Contrast Adjustment Techniques for Low-Light Images

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Abstract

This research aims to enhance the quality of low-light digital images by implementing and evaluating three signal processing techniques: Power-Law Transformation, CLAHE, and Adaptive Thresholding. All algorithms were developed in Python and tested on a custom dataset. The results indicate that Power-Law Transformation ($\gamma < 1$) yields the most perceptually natural results by recovering hidden details without color distortion. CLAHE provided superior local contrast enhancement, revealing details in non-uniformly illuminated regions while suppressing noise artifacts found in standard equalization. Finally, Adaptive Thresholding proved effective for edge detection and structural segmentation rather than visual enhancement.

1 Introduction

The primary focus of this project stems from a very common frustration in day-to-day life: taking photos in poor lighting—such as outdoors in the evening or in a dimly lit classroom—only to find the resulting image consists mostly of noise and darkness. The majority of these images suffer from compromised quality, with much of the "hidden" data remaining unrecoverable. Proper identification and retrieval of information from these dark pixels are necessary not just for aesthetics, but for automated systems like security cameras.

Project Goal: Our goal was moving beyond theoretical concepts and implementing robust signal processing methods to recover the data lost in hidden dark regions.

The main objectives of this project are:

- To develop a sound understanding of the mathematics behind image enhancement.
- To implement contrast adjustment algorithms using Python.

- To curate a comprehensive dataset of images taken under poorly lit real-world conditions.

2 Methodology

In this research, we concentrated on three algorithms that improved the quality of images by processing the image intensities through a series of steps.

2.1 Power-Law Transformation (Gamma Correction)

The Power-Law Transformation is a fundamental technique for contrast manipulation. It maps the input pixel intensity (r) to the output pixel intensity (s) using the formula:

$$s = c \cdot r^{\gamma} \tag{1}$$

where c is a constant (typically 1) and γ is the gamma value. For low-light enhancement, we specifically focused on $\gamma < 1$, which expands the range of dark input values into a wider range of output values, effectively brightening the shadow regions.

Group Implementation Note (Parameter Tuning): We conducted a systematic test with various gamma values to find the "sweet spot" for our dataset.

- $\gamma = 0.2$: Resulted in an overly bright, washed-out image.
- $\gamma = 0.8$: Provided only a slight, insufficient improvement.
- $\gamma = 1.0$: Represented the original image (no change).
- **Decision:** We settled on

2.2 CLAHE (Contrast Limited Adaptive Histogram Equalization)

Standard histogram equalization often amplifies noise in near-constant regions. To mitigate this, we implemented **CLAHE**. Unlike the global approach, CLAHE divides the image into small tiles (defined by *tileGridSize*) and equalizes the histogram of each tile individually. Contrast amplification is limited by a *clipLimit* parameter to prevent noise from becoming dominant.

Implementation Logic: To prevent unnatural color shifts, we did not apply CLAHE to RGB channels directly. Instead, the workflow was:

1. Convert image from BGR to **LAB** color space.

2. Apply CLAHE only to the **L (Lightness)** channel.
3. Merge channels and convert back to BGR.

Group Observation: Tuning the CLAHE parameters was critical. We experimented with the *clipLimit* between 2.0 and 4.0. We observed that setting the *tileGridSize* too small created a "mosaic effect" on the images. We achieved the best balance between local detail and noise suppression using a *clipLimit* of 2.0 and a grid size suitable for our image resolution.

2.3 Thresholding

Thresholding is primarily a segmentation technique that creates binary images. We utilized **Adaptive Thresholding** because low-light images often suffer from non-uniform illumination, making a single global threshold ineffective.

The algorithm calculates the threshold for a pixel based on a small region around it (defined by *block_size*) minus a constant C.

$$T(x, y) = \text{mean}(neighborhood) - C \tag{2}$$

Parameters Used:

- **Method:** Adaptive Gaussian Thresholding.
- **Block Size:** 11 (Size of the pixel neighborhood).
- **C:** 2 (Constant subtracted from the mean).

Implementation Detail: Interestingly, we applied adaptive thresholding to each BGR channel separately and then merged them. While this removed texture, it proved highly effective for edge detection and identifying structural boundaries in the dark, which is useful for computer vision tasks rather than visual enhancement.

3 Data and Implementation

3.1 Dataset Collection

A custom dataset was curated for this project. Group members contributed by capturing real-world low-light images (e.g., night scenes, unlit rooms, shadows) and compiling them into the project repository. The dataset consists of approximately 30 images in '.jpg' and '.png' formats, stored in the `dataset/` directory.

3.2 Python Implementation

The project was implemented in Python using the OpenCV and NumPy libraries. All enhancement techniques were applied automatically to the images located in the `dataset/` directory. The processed outputs were saved into separate folders under `results/dataset_results/` for systematic comparison.

3.2.1 Power-Law Transformation

The Power-Law Transformation was applied to each image to enhance global brightness and contrast. A gamma value smaller than one ($\gamma = 0.5$) was selected to amplify dark intensity levels commonly found in low-light images. The enhanced images were saved in the following directory:

- `results/dataset_results/power_law/`

This method preserves the overall color distribution while significantly improving visibility in shadowed regions.

