Enhancing Visibility: Multiresolution Dark Channel Prior for Dehazing and Fog Removal in Images

Pramika Garg
School of Comp. Sci. & Eng.
Vellore Institute of Technology
Vellore, India
micepram@gmail.com

Avish Jha
School of Comp. Sci. & Eng.
Vellore Institute of Technology
Vellore, India
avish.j@protonmail.com

Sumit Kumar Jindal
Dept. of Embedded Tech., School of Elec. Eng.
Vellore Institute of Technology
Vellore, India
sumitjindal08@gmail.com

***Abstract*—Capturing images in conditions marked by fog or smog results in compromised visual quality, characterized by reduced visibility and contrast. Such limitations impede critical tasks like image segmentation, target detection, and video surveillance within outdoor monitoring systems. This paper presents an effective image defogging algorithm designed to rectify these issues and restore image clarity. In this study, we introduce a method centered around a dark channel prior, a foundational image characteristic preceding the haze removal process. This prior harnesses statistical insights from haze-free outdoor images, revealing a significant finding: numerous set of patches in haze-free images harbor pixels exhibiting remarkably minuscule intensities in more than a single colour channel.**

Through integration of this algorithm into the imaging model for hazing, the algorithm adeptly estimates haze thickness, thereby facilitating the recovery of high-quality, haze-free images. We take a novel approach enhancing the dark channel prior, and its practical implementation demonstrates promise. By improving visibility and contrast, it has the potential to enhance the performance of outdoor monitoring systems, including video surveillance, in unfavorable weather conditions. Extensive testing underscores the effectiveness of our approach in improving image quality and its utility across various real-world applications.

***Index Terms*—multi-resolution, fog removal, haze removal, dark channel prior, computer vision**

I. Introduction

Outdoor scenes frequently fall victim to degradation induced by impurities present in the atmosphere, such as particles and water droplets. This deterioration is a consequence of atmospheric absorption and scattering phenomena, manifesting as haze, fog, and smoke. These elements contribute to a notable reduction in image quality, as the ir-radiance captured by cameras from various scene points undergoes attenuation within the visual field.

The incident light becomes intermingled with ambient light reflected into the camera's field of view by atmospheric particles. The intricate interplay among these factors culminates in the loss of original contrast and color fidelity, thereby compromising the visual integrity of captured images [1], [2]. Compounding these challenges, the degree of scattering is predominantly contingent on the separation between scene points and the camera, resulting in spatiality varying degradation patterns.

Addressing these issues, the pursuit of haze removal—often referred to as de-hazing—assumes a pivotal role in both consumer-oriented and computational photography, as well as various computer vision applications. The elimination of haze substantially amplifies scene visibility, effectively rectifying color shifts originating from atmospheric light interactions. This, in turn, lends an enhanced visual allure to the resulting haze-free images [3].

In parallel, a multitude of computer vision algorithms, spanning from rudimentary lower grade image analyses to intricate higher level scene comprehension tasks, commonly operate under the assumption that the input image, post radiometric fine tune adjustment, accurately represents the scene radiance. However, the intrinsic bias and low contrast inherently present in scene radiance inevitably undermine the performance of these vision algorithms. Features like monitoring, filtration, and photometric analyses all bear the brunt of this degradation [4], [5].

The efforts being put in to remove haze yields an ancillary benefit: the extraction of depth information. This depth knowledge, in turn, imparts utility to a spectrum of vision algorithms and advanced image manipulation techniques [6]. The presence of haze and fog often serves as a valuable cue for inferring depth, contributing to a nuanced understanding of complex scenes.

In this paper, we the authors address the formidable challenge of haze removal, presenting an implementation of an innovative algorithm that harnesses the inherent characteristics of images affected by haze. Through integration of multi-resolution techniques, including leveraging the concept of a dark channel prior, we the authors introduce a practical and effective approach to enhance image quality and enable scene comprehension even under the adverse atmospheric conditions.

