Image Defogging using Dark Channel Prior and Contrast Limited Adaptive Histogram Equalization Techniques

Ankit Gautam (IIT2022153)
Sudhir Kumar (IIT2022173)
Ankit Raj (IIT2022174)
Sudhanshu Singh (IIT2022177)
Pushkar Kumar (IIT2022213)

Department of Information Technology
Indian Institute of Information Technology, Allahabad
Prayagraj, India

***Abstract*—Enhancing the clarity of photos taken in cloudy conditions is a major problem for computer vision applications including outdoor photography, surveillance, and autonomous vehicles. Two defogging methods—Dark Channel Prior (DCP) and Contrast Limited Adaptive Histogram Equalization (CLAHE)—are compared in this paper. . OpenCV is used to implement these methods, and metrics such as the Structural Similarity Index (SSIM) and Peak Signal-to-Noise Ratio (PSNR) are used to assess how well they perform. According to our findings, CLAHE mostly improves local contrast without necessarily getting rid of the haze, whereas DCP is excellent at getting rid of fog.**

***Index Terms*—Image Defogging, Dark Channel Prior, CLAHE, PSNR, SSIM, OpenCV.**

I. Introduction

Images captured in outdoor settings frequently have restricted vision because of mist, haze, or fog. Due to light scattering caused by these atmospheric circumstances, appearances appear fuzzy and have low contrast. Therefore, increasing visibility in cloudy photos has become essential for applications such as outdoor monitoring, remote sensing, and autonomous driving.

Several methods have been proposed to tackle this issue. The *Dark Channel Prior (DCP)* [1] is one of the most effective methods to remove fog from images by estimating the thickness of the haze. Another method, *Contrast Limited Adaptive Histogram Equalization (CLAHE)* [2], enhances local contrast but does not directly remove atmospheric effects. In this paper, we evaluate the effectiveness of both methods using both qualitative and quantitative metrics.

II. Background and Related Work

Various techniques have been developed to improve the visibility of fog-degraded images. Early techniques like histogram equalization and Retinex theory aimed to improve contrast globally [2]. However, these methods often resulted in noise amplification in uniform regions.

DCP [1] is specifically designed to handle fog and haze removal by analyzing outdoor images where at least one color channel has very low intensity in non-sky regions. CLAHE, on the other hand, distributes brightness across small tiles of an image, thereby enhancing local contrast without focusing on atmospheric distortions like fog. Despite the rise of learning-based methods such as DehazeNet [4], traditional approaches like DCP and CLAHE remain popular due to their simplicity and efficiency.

III. Methodology

A. Dark Channel Prior (DCP)

Dark Channel Prior (DCP) is a widely used image defogging technique based on the observation that, in most non-foggy outdoor images, at least one color channel (Red, Green, or Blue) exhibits very low intensity in certain regions.

1) Problem Overview: In foggy conditions, images lose clarity because atmospheric particles scatter light, reducing contrast and color vibrancy. This scattered light, known as *atmospheric light*, obscures distant objects.

2) The Concept of Dark Channel: DCP works by leveraging the fact that, in non-foggy images, there are areas where one of the three color channels (R, G, B) has very low values. This observation is used to compute the *dark channel* for a given pixel x:

$$\text{Dark Channel}(x) = \min_{c \in \{R,G,B\}} \left(\min_{y \in \Omega(x)} I^c(y) \right)$$

[5] where $I^c(y)$ is the intensity of color channel c (R, G, or B) at pixel y, and $\Omega(x)$ is a small patch centered around pixel x.

3) Fog's Influence on the Dark Channel: In foggy images, the dark pixels appear brighter due to the scattered atmospheric light. The dark channel becomes brighter, providing a way to estimate the presence of fog.

