Optimization of Single Image Dehazing Based on Stationary Wavelet Transform

M. Ravi Sankar[1], P. Rama Krishna[2], A. Yamini[1], Ch. Manikanta[1], R. Rupa Swathika[1], Y. Tanuja Tulasi[1], and B. Elisha Raju[3](✉)

[1] Department of ECE, Sasi Institute of Technology and Engineering, Tadepalligudem, India
[2] Department of IoT, Seshadri Rao Gudlavalleru Engineering College, Gudlavalleru, India
[3] Department of ECE, Vishnu Institute of Technology, Bhimavaram, India
elisharaju.b@vishnu.edu.in

Abstract. Dehazing of images holds a crucial significance in the domains of artificial intelligence and picture dispensation, primarily due to the detrimental impact of haze on visual quality, thereby impeding the effectiveness of subsequent tasks. Over the past years, the stationary wavelet transform (SWT) has gained prominence as a potent tool for image dehazing, owing to its capability to capture both frequency and location information effectively. The objective of this study is to enhance the visual quality of a dehazed image by leveraging the multi-level stationary wavelet transform (SWT). This approach facilitates reducing image dimensions without compromising image quality. Using the advantage of SWT, an efficient dehazing methodology based on sub band image model has been implemented in this work. The efficiency of proposed methodology has been evaluated in terms of PSNR, SSIM, and MMSE. This study includes a comparative analysis between DHWT and SWT concerning the mentioned parameters. The investigational results clearly demonstrate that the proposed method delivers outstanding visual quality after dehazing. Compared to DHWT, the SWT-based dehazing method achieves a remarkable 11.13% improvement in PSNR, 13.93% enhancement in SSIM, and a significant 40% reduction in MSE.

Keywords: Image dehazing · Stationary wavelet transform · Haar wavelet transform · Enhancement · Efficiency

1 Introduction

Image dehazing is a crucial image enhancement technique that aims to improve the visibility and quality of hazy or foggy images [1]. It addresses the problem of image degradation caused by atmospheric scattering, which occurs when light interacts with particles and molecules in the atmosphere, leading to reduced contrast, colour distortion, in the taken images [2]. The existence of haze in images can significantly impact various applications, such as surveillance, outdoor photography, computer vision, and remote sensing [3]. It not only affects the aesthetics of images but also hinders the performance of image analysis algorithms and visual perception. Dehazing includes

P. Pareek et al. (Eds.): IC4S 2023, LNICST 536, pp. 414–421, 2024.
https://doi.org/10.1007/978-3-031-48888-7_35

reducing or eliminating haze effects to produce clearer, more aesthetically pleasing photographs [4]. Various picture dehazing algorithms have been developed to accomplish this, ranging from conventional methods based on single-image processing techniques to sophisticated methods utilizing numerous images and advanced machine learning models. Estimating the amount of haze or ambient light present in the picture is the main obstacle in image dehazing [5]. Once the atmospheric light has been calculated, the haze can be successfully eliminated or diminished, revealing the real details of the scene. Taking use of developments in computer vision, deep learning [6, 7], and image processing [8–11], image dehazing systems [12, 13] are still developing.

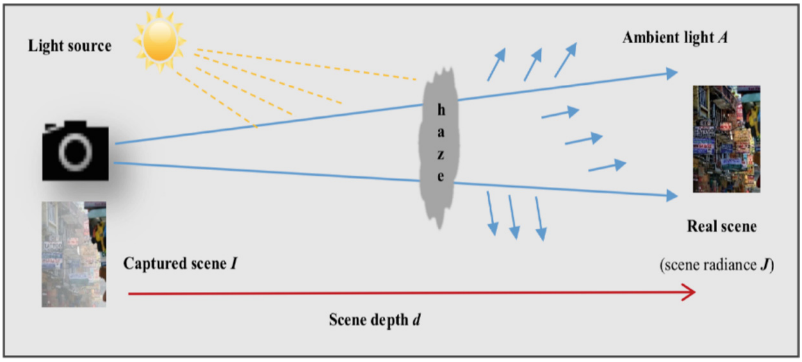


Fig. 1. Haze conception model [13].