3.2.2 CLAHE Enhancement

CLAHE (Contrast Limited Adaptive Histogram Equalization) was employed to improve local contrast while preventing excessive noise amplification. The images were converted to the LAB color space, and CLAHE was applied only to the Lightness (L) channel before converting back to the original color space. The resulting images were stored in:

- `results/dataset_results/clahe/`

CLAHE provided superior local detail enhancement, particularly in regions with uneven illumination.

3.2.3 Thresholding

Adaptive thresholding was used to generate high-contrast binary representations of the images. This method computes a local threshold for each pixel based on neighborhood statistics, making it suitable for non-uniformly illuminated low-light scenes. Thresholding results were saved in:

- `results/dataset_results/thresholding/`

While thresholding effectively highlights edges and object boundaries, it removes grayscale and color continuity, making it more suitable for segmentation and structural analysis rather than natural image enhancement.

4 Results and Discussion

We analyzed the comparative outputs of the algorithms on our dataset. **Power-Law Transformation** proved to be the most perceptually pleasing method, recovering dark details naturally without washing out colors. **Histogram Equalization** maximized global contrast but came at the cost of amplifying noise in uniform regions. Finally, **Adaptive Thresholding** effectively isolated structural edges.

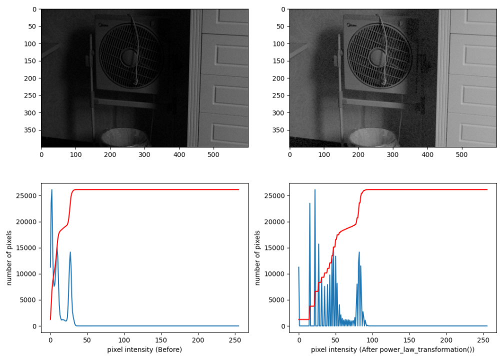
(a) Comparison Part 1

(b) Comparison Part 2

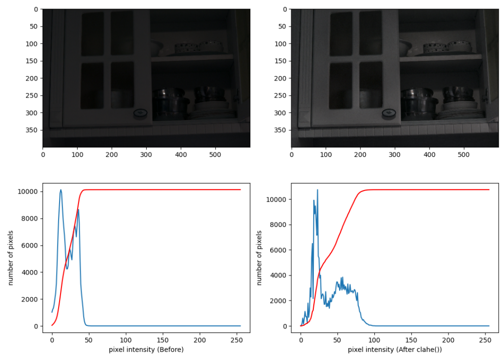
(c) Comparison Part 3

Figure 1: Visual comparison of the proposed methods. The images are displayed in the following order: (1) Original Input, (2) Power-Law Transformation, (3) CLAHE Enhancement, and (4) Adaptive Thresholding.

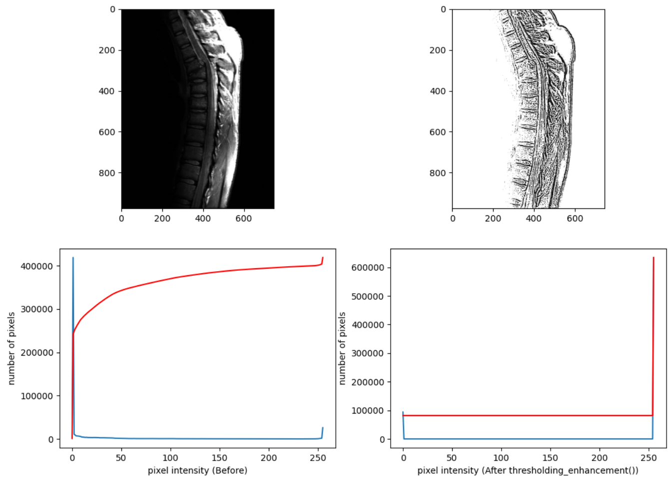
Furthermore, to validate the mathematical contrast adjustment, we analyzed the pixel intensity distributions using histogram analysis. As seen in Figure 2, the transformation successfully shifts the pixel intensity distribution from the dark region (left side) towards the center, creating a balanced histogram for enhancement techniques, while producing distinct binary peaks for the thresholding segmentation.



(a) Power-Law Analysis



(b) CLAHE Analysis



(c) Thresholding Analysis

Figure 2: Detailed histogram and CDF analysis of the three methods. (a) Power-Law shifts intensity to the right. (b) CLAHE spreads contrast locally. (c) Thresholding creates binary peaks.

5 Conclusion

In this study, we demonstrated that simple signal processing operations can significantly improve image interpretability. While Histogram Equalization is powerful for maximizing information content, Power-Law Transformation offers superior perceptual quality for low-light photography. Future improvements could involve implementing Retinex theory or Deep Learning-based Low-Light Image Enhancement (LLIE).

References

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4. Thresholding Tutorial: `https://docs.opencv.org/4.x/d7/d4d/tutorial_py_thresholding.html`
5. Clahe Equalization: `https://docs.opencv.org/4.x/d6/db6/classcv_1_1CLAHE.html`