Experimental Report: Analysis of Self-Similarity and Gaussianity Hypotheses in Images and Comparison of NL-Bayes with BM3D

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1 Self-Similarity Hypothesis

1.1 Experimental Setup

To evaluate self-similarity, we selected three distinct images and selected the patch (red dot) that we are looking for its similar patches:

- Edge Image: Features strong contrasts like we see in the following building edges against the sky figure:

Figure 1: Roof neighborhood

- Textured Image: Contains compelx pattern like in the following natural image displaying the texture of trees:

Figure 2: Trees neighborhood

- Plain Image: arguably smooth region with tiny changes like we observe in the following wall:

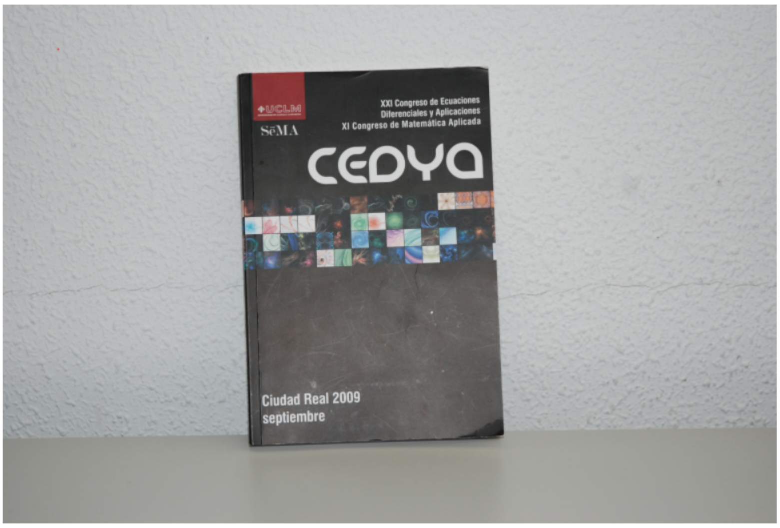


Figure 3: Wall neighborhood

For each image, a central 10×10 patch was selected, and similar patches were identified within a 120×120 search window. Parameters such as patch size, number of similar patches, and orientation normalization were varied to analyze their effects.

1.2 Results

- **Edge Image**: Most similar patches were concentrated along the building's edges, sharing a high contrast between the roof and the sky. Orientation normalization improved similarity by aligning patches with varying rotations.

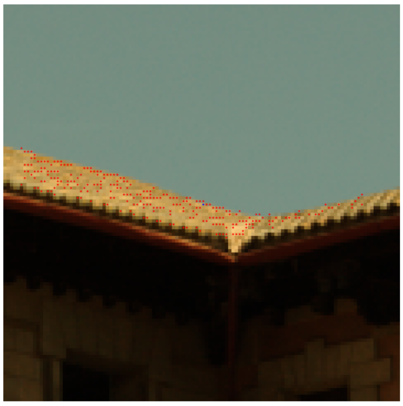


Figure 4: Roof neighborhood case with orientation noramlization

- **Textured Image**: Similar patches exhibited high variance, reflecting diverse foliage patterns. While visually consistent with the texture, patches showed less spatial clustering compared to the edge image. We note that patches are mainly in the darker side to maximize similarity with the patch in consideration that is quite dark.

Figure 5: Trees neighborhood

- **Plain Image**: Despite low texture, similar patches were found near subtle surface bumps. These patches demonstrated low variance and were highly consistent with the original patch.

