Super-Resolution Image Reconstruction Using KL Divergence Optimization

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Problem Statement

Problem: Low-resolution (LR) images are often used in various applications like satellite imagery, medical imaging, and surveillance. Reconstructing high-resolution (HR) images from these LR inputs while preserving critical details is a significant challenge.

Objective: This work aims to optimize HR image patches from LR images using Kullback-Leibler (KL) divergence, improving resolution and preserving fine details.

Exploratory Data Analysis (EDA)

Dataset Overview:

- Low-resolution images: Size (510, 339) and (510, 384), count: 29 and 10 respectively.
- High-resolution images: Size (2040, 1356) and (2040, 1536), count: 29 and 10 respectively.
- The dataset includes a variety of images, such as natural scenes and objects, with diverse texture and color characteristics.

Methodology: KL Divergence for Optimization

KL Divergence Optimization Steps:

1. Compute the histogram distribution of the LR patch.
2. Initialize HR patch using bicubic interpolation from LR patch.
3. Iteratively update HR patch by adjusting pixel values based on the gradient of KL divergence.

The process involves adjusting HR image patches to match the distribution of LR image patches using KL divergence.

Methodology: Super-Resolution and Hyperparameter Tuning

Super-Resolution Process:

- Divide LR image into smaller patches.
- Optimize each HR patch to match its LR patch distribution.
- Reconstruct HR image by combining optimized patches.

Hyperparameter Tuning via Grid Search:

- Patch size
- Alpha (learning rate)
- Number of bins for histogram computation
- Maximum number of iterations

Models and Algorithms

KL Divergence Optimization Model:

- Uses KL divergence to measure the difference between LR and HR pixel distributions.
- Gradient descent optimization to adjust HR patches iteratively.
- Final reconstruction involves merging optimized patches.

The model uses SSIM (Structural Similarity Index) to evaluate the image quality after reconstruction.

Results: Qualitative and Quantitative

Qualitative Results:

- HR images reconstructed from LR input show a significant improvement in details and resolution.

Figure: Reconstructed HR Image using KL Divergence Optimization

Quantitative Results:

- Average SSIM : 0.4679
- Average MAE: 166.50

Results: Comparison

Comparison of LR and HR Images:

- Before: LR images are blurry with missing fine details.
- After: HR images show more clarity and finer texture details.

The KL divergence optimization method significantly improves image quality compared to traditional methods like bicubic interpolation.

Conclusion and Future Work

Conclusion:

- KL Divergence is an effective method for improving image resolution from LR images.
- The model preserves fine details and improves SSIM scores.

Future Work:

- Incorporate additional loss functions (e.g., perceptual loss).
- Expand testing to include more diverse datasets.
- Investigate optimization techniques for faster processing.