Image Dehazing

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***Abstract*—We present a new method to improve the visibility of images taken in foggy conditions. Our method uses a boundary constraint on the transmission function, which describes how much light is blocked by the fog. We combine this constraint with a contextual regularization that minimizes the difference between neighboring pixels. We formulate this as an optimization problem and solve it efficiently using a variable splitting algorithm. Our method works well on a single image without requiring any specific assumptions. It can produce clear images with natural colors and fine details. We show the performance of our method on various foggy images.**

***Index Terms*—image processing,single image dehazing, visibility enhancement**

I. Introduction

Capturing images in foggy weather conditions often results in poor visibility, where distant objects lose contrast and become blurred, as depicted in Figure 1. This degradation occurs due to the attenuation of reflected light by atmospheric particles, such as dust and water droplets, blending with scattered atmospheric light. Consequently, the colors of objects in the distance fade, converging with the fog's appearance, dictated by their proximity to the camera.

Haze removal methods in the past depended on depth data or multiple observations of the same picture using methods such as polarizers or scattering models based on physics. These techniques did, however, have some drawbacks. Recent years have seen notable progress in single-image dehazing, which is particularly difficult because of the little scene structure information available. Notable examples include Tan's emphasis on local contrast maximization, Fattal's revised picture creation model, and He et al.'s dark channel prior.

This report centers on a novel approach to single-image dehazing, acknowledging its inherent under-constrained nature. Our method proposes an innovative boundary constraint on scene transmission, coupled with weighted L1-norm-based contextual regularization among neighboring pixels. This approach, requiring only a few general assumptions, aims to efficiently restore haze-free images with vivid colors and fine edge details, overcoming the limitations of previous methods.

Our contributions include a geometrically interpretable constraint on scene transmission, proving remarkably effective in preserving fine edge details and colors. Additionally, we introduce a novel contextual regularization employing a filter bank, contributing to noise reduction and enhancement of specific image structures. Finally, our efficient optimization scheme ensures the rapid dehazing of large-sized images, addressing a crucial aspect for practical applications where processing time is paramount.

Fig. 1. Hazy photo of a city

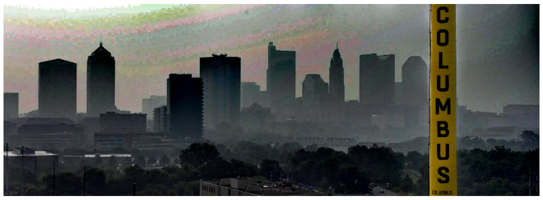

Fig. 2. Dehazed Photo

Fig. 3. Transmission Map

Figure 2 illustrates the compelling dehazing results achieved by our method, showcasing its ability to significantly improve image clarity, maintain faithful colors, and preserve fine edge details in the presence of atmospheric haze. In the subsequent sections, we delve into the details of our proposed methodology, highlighting its key components and demonstrating its efficacy through experimental results.

II. Theory

The following linear interpolation model is widely used to explain the formation of a haze image

$$I(x) = t(x)J(x) + (1 - t(x))A \tag{1}$$

where I(x) is the observed image, J(x) is the scene radiance, A is the global atmospheric light, and t(x) is the scene transmission.

- **Atmospheric Light Estimation:**
  The atmospheric light *(A)* represents the maximum intensity value in a hazy image and is assumed to correspond to the scattering of sunlight. It is estimated by selecting the brightest pixels in the image.
- **Transmission Map Estimation:**
  The transmission map *(t(x))* represents the ratio of scene radiance to the observed intensity at each pixel and is inversely proportional to the haze. It is estimated using the following equation:

  $$t(x) = e^{-\beta d(x)} \tag{2}$$

  Here, β is the haze parameter, and *d(x)* is the scene depth, which can be estimated based on the assumption that distant objects have higher haze.
- **Dehazing:**
  The goal of image dehazing is to recover the scene radiance J(x) from I(x) based on Eq.(1). This requires us to estimate the transmission function t(x) and the global atmospheric light A. Once t(x) and A are estimated, the scene radiance can be recovered by:

  $$J(x) = \frac{t(x)I_{hazy}(x) - A}{[max(t(x), \epsilon)]^{\delta}} + A \tag{3}$$

  where is a small constant (typically 0.0001) for avoiding division by zero, and the exponent δ, serving as the role of the medium extinction coefficient β in Eq.(2), is used for fine-tuning the dehazing effects.