4) Steps in DCP: The key steps involved in applying DCP to an image are as follows:

1) **Dark Channel Estimation** The dark channel is calculated by finding the minimum intensity value for each pixel across the three color channels.
2) **Atmospheric Light Estimation** Atmospheric light, A, is estimated from the brightest pixels in the dark channel, as these pixels are most affected by fog.
3) **Transmission Map Calculation** The transmission map, $t(x)$, indicates how much of the scene is visible through the fog. It is computed as:

$$t(x) = 1 - \omega \cdot \frac{\min_{c\in\{R,G,B\}} I^c(x)}{A^c}$$

[5] where $I^c(x)$ is the intensity of color channel c at pixel x, A^c is the atmospheric light in color channel c, and ω is a constant (usually $\omega = 0.95$).
4) **Scene Radiance Recovery** The clear image is recovered using:

$$J(x) = \frac{I(x) - A}{t(x)} + A$$

[5] where $J(x)$ is the recovered image at pixel x, $I(x)$ is the original foggy image at pixel x, and $t(x)$ is the transmission map.

5) Advantages and Disadvantages of DCP: **Advantages:**

- **Effective in Low Light Conditions:** DCP performs well in conditions with significant haze and low visibility.
- **Model-Free:** It does not require extensive prior knowledge about the scene, making it versatile.
- **Fast Computation:** DCP is computationally efficient, enabling quick processing of images.

Disadvantages:

- **Limitations in Bright Scenes:** DCP may struggle with images that are overly bright or do not conform to its assumptions.
- **Loss of Details in Fine Structures:** It may result in the loss of fine details in highly textured areas.
- **Dependence on Transmission Map Estimation:** Errors in estimating the transmission map can lead to inaccuracies in the final image.

B. CLAHE (Contrast Limited Adaptive Histogram Equalization)

Contrast Limited Adaptive Histogram Equalization (CLAHE) is a technique that enhances the contrast of images by applying histogram equalization locally, within small regions of the image (referred to as tiles), rather than across the entire image. This localized approach allows CLAHE to avoid the typical issues of global histogram equalization, such as over-amplification of noise or the creation of unnatural-looking images.

1) Traditional Histogram Equalization vs. CLAHE: The pixel intensity values are redistributed to cover the entire range of possible values (from 0 to 255 for 8-bit pictures) in traditional histogram equalization. This technique disperses the most common intensity values, which enhances the image's overall contrast. Nevertheless, standard histogram equalization can lead to over-enhancement in photographs with broad homogeneous areas (such as the sky or fog), which might distort the image or magnify noise.

In order to reduce overamplification of noise, limit contrast enhancement within each local region, and prevent unnatural contrast rises, CLAHE tackles these issues. By using **contrast limiting**, it makes sure that the amount of enhancement in each area of the picture is kept under control.

2) How CLAHE Works: CLAHE divides the image into small, non-overlapping regions called *tiles*. Within each tile, the histogram of pixel intensities is equalized, but the contrast is limited to a specified maximum value. This prevents the noise from being over-enhanced in regions of the image where contrast is naturally low.

The borders of the tiles are blended to prevent sharp edges between them after the contrast within each tile has been improved, guaranteeing that the overall image appears natural. Because of its tile-based methodology, CLAHE is very good at boosting local contrast in dim or cloudy images without adding artifacts.

3) Steps in CLAHE: The key steps involved in applying CLAHE to an image are as follows:

1) **Convert the Image to LAB Color Space:** The image is first converted from the RGB color space to the LAB color space. This conversion separates the intensity information (luminance) from the color information. The luminance channel (L-channel) is where the contrast enhancement will take place, leaving the color information intact in the A and B channels.
2) **Apply CLAHE to the Luminance Channel:** After the image is in LAB space, CLAHE is solely applied to the luminance (L-channel), which manages the image's contrast and brightness. The chromatic information is still contained in the A and B channels. Contrast limiting makes ensuring that any pixel intensity augmentation within the L-channel is regulated, avoiding excessive contrast changes or overamplification of noise.
3) **Recombine the Enhanced L-channel with the Original A and B Channels:** The original A and B channels are mixed with the modified L-channel following the application of CLAHE to the L-channel. The final output image with improved contrast is created by converting the recombined LAB image back to the RGB color space.

