Enhance the given low-contrast image using adaptive histogram equalization and standard histogram equalization methods and compare the results

GNR607 - Principles of Satellite Image Processing

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Overview

Theoretical Background

Motivation for Enhancement

- **The Problem:** Satellite imagery often suffers from low contrast due to atmospheric scattering or sensor limitations.
- **Impact:** When an image contains gray levels clustered in a narrow range, the ability to interpret features is hampered.
- **Objective:** To utilize the full dynamic range of the display device by transforming the image such that gray levels have a more uniform distribution.

Standard Histogram Equalization (HE)

Standard HE is a global technique that transforms the intensity values of an image so that the output histogram is approximately uniform.

Let r be the input intensity ($0 \leq r \leq L-1$) and s be the output intensity. The transformation $T(r)$ is based on the Cumulative Distribution Function (CDF):

$$s_k = T(r_k) = (L-1)\sum_{j=0}^{k} p_r(r_j) = (L-1)\sum_{j=0}^{k} \frac{n_j}{n} \tag{1}$$

Where:

- n is the total number of pixels.
- n_j is the number of pixels with gray level r_j.
- $p_r(r_j)$ is the probability of occurrence of gray level r_j.

Adaptive Histogram Equalization (AHE)

Limitation of Standard HE: Since HE uses global statistics, it can wash out details in small regions or amplify noise in homogeneous areas.

The AHE Approach:

- The image is divided into small rectangular tiles (e.g., 8×8 grid).
- The histogram and CDF are computed locally for each tile.
- Pixel intensities are redistributed based on these local histograms.
- **Contrast Limiting:** To prevents noise amplification, the histogram height is clipped (Clip Limit) before computing the CDF.
- Artifacts at tile borders are removed using bilinear interpolation.

Methodology & Implementation

Evaluation Metrics

To quantitatively compare the enhancement methods, we utilized the following metrics:

1. Shannon Entropy (Information Content): Higher entropy indicates more detail and information.

$$H = -\sum_{i=0}^{L-1} p(i) \log_2 p(i) \tag{2}$$

2. Absolute Mean Brightness Error (AMBE): Measures the preservation of average brightness (lower is often preferred for naturalness, though distinctness is prioritized in analysis).

$$AMBE = |\mu_{original} - \mu_{enhanced}| \tag{3}$$

Implementation: Metrics Code

```python
def calculate_entropy(image):
    hist = cv2.calcHist([image], [0], None, [256], [0, 256])
    prob_dist = hist / hist.sum() # Normalize to probabilities
    prob_dist = prob_dist[prob_dist > 0] # Avoid log(0)
    entropy = -np.sum(prob_dist * np.log2(prob_dist))
    return entropy

def calculate_ambe(image_original, image_enhanced):
    mean_orig = np.mean(image_original)
    mean_enh = np.mean(image_enhanced)
    return abs(mean_orig - mean_enh)
```

Implementation: Enhancement Pipeline

```python
def analyze_and_report(image_path):
    original_img = cv2.imread(image_path, 0)

    # 1. Standard Histogram Equalization
    he_img = cv2.equalizeHist(original_img)

    # 2. Adaptive Histogram Equalization (AHE)
    # Using grid size (8,8) and clip limit to control contrast
    ahe_processor = cv2.createCLAHE(clipLimit=1000.0,
                                    tileGridSize=(8,8))
    ahe_img = ahe_processor.apply(original_img)

    # ... (Metrics calculation follows)
```

Results & Comparison

Visual Comparison

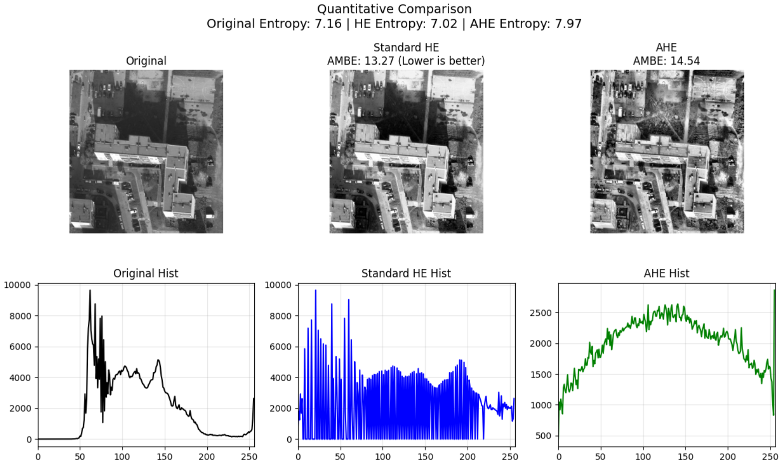

Figure 1: Comparison of Original, Standard HE, and AHE results along with their histograms.

Quantitative Analysis

The following metrics were obtained from the processing pipeline:

Metric	Original	Standard HE	AHE
Entropy (Detail)	7.1561	7.0176	**7.9662**
Std Dev (Contrast)	42.3526	73.2710	67.2885
AMBE (Brightness Error)	N/A	13.2726	14.5412

Table 1: Comparative analysis of enhancement methods.

Interpretation of Results

- **Entropy:**
  - The **AHE** method achieved the highest entropy (**7.97**), indicating it successfully recovered the most local details and texture information from the satellite image.
  - Standard HE actually slightly reduced entropy compared to the original, likely due to merging adjacent gray levels in the global mapping.
- **Contrast (Std Dev):**
  - Both methods significantly increased the standard deviation, confirming contrast enhancement.
- **AMBE:**
  - Standard HE yielded a slightly lower AMBE (13.27) compared to AHE (14.54), meaning it preserved the global mean brightness slightly better, though AHE's trade-off yielded superior local detail visibility.

Conclusion

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- Standard Histogram Equalization successfully stretches the dynamic range but fails to preserve local details in complex satellite imagery.
- **Adaptive Histogram Equalization (AHE)** proves superior for this application. By operating on local tiles (8×8), it enhances local contrast without over-amplifying noise or washing out global features.
- Quantitative analysis confirms that AHE maximizes information content (Entropy ≈ 7.97) while maintaining acceptable brightness preservation.

Thank You