However, dehazing from a single image is highly underconstrained, since the number of unknowns is much greater than the number of available equations. Thus, we have to first exploit more constraints on the unknowns.

III. Some Important Concepts

- **Haze Removal:** The process of removing haze or fog from an image to enhance visibility and improve image quality.

- **Single Image Dehazing:** The task of dehazing an image using only the information present in a single input image, without requiring multiple images or depth information.

- **Boundary Constraint:** A constraint that ensures the extrapolation of the scene radiance during dehazing does not cross over the boundary of the radiance cube defined by two constant vectors. This constraint helps maintain color accuracy and prevent artifacts in the dehazed image.

- **Contextual Regularization:** A regularization technique that involves incorporating a filter bank into image dehazing to improve the quality and fidelity of the dehazed image. It helps preserve fine image details and reduces artifacts.

- **Atmospheric Light:** The light scattered by aerosols such as dust and water droplets in the air that affects the visibility and color of objects in the image. Estimating the atmospheric light is an important step in dehazing.

- **Transmission Function:** A function that represents the amount of scene radiance reaching the camera at each pixel. Estimating the transmission function is essential for dehazing the image.

- **Dark Channel Prior:** An assumption that the pixel-wise dark channel of the hazy image is zero, which helps estimate the transmission function. However, this assumption may fail in certain cases, leading to distorted colors and artifacts in the dehazed image.

IV. How the Code Works

A. Libraries

- **cv2**: OpenCV library for image processing.
- **tkinter**: Library for creating GUI applications.
- **filedialog**: Module in tkinter for opening file dialogs.
- **numpy**: Library for numerical operations.
- **copy**: Module for shallow and deep copy operations.

B. Code Explained

Lets divide the image dehazing process into various sections for ease of understanding.Below is the explanation of each and every function in the code.

1) Airlight Estimation: The code estimates the airlight by performing erosion operations on the hazy image.

a) AirlightEstimation:

- **Purpose:** Estimates the airlight value for each channel in the input hazy image.
- **Significance:** Accurate airlight estimation is crucial for correctly modeling the atmospheric light in the scene.

2) Boundary Constraint: The BoundCon function applies boundary constraints to the transmission map based on the dark channel prior. It uses color information and morphological operations.

a) BoundCon:

- **Purpose:** Applies boundary constraints to the transmission map based on the dark channel prior.
- **Significance:** Helps refine the transmission map by considering local image statistics and enforcing certain constraints.

3) Contextual Regularization: The CalTransmission function calculates the transmission map with contextual regularization using Kirsch filters and an iterative refinement process.

a) psf2otf:

- **Purpose:** Converts Point Spread Function (PSF) to Optical Transfer Function (OTF).
- **Significance:** OTF represents the blurring in the image due to atmospheric effects. This function prepares the PSF for subsequent operations.

b) zero_pad:

- **Purpose:** Extends an image to a specified size with zeros.
- **Significance:** Used in the PSF to OTF conversion process to ensure proper padding, which is crucial for accurate FFT operations.

c) CalculateWeightingFunction:

- **Purpose:** Computes the weighting function based on circular convolution with a given filter.
- **Significance:** Used in transmission map calculation. The weighting function helps emphasize certain image features during the dehazing process.

d) LoadFilterBank:

- **Purpose:** Initializes a filter bank, specifically Kirsch filters (shown in Fig 4).
- **Significance:** The Kirsch filters are later used in the contextual regularization step for transmission map calculation.

e) CalTransmission:

- **Purpose:** Calculates the transmission map for dehazing using Kirsch filter-based contextual regularization.
- **Significance:** Contextual regularization helps enhance image features and refine the transmission map.

f) circularConvFilt:

- **Purpose:** Performs circular convolution filter operation on the input image.
- **Significance:** Used in the transmission calculation step for convolving the image with Kirsch filters.

