A Robust Low-Complexity Star Centroiding Algorithm for Autonomous Navigation under Lunar Noise Conditions

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Abstract

Star-based navigation on the lunar surface is severely degraded by strong regolith reflections, abrupt illumination transitions, and sensor-induced noise, all of which lower the signal-to-noise ratio (SNR) and impair centroiding accuracy. Existing methods address this trade-off poorly: classical center-of-mass (COM) and Gaussian fitting are computationally light but noise-sensitive, whereas iterative weighting and learning-based approaches improve accuracy at the cost of high computational load and large training data. This study addresses this gap by proposing a low-complexity yet robust star centroiding algorithm tailored for lunar-surface imagery. The pipeline integrates median filtering for impulse-noise suppression, an adaptive global threshold (set at 30 % of peak intensity) for star-region segmentation, and an intensity-weighted COM estimator for sub-pixel localization. The method was implemented in MATLAB R2023b and evaluated on 30 Stellarium-derived star fields, each corrupted by Gaussian, Poisson, salt-and-pepper, speckle, and solar-glare noise spanning SNRs from -4.71 dB to 0.72 dB. Benchmarked against standard COM, Gaussian fitting, and the Sieve Search Algorithm (SSA), the proposed method achieves the lowest average root-mean-square error (RMSE = 1.218 pixels), the lowest Euclidean distance error (1.143 pixels), and the lowest false detection rate (FDR = 6.716%), corresponding to relative reductions of 21.5 %, 16.7 %, and 32.7 % over the best baseline, respectively. The algorithm's favorable accuracy-complexity trade-off makes it well-suited for resource-constrained onboard processors in future lunar exploration and autonomous spacecraft navigation missions.

Author keywords

autonomous navigation; harsh lunar environment; image processing; lunar navigation; star centroiding

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