4) Advantages of CLAHE: The main benefit of CLAHE is that it can improve contrast on a localized basis, which is very helpful for photographs that have areas with different lighting. In addition, the contrast-limiting function makes sure that the conventional histogram equalization artifacts—such as noise over-enhancement or unnatural contrast in homogenous regions—are avoided.

- **Prevents Over-enhancement:** By applying contrast limiting, CLAHE avoids the common problem of over-amplifying noise or small variations in uniform areas.
- **Enhances Local Contrast:** CLAHE enhances fine details in specific regions of the image, making it effective in images where some areas are darker or brighter than others.
- **Efficient and Easy to Implement:** CLAHE is computationally efficient and relatively easy to implement, making it suitable for real-time applications such as video enhancement or medical imaging.

5) Limitations of CLAHE: While CLAHE works well for boosting local contrast, it is not intended to eliminate haze or fog. Much depends on the type of image as to how well it works to improve visibility. Compared to techniques like Dark Channel Prior (DCP), CLAHE is less effective for severe fog removal since it does not simulate the atmospheric scattering effects that result in haze or fog. However, it is helpful for photos that have weak contrast because of lighting circumstances.

- **Not Suitable for Heavy Fog or Haze Removal:** CLAHE improves local contrast but does not specifically target atmospheric scattering. It may enhance visibility in foggy images but does not remove fog as effectively as DCP.
- **May Introduce Artifacts in Uniform Regions:** In some cases, CLAHE can introduce unwanted artifacts, such as checkerboard patterns, in regions of the image with very uniform intensity.

IV. Evaluation Metrics

The performance of both methods is evaluated using the following metrics:

- **Peak Signal-to-Noise Ratio (PSNR)**: This metric measures the ratio between the maximum possible pixel value and the noise introduced by the image processing. A higher PSNR value indicates better image quality.

$$PSNR = 10 \cdot \log_{10}\left(\frac{MAX_I^2}{MSE}\right) \tag{1}$$

  where MAX_I is the maximum possible pixel value, and MSE is the mean squared error.
- **Structural Similarity Index (SSIM)**: SSIM measures the structural similarity between the processed and original images. An SSIM value closer to 1 indicates higher similarity.

$$SSIM(x,y) = \frac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)} \tag{2}$$

  where μ_x and μ_y are the average pixel values, σ_x^2 and σ_y^2 are the variances, and σ_{xy} is the covariance of the two images. C_1 and C_2 are constants to stabilize the division.

V. Results and Analysis

In this study, we collected samples from twelve foggy images, each exhibiting different conditions. The images varied significantly, with some containing heavy fog and haze, while others featured lighter atmospheric conditions. Additionally, the images were captured under diverse lighting conditions, including nighttime and sunny daytime settings.

A. Example Fogged Images

Here are a few examples of fogged images along with their defogged counterparts using both DCP and CLAHE methods.

Fig. 1. Fogged Image 1.

Fig. 2. Defogged Image 1 (CLAHE).

Fig. 3. Defogged Image 1 (DCP).

Fig. 4. Fogged Image 2.

Fig. 5. Defogged Image 2 (CLAHE).

Fig. 6. Defogged Image 2 (DCP).

Fig. 7. Fogged Image 3.

Fig. 8. Defogged Image 3 (CLAHE).

Fig. 9. Defogged Image 3 (DCP).

We applied both the Dark Channel Prior (DCP) and Contrast Limited Adaptive Histogram Equalization (CLAHE) methods to these images, recording the resulting data in a CSV file. To evaluate the performance of each method, we calculated several key metrics: mean, maximum, minimum, and standard deviation for both Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity Index (SSIM). This data was subsequently utilized to generate plots and summarize the performance metrics in the accompanying table. I.

