, yet most remote sensing focuses on daytime imaging.

Human Activity Insights: Artificial lighting drives night-time activities, reflecting social factors like wealth and urban development.

Environmental Impact: Night-time light emissions reveal light pollution, affecting ecosystems and energy consumption.

Approach

Dark Frame Analysis: Analyzed aerial dark frames to pinpoint noise: hot/dead pixels (R, G, B), banding, FPN, and random (dark current, shot, read).

Noise Degradation: Simulated realistic noise (hot/dead pixels, banding, FPN, random) for 8/12/16-bit depths with diverse patterns.

Lightweight DNN Design: End-to-end trainable deep neural network (DNN) with 20K parameters optimized for low-light denoising and suitable for real-world deployment

Noise Injection: Aerial images injected with varied noise combinations and intensities during training; online injection creates unique mini-batch patterns, boosting generalization.

Native Noise Removal: Post-training, the DNN efficiently processes raw test images, effectively removing native noise artifacts to enhance image quality.

Challenges :

Sensor Limitations:
- Low spatial resolution restricts detail capture in aerial and satellite images.
- Limited spectral information hinders material and feature identification.
- Poor radiometric sensitivity reduces signal detection in low-light conditions.
- Infrequent revisits limit timely monitoring of dynamic events.

Complex Noise Artifacts:
- Hot/Dead Pixels: Defective pixels stuck at R, G, B (bright) or black (dark) values in both aerial and satellite sensors.
- Banding Noise: Gradient-like readout or amplifier glow artifacts, prominent in long-exposure dark frames.
- Fixed-Pattern Noise (FPN): Column/row variations from sensor non-uniformity, affecting both platforms.
- Random Noise: Dark current (thermal), shot, and read noise degrade low-light signals.

Impact of Noise:
- Reduces signal-to-noise ratio, impairing classification, detection, and damage assessment.
- Exacerbates challenges in low-light aerial and satellite imagery analysis.

Traditional Methods Fail:
- Filtering (e.g., Gaussian, median) cannot address diverse, ill-posed noise patterns.
- Scarcity of paired noisy-clean datasets limits training for denoising models.

Noise Degradation

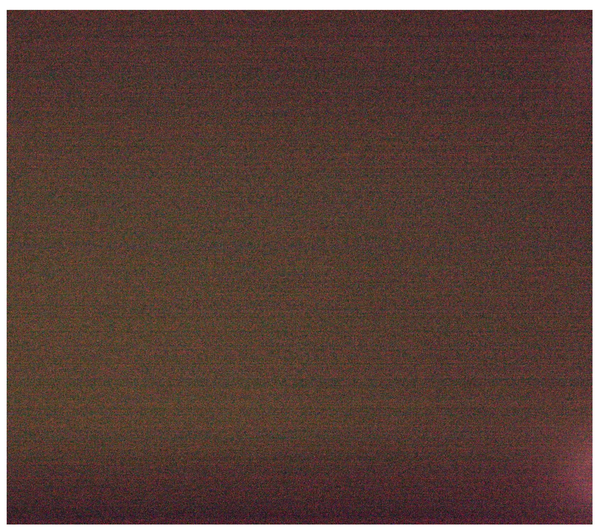
Dark Frame: Closed-shutter image capturing noise (hot/dead pixels, banding, FPN, random) in low-light.

Noise Patterns: Reveals specific noise types (e.g., FPN, banding) for realistic modeling.

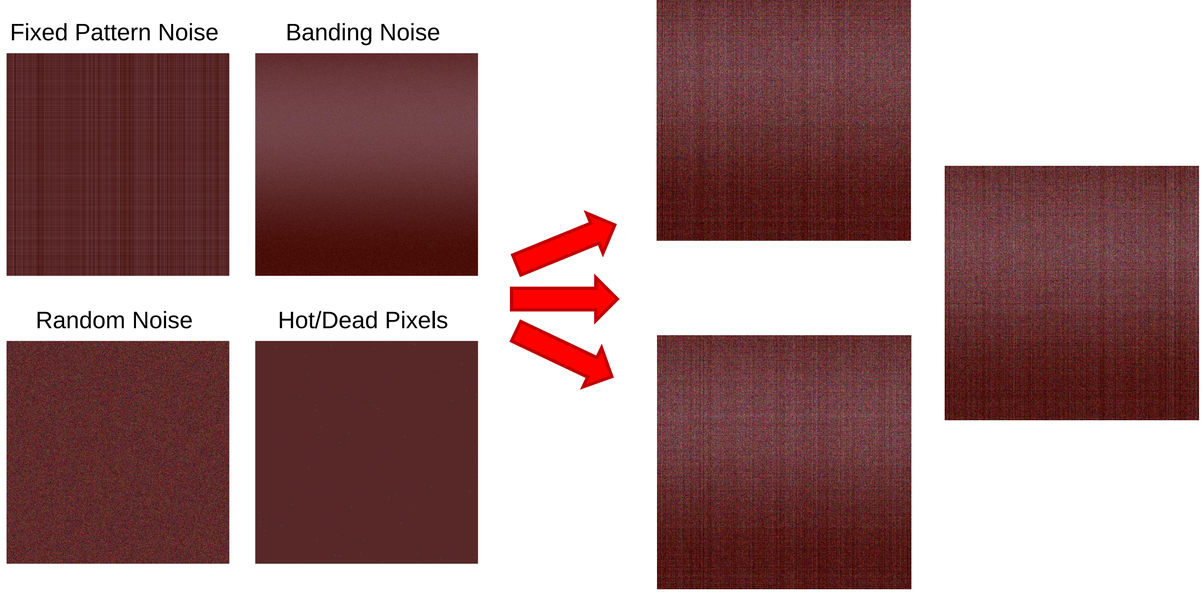
Intensity Data: Offers noise amplitude and distribution for varied simulation intensities.

