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Hybrid Adaptive Color Recovery (HACR): A Fundamental Pre-Processing Step for Image Restoration

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Abstract- Images captured in challenging environments such as haze, underwater scenes, or artificial lighting often suffer from color degradation. In many cases, one color channel becomes weak, leading to loss of important visual information. To address this problem, this paper proposes a preprocessing method called Hybrid Adaptive Color Recovery (HACR). The method analyzes the relationship between color channels and adaptively compensates the weakened channel to restore color balance. By acting as a preprocessing step, HACR helps improve the performance of image restoration techniques. Experimental results show that the proposed method produces more consistent colors and better visual quality compared to conventional preprocessing approaches.

Index Terms— Image Restoration, Color Channel Recovery, Preprocessing, Degraded Images, Adaptive Color Compensation.

I. INTRODUCTION

With the increasing use of digital cameras and imaging devices, images are captured in many different environments. However, images taken under challenging conditions such as haze, underwater scenes, or artificial lighting often suffer from color degradation. In such cases, one color channel may become weak due to light attenuation or uneven illumination, which leads to loss of visual information and reduced image quality [1], [2].

Several image restoration methods have been proposed to improve degraded images. Dehazing techniques such as the Dark Channel Prior have been widely used for outdoor image restoration [2]. Similarly, color constancy methods aim to correct color distortions caused by illumination changes [4], [5]. In addition, underwater image enhancement techniques have been developed to address wavelength-based light attenuation [6], [17]. However, these methods may not perform well when one color channel is severely attenuated.

To address this issue, this paper proposes a preprocessing method called Hybrid Adaptive Color Recovery (HACR). The proposed method analyzes the relationship between color channels and adaptively compensates the weakened channel using local color information. By acting as a preprocessing step, HACR helps improve the performance of various image restoration techniques.

1.1 Applications of Color Recovery

Color recovery techniques are useful in several real-world applications. They can improve the visibility of images captured in hazy environments, restore color information in underwater scenes, and correct color distortions caused by artificial lighting. In addition, preprocessing approaches such as HACR can enhance the performance of computer vision systems used for image analysis, object recognition, and environmental monitoring [6], [17].

1.2 Literature Survey

Several studies have focused on improving image quality in challenging environments where color degradation occurs. Ancuti et al. [1] proposed the Color Channel Compensation (3C) method as a preprocessing step to recover weakened color channels and improve image enhancement results. He et al. [2] introduced the Dark Channel Prior technique for removing haze from images, which is widely used in image restoration. Finlayson and Trezzi [4] developed the Shades of Gray method to correct color distortions caused by illumination changes. In addition, Li et al. [6] and Chiang and Chen [17] proposed techniques for underwater image enhancement to address color loss caused by light absorption in water. These studies highlight the importance of preprocessing methods for improving the performance of image restoration techniques.

1.3 Motivation

Many degraded images experience the loss of a dominant color channel, which significantly reduces the effectiveness of traditional image restoration methods. This limitation highlights the need for an efficient preprocessing technique that can recover missing or weakened color information and provide improved input for image restoration algorithms, ultimately enhancing overall image quality and restoration performance.

1.4 Objectives of the Project

The objectives of this work are :-To study and analyze the problem of color channel degradation in images captured under challenging conditions such as haze, underwater environments, and artificial lighting [1], [2].-To develop a preprocessing method called Hybrid Adaptive Color Recovery (HACR) for recovering weakened color channels [1].-To analyze the relationships between different color channels and use them to compensate for missing or degraded color information [4], [5].-

1.5 Scope of the Work

This work focuses on recovering degraded color information as a preprocessing step. The proposed HACR method compensates weakened color channels and improves the performance of image restoration techniques [1], [2], [4].

II. RELATED PRE-PROCESSING TECHNIQUES FOR COLOR RESTORATION

2.1 Color Channel Compensation (3C)

2.1.1 Introduction

Color Channel Compensation (3C) is a preprocessing technique introduced to address color degradation in images captured under challenging environments such as haze, underwater conditions, and artificial lighting [1]. In such situations, one color channel often becomes highly attenuated, which reduces image quality and affects the performance of restoration algorithms. The 3C method works by analyzing the relationship between color channels and compensating for the weakened channel using information from the remaining channels. By reconstructing the lost color information, the method improves color balance and provides better input for image enhancement techniques. Therefore, 3C is considered an effective preprocessing step in many image restoration applications and helps improve the visual quality of degraded images. It also enhances the performance of dehazing, color correction, and underwater image restoration methods [1], [2].