4) Overall Dehazing Process: The main dehazing process involves estimating airlight, applying boundary constraints, calculating transmission, and then removing haze using the estimated transmission and airlight.

$$\begin{bmatrix}-3&-3&-3\\-3&0&5\\-3&5&5\end{bmatrix}\quad\begin{bmatrix}-3&-3&-3\\-3&0&-3\\5&5&5\end{bmatrix}\quad\begin{bmatrix}-3&-3&-3\\5&0&-3\\5&5&-3\end{bmatrix}$$

$$\begin{bmatrix}-3&-3&5\\-3&0&5\\-3&-3&5\end{bmatrix}\quad\begin{bmatrix}-1&-1&-1\\-1&8&-1\\-1&-1&-1\end{bmatrix}\quad\begin{bmatrix}5&-3&-3\\5&0&-3\\5&-3&-3\end{bmatrix}$$

$$\begin{bmatrix}-3&5&5\\-3&0&5\\-3&-3&-3\end{bmatrix}\quad\begin{bmatrix}5&5&5\\-3&0&-3\\-3&-3&-3\end{bmatrix}\quad\begin{bmatrix}5&5&-3\\5&0&-3\\-3&-3&-3\end{bmatrix}$$

Fig. 4. A bank of high-order filters used in our project. It consists of eight Kirsch operators and a Laplacian operator for preserving image edges and corners.

a) ‘image_dehazer‘ class:

- **Purpose:** Encapsulates the entire dehazing process with various parameters.
- **Significance:** Provides a structured approach to dehazing. Methods within the class handle airlight estimation, boundary constraints, transmission calculation, and haze removal.

b) remove_haze:

- **Purpose:** Orchestrates the entire dehazing process.
- **Significance:** Calls methods from the image_dehazer class to estimate airlight, apply boundary constraints, calculate transmission, and remove haze.

5) Display and Input Handling:

a) select_image and resize_image:

- **Purpose:** Allow the user to interactively select an image and resize it.
- **Significance:** Prepares the input image for the dehazing process, making it suitable for display.

6) Image Display:

a) Display Functions (cv2.imshow, cv2.waitKey, cv2.destroyAllWindows):

- **Purpose:** Display hazy and dehazed images.
- **Significance:** Allows visual inspection of the results.

V. Results

A. Dealing with weather at ports

Image dehazing is crucial for optimizing visibility and clarity in port, ship, and dock images affected by atmospheric conditions like fog and haze. In these environments, dehazing plays a vital role in enhancing surveillance footage for improved security, aiding navigation in adverse weather conditions, and facilitating efficient traffic management. It is instrumental in asset monitoring, enabling better inspection of cargo, ships, and infrastructure. Additionally, dehazing enhances the performance of automated systems, such as object recognition and autonomous vehicles in port areas. Clearer images also contribute to accurate documentation, compliance monitoring, and reporting.In summary, the application of image dehazing in ports has multifaceted advantages, ranging from security and navigation to documentation, marketing, and training.