Decomposing the hazy image into several frequency bands is the fundamental concept behind image dehazing using wavelet transform [14]. The low-frequency sub bands, which hold the information about the global lighting, are supposed to be haze-affected, but the high-frequency sub bands, which contain the fine details of the image, are believed to be haze-free [15]. The haze is removed from the image by applying a dehazing algorithm to the low-frequency sub bands. After the dehazing procedure, the wavelet transform can also be employed for enhancement. As a result, wavelet transform image dehazing is a potent method for reducing haze from photos while maintaining their fine details and edges. It is a potential strategy for a variety of applications, including remote sensing, surveillance, and outdoor photography [16].

2 Literature Review

Image dehazing stands as a fundamental and crucial task in the realm of image processing and computer vision. Over the years, substantial research efforts have been devoted to developing effective algorithms and techniques in this domain. This paper [17] presents a single image dehazing based on deep learning. In [18], the DCP algorithm is presented for single image dehazing, leveraging the observation that pixels in non-hazy regions tend to have very low values in at least one-color channel. Additionally, the authors of [19] propose an image dehazing method utilizing the discrete wavelet transform. Furthermore, in [20], a multi-scale convolutional neural network for single image dehazing is proposed, utilizing a multi-scale approach to capture both local and global information within the image.

In [21], the authors propose an image dehazing method utilizing the stationary wavelet transform. In [22], a deep learning-based approach for single image dehazing is presented, featuring a multi-scale multi-feature fusion network to capture both local and global information in the image. A novel image dehazing method is introduced in [23], which employs the discrete wavelet transform. Furthermore, in the same paper, another image dehazing method utilizes the stationary wavelet transform [24]. In this paper [25], another image dehazing method is introduced, utilizing wavelet-based local contrast enhancement. Additionally, this paper presents an image dehazing method [26] based on wavelet transform and adaptive histogram equalization. Moreover, a novel image dehazing method [27] based on the wavelet transform and non-local means filter has been proposed.

3 Methodology

The Dark Channel Prior (DCP) algorithm is a widely used method for image dehazing [28]. However, it may not work well for images with uniform or near-uniform haze, as the dark channel may not be well defined in such cases [28]. The typical model of haze formation has been represented using (1). In conventional dehazing systems (DCP), the dark channel is epitomized using (2).

$$I_{haze}(x) = J_{haze-free}(x) \times e^{-\beta d(x)} + A \times (1 - e^{-\beta d(x)}) \tag{1}$$

$$J^{dark}(x) = \underset{y \in \Omega(x)}{min} \left(\underset{c \in \{r, g, b\}}{min} J^{c}(y) \right) \tag{2}$$

3.1 Image Model

The clear image, which symbolizes the light reflected from things' surfaces, is the first part. The scattering transmission, often known as haze, is the second element. Equation (3) can be used to express a picture's optical model.

$$I_c = J_c \odot t + a_c \times (1 - t), where\ c = 1, 2, 3 \ldots \tag{3}$$

3.2 Sub-band Image Model

Given that the optical image model implies that the transmission rate is uniformly distributed throughout the environment, the frequency response of haze in images should mostly be distributed across the low-frequency sub-band [29]. The light distribution t can be expressed by using (4). Exploiting the SWT, which can be expressed by Eq. (5). Furthermore, the corresponding reconstruction algorithm, known as IDSWT (Inverse Discrete Stationary Wavelet Transform), is represented by Eq. (6).

$$t = e^{-\beta d} \tag{4}$$

$$\begin{cases} A_{j,k_1k_2} = \sum_{n_1}\sum_{n_2} h_0^{\uparrow 2^j}(n_1 - 2k_1) h_0^{\uparrow 2^j}(n_2 - 2k_2) A_{j-1,n_1,n_2} \\ D^1{}_{j,k_1k_2} = \sum_{n_1}\sum_{n_2} h_0^{\uparrow 2^j}(n_1 - 2k_1) g_0^{\uparrow 2^j}(n_2 - 2k_2) A_{j-1,n_1,n_2} \\ D^2{}_{j,k_1k_2} = \sum_{n_1}\sum_{n_2} g_0^{\uparrow 2^j}(n_1 - 2k_1) h_0^{\uparrow 2^j}(n_2 - 2k_2) A_{j-1,n_1,n_2} \\ D^3{}_{j,k_1k_2} = \sum_{n_1}\sum_{n_2} g_0^{\uparrow 2^j}(n_1 - 2k_1) g_0^{\uparrow 2^j}(n_2 - 2k_2) A_{j-1,n_1,n_2} \end{cases} \tag{5}$$