Sensor Artifacts: Highlights sensor-specific defects (e.g., hot pixel, sensor degradations) to refine degradation parameters.

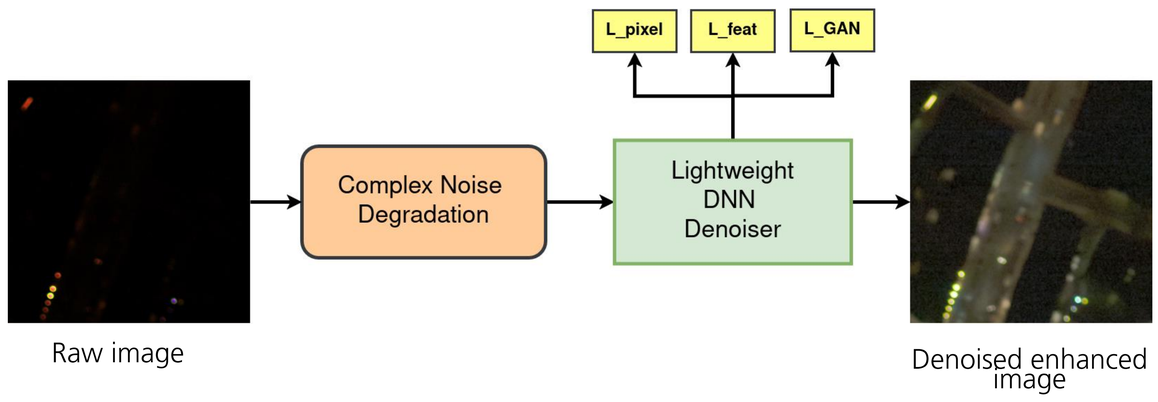
Dark Frame - Canon EOS 1Ds Mark III



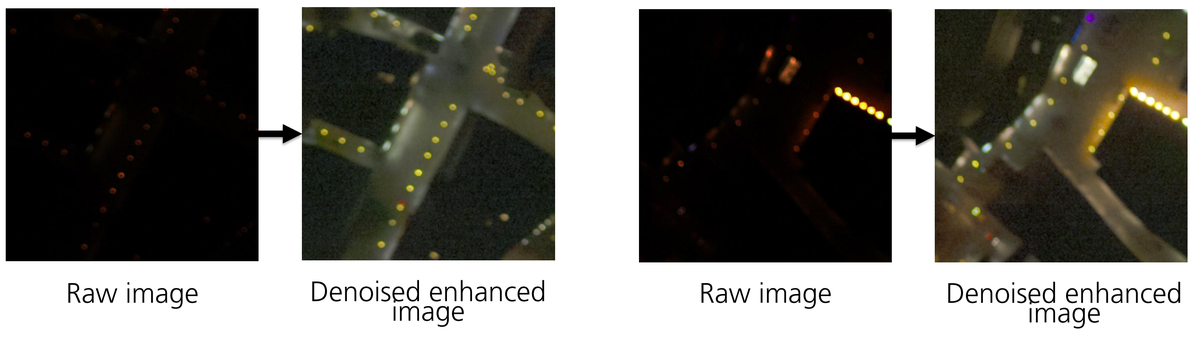
Noise Simulation



DNN Denoiser

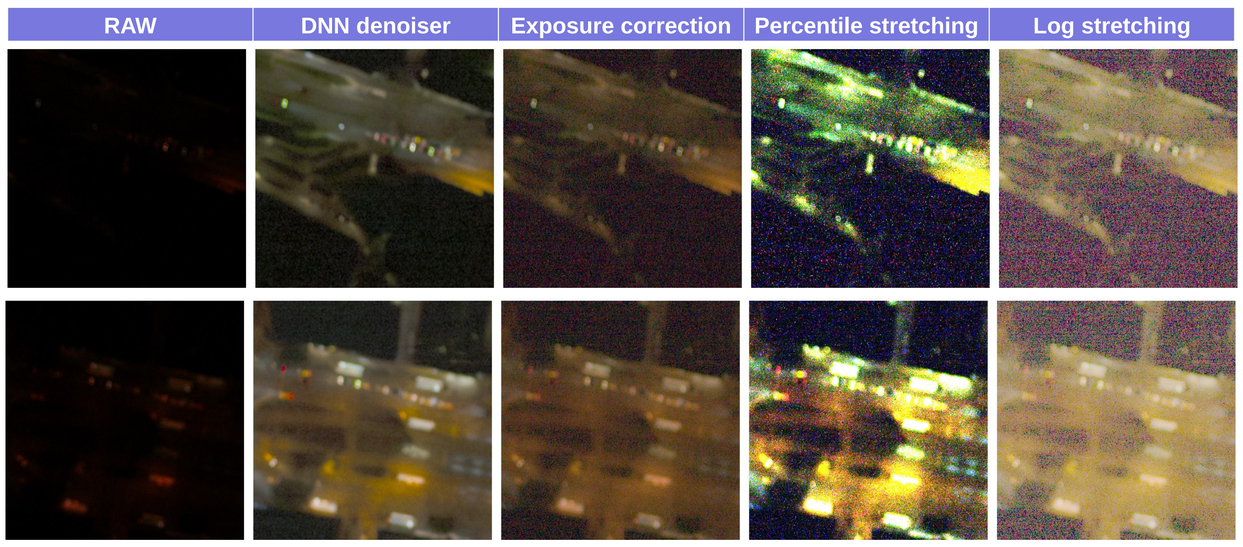


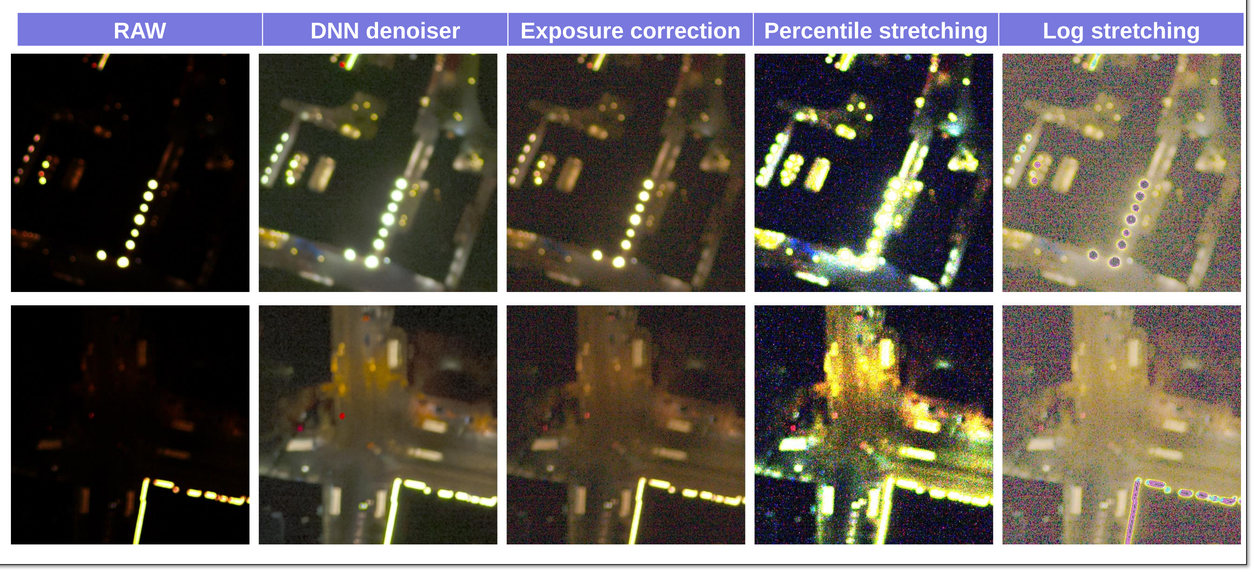
Results



Real-World Processing

- Raw night-time images are adjusted via exposure or percentile stretching for proper exposure, enabling downstream tasks like street lamp classification.
- The DNN denoiser removes noise and enhances images, allowing direct use in downstream applications with improved quality.





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