Fig. 5. Input Hazy Image of a ship

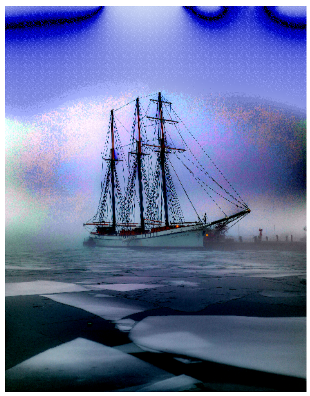

Fig. 6. Output dehazy image

B. satellite imagery

The application of image dehazing in satellite imagery is crucial for enhancing visibility and clarity, especially when atmospheric conditions like haze or pollution obscure details. Dehazing techniques improve feature extraction, supporting tasks such as urban planning, agriculture monitoring, and environmental studies. This technology ensures more accurate image analysis by computer vision algorithms, facilitating object detection, classification, and segmentation. Clearer satellite images are instrumental in disaster response, enabling quick and precise assessments of affected areas. Moreover, dehazing contributes to effective environmental monitoring, military and security applications, infrastructure planning, and scientific research in fields like meteorology and climatology. In essence, image dehazing enhances the quality of satellite data, making it indispensable for a diverse range of applications that rely on accurate and detailed observations of Earth's surface.

C. Traffic Management

Image dehazing plays a crucial role in traffic management by enhancing visibility on roads and highways, allowing for more effective monitoring and control. In the context of traffic management, dehazing techniques contribute to improved surveillance footage, enabling authorities to assess real-time traffic conditions more accurately. This enhanced visibility aids in the proactive identification of potential congestion points or roadblocks, facilitating timely interventions and optimizing traffic flow. Additionally, image dehazing is valuable for checking up on road conditions beforehand, offering clearer insights into weather-related challenges or other obstacles that may impact transportation. Moreover, in the realm of law enforcement and security, dehazing assists in obtaining clearer images of vehicles, supporting efforts to identify and track specific vehicles of interest. Overall, image dehazing proves to be a versatile tool for traffic management, road condition assessment, and targeted vehicle monitoring, ultimately contributing to more efficient and secure transportation systems.

Fig. 7. Input Hazy Images From Satellite

Fig. 8. Output Dehazed Image

Fig. 9. Input Hazy Images From Satellite

Fig. 10. Output Dehazed Image

D. Transmission Maps

In image dehazing, a transmission map is a key component used to model the attenuation of light due to atmospheric haze. It represents the ratio of the observed intensity of light at a pixel to the true scene radiance at that pixel. The transmission map is crucial for estimating and subsequently removing the effects of haze from the hazy image.

In simple terms, the transmission map (t(x)) provides information about how much light is scattered or absorbed by the haze at each pixel. It is a continuous function ranging from 0 to 1, where 0 indicates a fully hazed pixel (no scene radiance reaches the observer), and 1 indicates a pixel unaffected by haze (full scene radiance is observed).

Below are the Transmission Maps obtained by performing dehazing on the three example cases:

1) Ship Dockyard
2) Satellite Imagery
3) Road Traffic

Fig. 11. Transmission Map of Ship at a Dockyard

Fig. 12. Transmission Map of a Satellite Image of a city

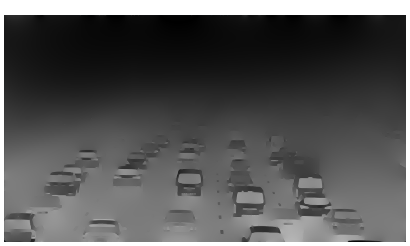

Fig. 13. Transmission Map of a Traffic filled road

VI. Conclusion

In conclusion, this report delves into the transformative capabilities of image dehazing, shedding light on its diverse applications and impact on visual data enhancement. By explaining the principles of how image dehazing is achieved through advanced algorithms and computational techniques, the report underscores its pivotal role in overcoming atmospheric challenges such as fog and haze. The testing phase, involving a variety of photos depicting different scenarios, showcased the effectiveness of dehazing in significantly improving visibility and clarity. Whether applied to satellite imagery for environmental monitoring, surveillance footage for security purposes, or road scenes for traffic management, the results consistently demonstrated the value of dehazing techniques. As technological advancements continue to refine these methods, the potential for image dehazing to revolutionize various industries and improve the interpretability of visual data remains promising, marking it as a vital tool in the world of image processing and computer vision.

VII. Appendix

Base Paper: ”Efficient Image Dehazing with Boundary Constraint and Contextual Regularization”

Github Link: GitHub Repository Link .

Video Link: YouTube Video Link.

VIII. Acknowledgment

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IX. References

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