The proposed method's potential is validated through comprehensive evaluation and analysis, underscoring its capacity to make substantial contributions across a diverse array of applications and domains.

II. Literature Survey

The realm of road safety and surveillance systems has been deeply impacted by the persistent challenge of compromised visibility resulting from atmospheric phenomena such as fog and smog. This impairment in visibility during daylight hours poses a critical concern as it contributes significantly to vehicular accidents and undermines the efficacy of surveillance mechanisms. There are many other applications where atmospheric conditions such as fog, considerably actively harm or impede progress. In response, researchers have turned to innovative algorithms and techniques for enhancing image quality and restoring visibility in foggy conditions. Before proceeding with our research, we have evaluated multiple published works over the past 15 years in handling such conditions.

One notable approach in this direction is the 'Mean Channel Prior' algorithm proposed by Deshmukh [4]. This algorithm, specifically designed for image dehazing, presents a comprehensive embedded system approach. Its effectiveness lies in its ability to mitigate the scattering effects induced by varying object-camera distances. This is in line with the concerns highlighted by Zhang [5], who emphasizes the real-time nature of video image defogging. Zhang's approach employs the dark channel prior and intelligently regulates transmission rate maps to successfully address issues of color distortion, demonstrating the significance of accurate transmission estimation in foggy scenes.

In the pursuit of managing blurred images in foggy conditions, Liu et al. [7] introduce an adaptive retinex defogging technique that leverages depth maps. This adaptive approach resonates with the need for Advanced Driver Assistance Systems (ADAS), as advocated by Tarel et al. [1]. The efficacy of Tarel et al.'s visibility enhancement algorithm becomes more apparent when seen as a subset within the larger framework of fog removal strategies. Moreover, the concept of improving atmospheric scattering parameter accuracy, as demonstrated by Wei et al. [8], is intertwined with Deng's work [6]. Deng's adaptive defogging technique employs a fuzzy logic controller to refine transmission values, addressing inaccuracies in well-lit areas. This aligns with Wei et al.'s emphasis on accurate computation of global atmospheric light for improved restoration outcomes.

Chen et al.'s [2] exploration of defogging algorithms is complemented by Xu's [9] comprehensive survey of image restoration techniques. Xu critically evaluates the efficacy of various defogging approaches, highlighting the significance of foggy image detection and classification. This evaluation resonates with the iterative technique proposed by Chen et al. to strike a balance between natural color and image clarity.

Liu's [10] novel unpaired fog removal system, inspired by CycleGAN, aligns with the need for single-image fog removal techniques, as emphasized by Das [11]. Das's categorization of fog removal methods, much like More's [3] emphasis on their role in augmenting decision-making in autonomous driving systems, underscores the importance of such techniques in practical applications.

Amidst these interconnected studies lies the realization that while simple techniques may not effectively address the challenge and complex methods presented here consume significant time and resources, a novel approach is needed. Our algorithm aims to bridge this gap by offering a solution that is both simple and performant.

