IGNIS

Infrared Geological Nano Imaging System

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Numerical Evaluation of the SNR

Improve the code in order to consider our specific target, the fumarole, and the background

Abstract

This report extends the previous SNR analysis by adapting the model to account for a subpixel target — a fumarole — within a mixed pixel captured by the FLIR BOSON 640 thermal camera. Since the target area is significantly smaller than the Ground Sample Distance (GSD), a weighted SNR formulation was implemented to more accurately represent the detectability of the target against the surrounding background. To address signal dominance by the background, normalization techniques were applied to the radiometric signals of both target and background. A synthetic dataset was generated across a range of mission-relevant parameters to statistically evaluate the behavior of the normalized weighted SNR. This refinement enhances the reliability of the detection model for small, low-contrast thermal features in the IGNIS mission scenario.

1. Use of Weighted SNR for Subpixel Target Detection

Since the fumarole (our target) is **smaller than the Ground Sample Distance (GSD)**, the detector captures a mixed signal from both the fumarole and the surrounding background. A standard SNR would overestimate the target's visibility by not distinguishing between these sources.

Weighted SNR accounts for the mixed pixel content and provides a more realistic measure of the target's detectability.

2. Methodology and Radiometric Signal Calculation

- **Radiance-Based Signal Computation**
  The thermal signal emitted by a surface at temperature T was computed using Planck's law across the 8–14 μm LWIR spectral range. The calculation steps are:

  - **Spectral Exitance (M_λ) was calculated:**

$$M_\lambda = \frac{C_1\left(e^{\frac{C_2}{\lambda T}} - 1\right)^{-1}}{\lambda^5}$$

- **Emissive Power (E_λ) accounted for the surface emissivity:**

  $$E_\lambda = \epsilon . M_\lambda$$

  where ϵ=0.95 for soil or fumarolic targets.

- **Transmittance and Sensor Response:**

  $$S\lambda = \lambda \cdot E\lambda \cdot \tau a \cdot \tau 0 \cdot \eta \cdot \Delta\lambda$$

  where:

  - τ_a is atmospheric transmittance,
  - τ_0 is optical transmittance of the camera,
  - η is detector quantum efficiency,
  - Δλ is the wavelength step.

- **Integrated Spectral Signal:**

  $$S_{sum} = \sum S\lambda$$

  This gives the total radiative signal per unit area.

- **Projection to Detector**
  To obtain the total signal at the detector for a given area A, viewing angle θ, and distance R:

  $$S = \frac{D^2 \cdot t \cdot cos_\theta \cdot A}{4 \cdot R^2 \cdot h \cdot c} \cdot S_{sum}$$

  Where:

  - D is lens diameter (derived from focal length and f-number),
  - t is integration time,
  - A is the emitting surface (target or background),
  - h, c are physical constants.

  This formulation was applied for both:

- **Background-only pixel**
- **Fumarole (target)** using a fixed area of $A = 100\,\mathrm{m}^2$

3. SNR Formulation and Weighted Calculation

- **Noise Equivalent Temperature Difference (NEDT)**
  To evaluate noise, the NEDT value (44.1 mK) was used. The corresponding radiative signal difference was computed as:
  - **Simulate signal from a surface at T + NEDT**
  - **Subtract** the background signal S(T)
  - **Project** this difference to the detector using the same radiometric projection formula.

  This yielded S_{NEDT}, the minimum detectable signal.

- **Mixed Pixel Model**
  Since the fumarole is subpixel, we simulate a pixel combining both:

$$S_{mix} = S_b \cdot (1 - \frac{A_t}{A_b}) + S_t$$

  Where:

  - $\boldsymbol{S_b}$ is the background-only pixel signal,
  - $\boldsymbol{S_t}$ is the fumarole signal (area = 100 m²),
  - $\boldsymbol{A_b}$ is pixel footprint (calculated from GSD),
  - This linear interpolation approximates partial area coverage.

- **Final Weighted SNR Calculation**

  The SNR is then:

$$SNR_{weighted} = \frac{S_{mix} - S_b}{S_{NEDT}}$$

  This quantifies how distinguishable the mixed pixel is from the pure background, normalized by the noise level.

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