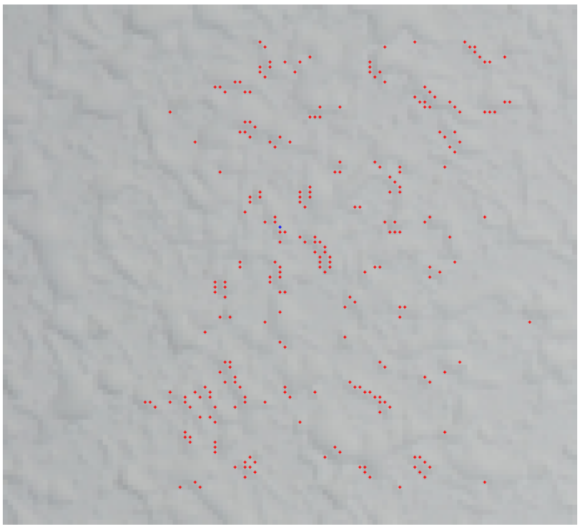


Figure 6: Wall neighborhood

1.3 Conclusion

The self-similarity hypothesis is validated, as similar patches were found in all images, with their quality influenced by texture and contrast. Normalization parameters significantly affected patch selection.

2 Gaussianity Hypothesis

2.1 Experimental Setup

Patches were analyzed using PCA to observe eigenvalue sparsity and GMMs to test Gaussianity. Anderson-Darling tests assessed normality.

2.2 Results

- **Edge Image**: PCA revealed considerably sparse eigenvalues, with the first few components capturing most of the variance. GMMs showed distinct clusters, corresponding to edges and shadows. The Gaussianity hypothesis cannot be rejected.

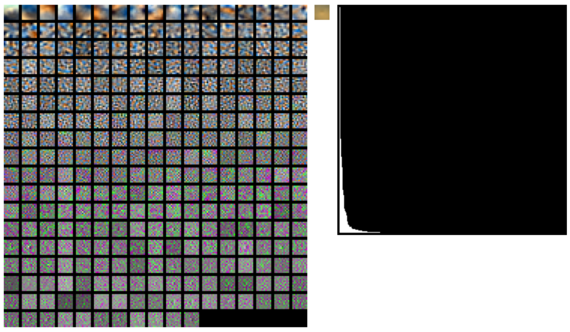


Figure 7: Roof neighborhood PCA

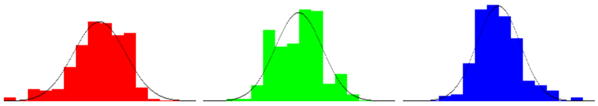


Figure 8: Anderson-Darling normality test for Roof neighborhood (0.3688 , 0.5360 , 0.1544)

- **Textured Image**: PCA was less sparse, indicating complex patterns. GMMs overlapped in some regions, and the Gaussianity hypothesis was rejected for all color channels.

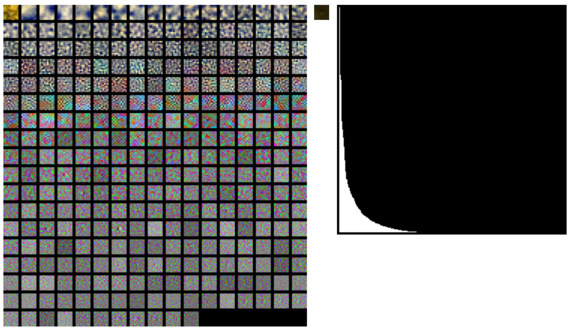


Figure 9: Trees neighborhood PCA

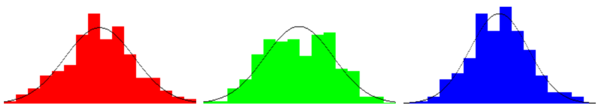


Figure 10: Anderson-Darling normality test for trees neighborhood (0.000 , 0.0005 , 0.0003)

- **Plain Image**: Eigenvalues quickly diminished, with noise dominating later components. GMMs fitted well, supporting the Gaussianity hypothesis mostly.

