Photon-limited Image Reconstruction for Low-Light Target Enhancement

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Motivation

- Night vision / infrared are intrinsically noisy due to low intensity levels
- Target detection / recognition from such noisy images is a challenging task
- How can we make the best use of available photons to maximize target detection performance?
One Strategy: Spatial Binning

- Large detector elements spatially aggregate photons for high SNR
- Yields insufficient resolution for effective target detection
- **Question:** Can we do better?
Alternative Approach: Computational Imaging

- Acquire high-resolution data with limited counts per pixel
- Use computational methods to mitigate resulting shot noise
- Result is a highly accurate estimate of scene with easily distinguishable targets of interest
Image acquisition is described by an inhomogeneous Poisson process model:

\[ y \sim \text{Poisson}(Af^*). \]

Here

- \( y \in \mathbb{Z}_+^m \) are observed photon counts,
- \( A \in \mathbb{R}_+^{m \times n} \) is the sensing matrix (optical system model), and
- \( f^* \in \mathbb{R}_+^n \) is the true scene intensity containing targets of interest.

**Goal:** The accurate estimation of \( f^* \) from \( y \) when

- the number of unknowns may be larger than the number of measurements \( (n \geq m) \),
- the total number of photon counts \( (\sum_{i=1}^{m} y_i) \) is low, and
- the scene \( f^* \) is compressible (admits a sparse approximation).
Propose a nonnegatively-constrained complexity-regularized MLE:

\[
\hat{f} \triangleq \arg \min_{f} \sum_{i=1}^{m} \left\{ (Af)_i - y_i \log(Af)_i \right\} + \tau \text{pen}(f)
\]

subject to \( f \geq 0 \)

Here \( \tau > 0 \) trades-off between data fidelity and estimate complexity.

Refer to proposed approach as \textbf{SPIRAL}\textsuperscript{1}: \textbf{Sparse Poisson Intensity Reconstruction ALgorithms}

Poster describes SPIRAL framework

\textsuperscript{1}Harmony, Marcia, and Willett, Submitted to \textit{IEEE Trans. Image Processing}, 2010
Imaging Simulation

Data $y$ \quad \xrightarrow{\text{SPIRAL}} \quad \text{Reconstruction} \hat{f}$
Imaging Simulation

**Traditional**

Mean Count = 245.06  
CNR = 31.02  
RMSE (%) = 15.51

**SPIRAL**

Mean Count (of data) = 1.90  
CNR = 27.14  
RMSE (%) = 8.47

**Conclusion:** Computational imaging drastically outperforms traditional approaches for target enhancement