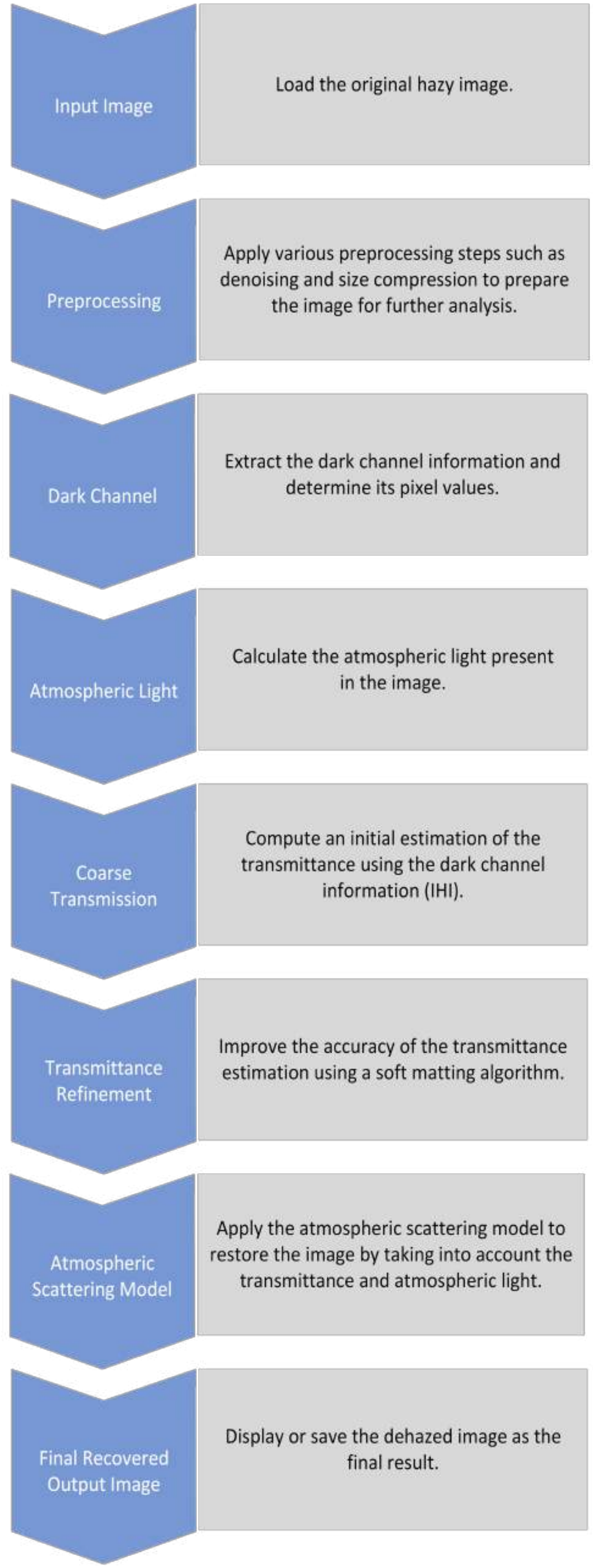

Fig. 1: Architecture of the Proposed System

It is important to restore visibility efficiently without compromising on quality, serving as a pragmatic alternative in the landscape of fog removal research. This literature survey not only captures the strides made in this field but also underscores the need for innovative, accessible, and effective fog removal methodologies.

III. Methodology

A. Dark Channel Prior

1) Observation and Definition: In the quest to remove fog from images, we begin with the Dark Channel Prior [12]. This concept stems from the observation that haze-free outdoor images consistently exhibit a certain property: within multiple colour channels for areas with the sky absent showcases notably lesser intensity at specific sections. Formally, we define the dark channel as follows:

$$
\begin{aligned}
J_{\text{dark}}(x) = \min(\min(J_c(y))),& \\
c \in \{r, g, b\},& \\
y \in \mathcal{N}(x)&
\end{aligned} \tag{1}
$$

Here, $J_c(y)$ represents a color channel of the image J, and $\mathcal{N}(x)$ defines a local patch centered at x.

2) Factors Influencing Dark Channel: The smaller intensities observed in the dark channel are influenced by three key factors. These include shadows cast by objects such as cars, buildings, leaves, and trees, as well as colorful objects or surfaces that lack significant variation in color channels. Additionally, darker shades in images, such as brown barks and black stones, contribute to these low values. These factors collectively contribute to the dark nature of the dark channel in natural outdoor images.

3) Validation and Statistics: To validate the efficacy of the dark channel prior, we conduct an empirical study. A dataset of 1000+ haze-free outdoor images is collected and processed. The histograms of pixel intensities within the dark channels are analyzed, showing that a significant portion of pixels have low intensity values, affirming the relevance of the dark channel prior.