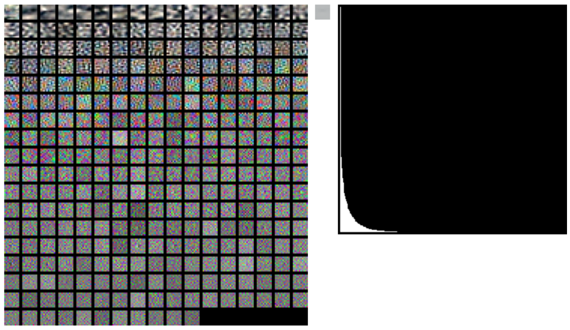


Figure 11: Wall neighborhood PCA

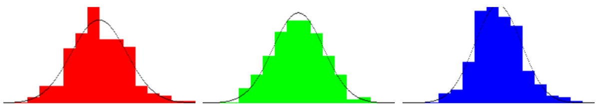


Figure 12: Anderson-Darling normality test for wall neighborhood (0.8882 , 0.0438 , 0.9243)

3 NL-Bayes and BM3D Comparison

3.1 Theoretical Differences

Both NL-Bayes and BM3D involve similar preprocessing and aggregation steps. However:

1. **Filtering**: NL-Bayes uses a Bayesian estimator, while BM3D relies on hard thresholding and transform-domain filtering.

2. **Patch Similarity**: NL-Bayes incorporates denoised patches for improved similarity, whereas BM3D processes all patches independently.

3.2 Experimental Results

Denoising was tested on complex image (a street) and natural image (trees) with constant noise level $\sigma = 40$ as follows:

(a) Street image

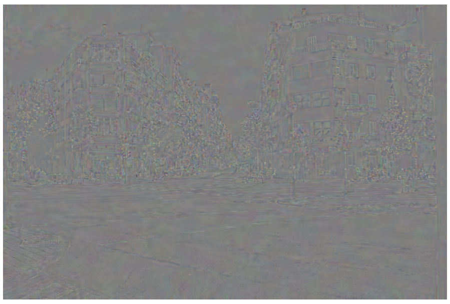
(b) Noisy street image

(a) Trees image

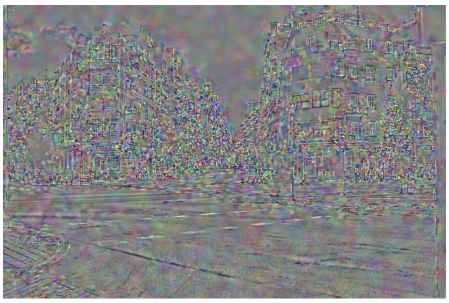
(b) Noisy trees image

PSNR and especially visual inspection using the difference image guided comparisons.

- **Street Image**: Both algorithms are close in terms of PSNR :
  $PSNR_{BM3D} = 29.2086dB \approx PSNR_{NL-Bayes} = 29.0864dB$

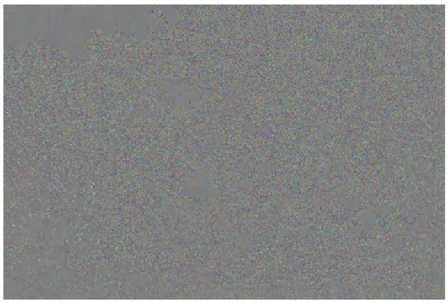


(a) difference DM3D

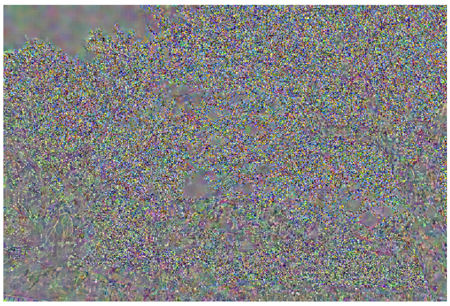


(b) Difference NL-Bayes

- **Trees Image**:Here as well, both algorithms are close in terms of PSNR :
  $PSNR_{BM3D} = 23.1365dB \approx PSNR_{NL-Bayes} = 23.5035dB$



(a) difference DM3D



(b) Difference NL-Bayes

3.3 Comparaison

NL-Bayes excels at preserving sharp details. Nevertheless, it tends to introduce artifacts especially in low-texture area (we see less distortions in the difference for the trees than for the street case).For BM3D, it achieves a more balanced performance, making it preferable for high-noise scenarios.