$$\begin{pmatrix} A_{j-1,n_1,n_2} \\ = \frac{1}{4}\sum_{i=0}^{3}\left\{\sum_{k_1}\sum_{k_2} h_1(n_1 - 2k_1 - i) h_1(n_2 - 2k_2 - i) A_{j,k_1k_2}\right. \\ + \sum_{k_1}\sum_{k_2} h_1(n_1 - 2k_1 - i) g_1(n_2 - 2k_2 - i) D^1_{j,k_1k_2} \\ + \sum_{k_1}\sum_{k_2} g_1(n_1 - 2k_1 - i) h_1(n_2 - 2k_2 - i) D^2_{j,k_1k_2} \\ + \sum_{k_1}\sum_{k_2} g_1(n_1 - 2k_1 - i) g_1(n_2 - 2k_2 - i) D^3_{j,k_1k_2} \end{pmatrix} \tag{6}$$

4 Simulation Outcomes

4.1 Subjective Analysis

The term subjective analysis refers to an analysis that bases its quality evaluation on the observers' perceptions of the image. For a variety of foggy images, the subjective analysis has been done (see Fig. 2).

4.2 Objective Analysis

The proposed methodology has been subjected to a thorough objective analysis, evaluating various metrics as mentioned in Table1. The comprehensive overview of the conducted analysis has been depicted in Table 1.

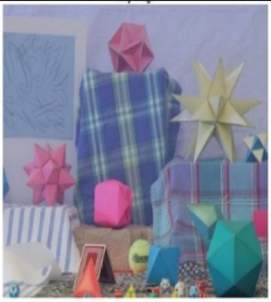
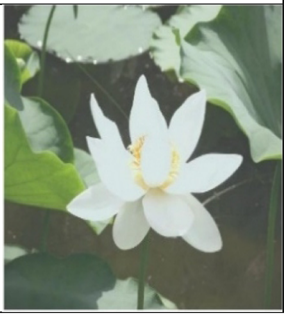
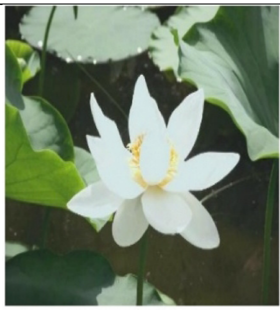
(a)Input Image	(b)Output Image	PSNR	SSIM
		69.7440	0.9503
		63.2154	0.8546
		65.9343	0.8657
		67.3452	0.9612

Fig. 2. (a) Input haze image (b) SWT based dehazed image.

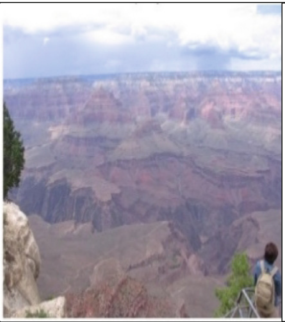
		68.8765	0.9406

Fig. 2. (*continued*)

Table 1. Performance metrics for DHWT and SWT

Image Name	Metric	DHWT	SWT(Proposed)
Image-1	MSE	0.0087	0.0073
	PSNR	62.7544	69.7440
	SSIM	0.8341	0.9503
Image-2	MSE	0.0065	0.0039
	PSNR	61.4634	63.2154
	SSIM	0.8535	0.8546
Image-3	MSE	0.0079	0.0098
	PSNR	64.7544	65.9343
	SSIM	0.7986	0.8657
Image-4	MSE	0.0092	0.0083
	PSNR	63.8243	67.3452
	SSIM	0.8345	0.9612
Image-5	MSE	0.0079	0.0069
	PSNR	61.4570	68.8765
	SSIM	0.8845	0.9406

5 Conclusion

The main goal of this study is to use the multi-level stationary wavelet transform (SWT) to improve the visual quality of dehazed photographs. This method enables image size reduction without sacrificing image quality. This work makes use of SWT to build an effective dehazing mechanism based on the sub-band image model. The suggested methodology's efficiency has been assessed utilizing performance indicators such as PSNR, SSIM, and MMSE. Based on these characteristics, a comparison of DHWT (Discrete Haar Wavelet Transform) and SWT was performed. The simulation results clearly show that the suggested approach provides excellent visual quality after dehazing. When compared to DHWT, the SWT-based dehazing method delivers a stunning 11.13% increase in PSNR, a 13.93% increase in SSIM, and a significant 40% decrease in MSE. These findings demonstrate the efficacy and superiority of the SWT-based technique to image dehazing.

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