TABLE I
COMPARISON OF DCP AND CLAHE METRICS

Metric	DCP	CLAHE
Average PSNR	27.9003	29.4003
Max PSNR	29.7375	32.4414
Min PSNR	27.1764	28.1736
Median PSNR	27.7162	29.1393
Std Dev PSNR	0.6692	1.2924
Average SSIM	0.7342	0.8259
Max SSIM	0.9231	0.9263
Min SSIM	0.5776	0.6995
Median SSIM	0.7267	0.8349
Std Dev SSIM	0.1137	0.0663

Comparing DCP and CLAHE performance shows significant PSNR and SSIM disparities. The peak signal-to-noise ratio of CLAHE (29.40 dB) is higher than DCP (27.90 dB) on average, indicating greater image quality. The maximal PSNR values, 32.44 dB for CLAHE and 29.74 for DCP, support this. DCP performs better in the minimal PSNR measure, suggesting visual clarity under difficult situations. CLAHE's average SSIM score of 0.826 is higher than DCP's 0.734, demonstrating its ability to preserve structural integrity and detail in processed images. The standard deviation in PSNR and SSIM values suggests that while CLAHE generally gives better image quality, DCP is more consistent across images. CLAHE improves local contrast and average quality, while DCP is still a good choice for image detail preservation.

To further illustrate the performance of the DCP and CLAHE methods, we present two graphs that visualize the evaluation metrics calculated from our analysis.

The first graph 10 displays the Peak Signal-to-Noise Ratio (PSNR) for each method across the twelve foggy images. PSNR is a widely used metric that quantifies the quality of the processed images by comparing them to the original, unprocessed images. Higher PSNR values indicate better image .

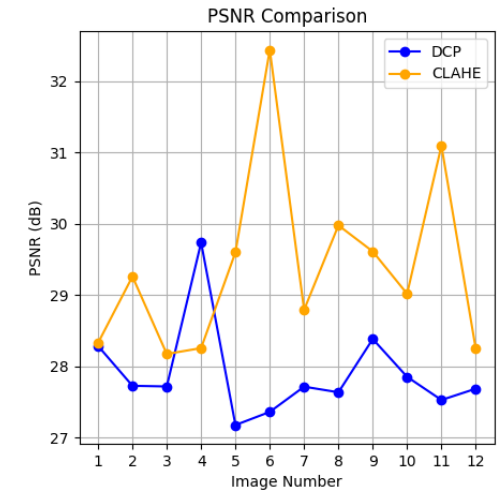

Fig. 10. CLAHE vs DCP PSNR comparison

The second graph 11 showcases the Structural Similarity Index (SSIM) for both methods. SSIM measures the similarity between the processed images and the original images, taking into account luminance, contrast, and structure. A higher SSIM value suggests greater perceptual similarity to the original image.

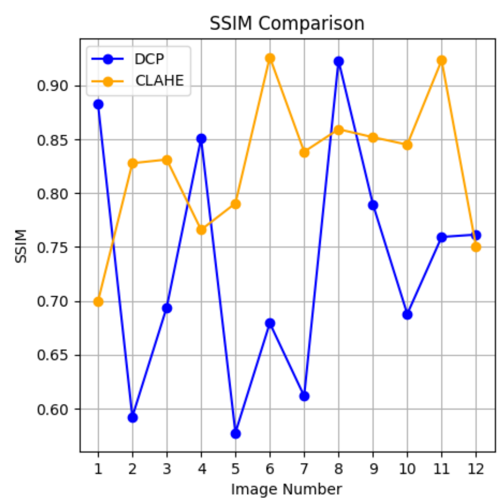

Fig. 11. CLAHE vs DCP SSIM comparison

These graphs provide a comprehensive overview of the effectiveness of each method, allowing for a visual comparison of their performance across various conditions.

VI. CONCLUSION

In this work, two popular methods for image defogging were compared: Dark Channel Prior (DCP) and CLAHE. Our results indicate that DCP is good in terms of fog removal and overall image quality restoration, even though CLAHE is successful at boosting local contrast. DCP is suggested for applications where fog reduction is essential. Although we saw that DCP reduces the overall contrast of the image and is less appealing to human eyes in some cases. We also saw that in DCP there was this white boundary arouds the objects making the image less realistic.

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