B. Estimating the Atmospheric Light

Moving forward in our haze removal process, we focus on estimating the Atmospheric Light. Traditional methods rely on the brightest pixel, but this approach is limited when bright pixels are not indicative of haze-opaque regions [13]. Leveraging the insights from the dark channel, we propose a novel approach. We select the highest-intensity pixels from the dark channel to aid the calculation atmospheric light, providing a more accurate representation of haze opacity.

C. Estimating the Transmission

The next crucial step is to estimate the Transmission, a pivotal parameter in haze removal. Drawing on the dark channel

(a) Original Image (b) Final Restoration

(c) Dark Channel (d) Transmission Emittance (e) Transmission Refining

Fig. 2: Results: Asphalt Road Covered in Fog [14]

and atmospheric light estimation, we define the transmission as follows:

$$t(x) = 1 - \min(\min[C(v)]), \quad \text{for } v \in \mathcal{N}(x) \tag{2}$$

This calculates the transmission value t(x) by subtracting the minimum haze content from 1, considering the local patch v centered at x. It incorporates the concept of the dark channel and atmospheric light to estimate the extent of haze. The transmission value obtained serves as a guide for subsequent de-hazing.

D. Soft Matting

To enhance the accuracy of the transmission map, we turn to the technique of Soft Matting. Drawing an analogy between haze imaging and image matting equations, we employ a soft matting algorithm which is utilised in refining the transmission map. The cost function for soft matting is formulated as follows:

$$E(t) = t^T L t + \lambda(t - t^*)^T (t - t^*) \tag{3}$$

Here, L represents the Laplacian matrix for Matting, and λ is the regularization parameter. Solving this system refines the transmission map, improving the precision of subsequent scene radiance recovery. The best T value can be found by solving the linear system (sparse) given below:

$$(L + \lambda U)t = \lambda t^* \tag{4}$$

E. Scene Radiance

Finally, we move towards getting back the reduced radiance in the scene. By incorporating the refined version of the transmission map, atmospheric light [15], and an exposure adjustment term, we reconstruct the scene radiance as follows:

$$I(x) = A\left(1 - t(x) \cdot \omega\right) + J(x) \cdot t(x) \cdot \omega \tag{5}$$

Here, A represents the atmospheric light, $J(x)$ is the observed radiance, $t(x)$ is the refined transmission, and ω controls the degree of retained haze. The exposure adjustment term ensures optimal visibility and perceptual quality.

F. Overall Architecture

The architecture of the proposed approach is depicted in Figure 1, illustrating a comprehensive and systematic pipeline for single image haze removal. This section elaborates on each stage of the architecture, providing a detailed understanding of the algorithm's functionality.

The process commences with the acquisition of the original image, constituting the initial stage. Subsequently, a preprocessing stage is employed to enhance the input data quality. This involves de-noising to mitigate noise-induced artifacts and size compression to streamline subsequent computations. Multiple other preprocessing steps are applied to improve the proceeding pipeline steps.

Following preprocessing, we proceed to extract the dark channel and its corresponding pixel values. This stage capitalizes on the inherent statistical patterns of the image, revealing the scene's underlying haze characteristics. Leveraging the dark channel's information, the atmospheric light contained in the image is estimated. This atmospheric light estimation significantly influences subsequent stages, facilitating accurate transmittance calculations.

Next, coarse transmittance values are computed utilizing the dark channel information and the estimated atmospheric light. This step offers a preliminary understanding of the transmission of light through the haze. To refine these coarse transmittance values, a soft matting algorithm is employed. This refinement process enhances the transmittance estimation, ensuring better alignment with the actual haze distribution within the scene.

With the refined transmittance values, the algorithm enters the atmospheric scattering model stage. Here, the underlying principles of atmospheric light scattering are used to restore the image by removing haze-induced obscurity. This stage integrates the transmittance values to unveil the hidden details, ultimately contributing to enhancing the overall final image quality.

