Developing an Image Processing Pipeline for DSLR Astrophotography Using Classical and Deep Learning Methods

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Motivation

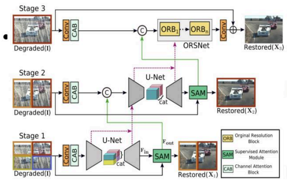
Amateur astrophotography with DSLR cameras faces several challenges that degrade image quality compared to professional setups. Key issues include:

- **Star Trails:** Caused by camera movement or Earth's rotation, leading to streaked stars instead of sharp points.
- **Non-Uniform Backgrounds:** Resulting from light pollution or sensor inconsistencies, reducing contrast and making faint details harder to see.
- **High Noise:** Introduced by dark current and shot noise, obscuring fine astronomical details.

We are developing an automated image processing pipeline, and comparing classical signal processing methods with neural network-based approaches.

Related Work

- A non-linear blur model has been proposed to model light streaks in low-light conditions, but this may fail with large saturated regions [1].
- With non-iterative thinning and Richardson-Lucy algorithm, one can extract deblur kernel and then deblurring it [2].



[3]

Light streak patch detection:

$$|\widehat{I}(\omega)|^2 \propto \|\omega\|^{-\beta}$$

$$|\widehat{I}(\omega)|^2|\widehat{L}(\omega)| \approx C$$

$$B = K * I + N$$

$$|\widehat{B}(\omega)|^2|\widehat{L}(\omega)| \approx |\widehat{I}(\omega)|^2|\widehat{K}(\omega)|^2|\widehat{L}(\omega)| \approx C|\widehat{K}(\omega)|^2$$

$$B \otimes B * L \approx C(K \otimes K)$$

$$d(P,B) = \min_C \|B \otimes B * L - C(P \otimes P)\|^2$$

[1]

References

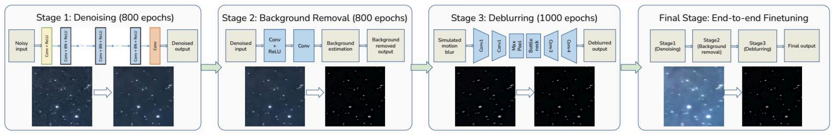
[1] Hu Z, Cho et al.,Deblurring Low-Light Images with Light Streaks, IEEE, 2014
[2] Su, Shao et al., Richardson-Lucy deblurring for the star scene under a thinning motion path, Satellite Data Compression, Communications, and Processing XI, 2015
[3]Zamir, Arora et al. Multi-Stage Progressive Image Restoration, CVPR, 2021
[4]Zamir, Arora et al. Restormer: Efficient Transformer for High-Resolution Image Restoration. CVPR, 2022.

Methods

Classical Method:

Step 1: Background gradient removal (morphological opening rolling-ball)
Step 2: PSF motion blur kernel estimation (local patch extraction)
Step 3: Richardson-Lucy deblurring
Step 4: Non-local Means denoising
Step 5: Star Mask + Boosting

Neural Network Method:



Dataset Pipeline:

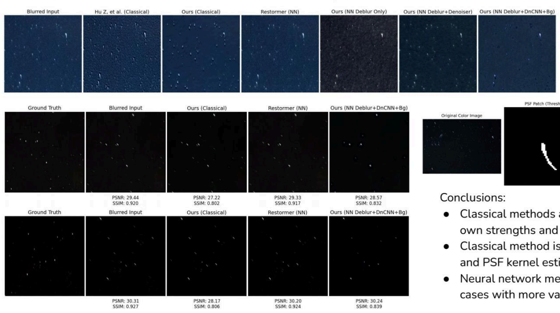
Stage 1 Denoising (train/val split (80/20)):
- Extract 200 random 256×256 patches from raw images (without star trails)
- Apply non-local means denoising

Stage 2 Background Removal:
- Use Stage1 target as input and remove background via Gaussian blur subtraction

Stage 3: Star Trail Simulation
- Use Stage2 target as input
- Apply random star trails with curvatures

Stage 4: "All-in-One" Degradation
- Use Stage2 input as clean reference
- Apply noise, partial background & star trails

Experimental Results



Conclusions:

- Classical methods and neural network methods each has its own strengths and weaknesses.
- Classical method is better at background gradient extraction and PSF kernel estimation.
- Neural network method performs better in more generalized cases with more variability.