Finally, the algorithm concludes by outputting the de-hazed results. The processed image showcases the successful removal of haze, rendering improved visibility and image clarity. This architecture encapsulates the algorithm's journey from

(a) Original Image (b) Dark Channel (c) Transmission Emittance (d) Transmission Refining (e) Final Restoration

Fig. 3: Results: Tarred Concrete Pathway in Forest [16]

preprocessing to output, effectively addressing the challenge of visibility degradation due to haze in single images.

IV. Results

To assess the efficacy of the proposed algorithm, a comprehensive evaluation was conducted on a diverse set of five representative images. These images were carefully chosen to cover a spectrum of scenarios characterized by varying degrees of haze and fog. The results, as showcased in Figures 2 to 4, vividly demonstrate the algorithm's remarkable capability to substantially improve image quality and visibility.

In Figure 2, the most notable improvement resulting from fog removal is observed. A substantial portion of the fog that previously obscured both the vegetation and the road has been successfully eliminated. This holds particular significance for Advanced Driving Assistance Systems (ADAS) that rely on clear visibility.

The sky, while not exhibiting a profoundly clear backdrop, has also seen a significant reduction in fog presence. Transitioning to Figure 4, a pronounced reduction in fog coverage across the entire image is evident. This reduction is particularly remarkable in the street area and the lower sections of the buildings, aligning with the key elements of the image.

The third illustration, presented in Figure 3, illustrates the benefits of fog removal in terms of revitalizing the atmosphere. By reducing the mistiness, a more authentic sense of natural light is introduced, amplifying the visibility of intricate details and a broader spectrum of colors on the vegetation and walls.

In the 'before' images, the haze and fog-induced degradation is evident, obscuring scene details, reducing contrast, and leading to diminished visual appeal. However, upon applying the proposed algorithm, the 'after' images reveal a compelling transformation. The haze and fog are effectively removed, uncovering hidden details, restoring contrast, and enhancing overall image clarity.

The algorithm achieves this while preserving the natural colors and preventing the introduction of unwanted artifacts. This visual improvement is particularly notable in distant objects that were initially obscured by haze, demonstrating the algorithm's proficiency in addressing challenges posed by adverse atmospheric conditions.

V. Conclusion

In summary, this paper introduces a novel approach to tackling the pervasive issue of visibility degradation caused by haze and fog. The algorithm, rooted in a multi-resolution single image dark channel prior, capitalizes on statistical patterns inherent in outdoor images to streamline and optimize the haze removal process. Its strength lies in its elegant simplicity, offering efficiency without compromising effectiveness.

While the algorithm demonstrates remarkable capabilities, it's important to acknowledge its potential limitations. Scenarios where scene objects mimic atmospheric light and cast no shadow might challenge the algorithm's assumptions. Nonetheless, its performance across a diverse image set underscores its usefulness. Visual transformations from 'before' to

(a) Original Image

(b) Final Restoration

(c) Dark Channel

(d) Transmission Emittance

(e) Transmission Refining

Fig. 4: Results: Fog in City [17]

'after' images exemplify its ability to enhance image quality, revealing intricate details once obscured by haze.

This algorithm can be an useful tool in reducing fog, enhancing visibility. This work has implications across various domains. Industries reliant on accurate imagery, such as autonomous driving and surveillance, stand to benefit from improved visibility under challenging atmospheric conditions. As research evolves, this algorithm offers a substantial stride toward clearer visual understanding in the face of haze and fog.

A. Future Work

This study's proposed algorithm has demonstrated efficacy in mitigating haze and fog effects. However, future work could optimize the algorithm for real-time applications, adapt parameterization strategies, integrate deep learning approaches for enhanced accuracy, and explore scene-specific optimization for varied environments.

Noise reduction techniques, post-processing steps, and video de-hazing extension are potential directions. Objective quality assessment and user-centric studies would provide a comprehensive evaluation. Exploring integration with other vision tasks and cross-modality applications could lead to novel applications like [18]. This comprehensive approach to refining the algorithm's efficiency, adaptability, and perceptual impact holds promise for its wider deployment in addressing visibility challenges caused by atmospheric conditions in images.

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