2.1.2 Methodology

Color Channel Compensation (3C) is a preprocessing technique designed to recover degraded color information in images captured under challenging environments such as haze, underwater scenes, or artificial illumination [1]. In such situations, one of the RGB color channels becomes highly attenuated due to light absorption or non-uniform illumination. This imbalance leads to loss of color information and reduces the effectiveness of many image restoration techniques

$$I^c_{a^*}(x) = I_{a^*}(x) - \kappa \cdot M(x) \cdot G(I_{a^*}(x))$$

$$I^c_{b^*}(x) = I_{b^*}(x) - \lambda \cdot M(x) \cdot G(I_{b^*}(x))$$

[1], [2].

The 3C method first converts the input RGB image into an opponent color space such as CIELAB, where color differences are represented using two opponent channels: the red–green channel $a^*$and the blue–yellow channel b^*. The method assumes that, in natural images, the average value of these opponent channels is approximately zero. Therefore, compensating the deviation from this mean helps restore the weakened color channel . The compensated opponent channels are computed as follows:

where $I_{a^*}(x)$and $I_{b^*}(x)$represent the original opponent color channels, $I^c_{a^*}(x)$and $I^c_{b^*}(x)$represent the compensated channels, $G(\cdot)$denotes Gaussian filtering used to estimate the local mean, and $\kappa$and λcontrol the level of compensation [1]. To avoid excessive correction

$$M(x) = \begin{cases} 0, & \text{if mean}(R, G, B) > 0.85 \\ 1, & \text{otherwise} \end{cases}$$

in bright regions, a masking function $M(x)$is used:

This mask ensures that color compensation is not applied to highly illuminated areas where the original color information is already reliable. After compensating the opponent channels, the image is converted back to the RGB color space. The resulting image contains improved color balance and can be effectively used as input for further image restoration methods such as dehazing, color correction, and underwater image enhancement [1], [2].

2.2 Dark Channel Prior (DCP)

2.2.1 Introduction

Dark Channel Prior (DCP) is a widely used image restoration method introduced by He et al. for removing haze and improving the visibility of degraded images [2]. Images captured in environments such as fog, haze, or underwater conditions often suffer from reduced contrast and poor visibility due to the scattering of light in the atmosphere or water medium. The DCP method is based on a statistical observation that in most haze-free outdoor images, at least one color channel within a small local patch has very low intensity values. This characteristic is referred to as the dark channel prior.

Using this prior knowledge, the algorithm estimates the transmission map of the scene and then restores the degraded image using the atmospheric scattering model. The estimated transmission map helps determine the amount of haze present in different regions of the image. By compensating for this haze effect, the DCP method enhances the visibility and contrast of the image.

Although DCP is highly effective for haze removal, its performance may degrade when the input image suffers from severe color channel attenuation. In such cases, preprocessing methods such as Color Channel Compensation (3C) can improve the quality of the input image before applying the DCP algorithm [1], [2].

2.2.2 Methodology

The Dark Channel Prior (DCP) approach is based on the atmospheric scattering model used to describe the generation of hazy images [2]. In accordance with the atmospheric scattering model, the image intensity is determined by two main factors: the direct transmission of the image radiance and the light scattered by the particles in the medium. The image formation model can be expressed as:

Where

$$I^{dark}(x) = \min_{y \in \Omega(x)} \left(\min_{c \in \{r,g,b\}} I^c(y) \right)$$

$I(x)$represents the observed hazy image, $J(x)$represents the scene radiance (haze-free image), $t(x)$represents the transmission map, and Arepresents the global atmospheric light [2].

To estimate the transmission map, the Dark Channel Prior is used. The dark channel of an image is defined as the minimum value in the red, green, and blue color

$$I^{dark}(x) = \min_{y \in \Omega(x)} \left(\min_{c \in \{r,g,b\}} I^c(y) \right)$$

channels in a small local patch:

where $\Omega(x)$represents a local patch centered at pixel x, and $c$denotes the color channels. Using the dark channel, the transmission map can be estimated as:

where $\omega$is a parameter that controls the amount of haze

$$t(x) = 1 - \omega \min_{y \in \Omega(x)} \left(\min_{c} \frac{I^c(y)}{A^c} \right)$$

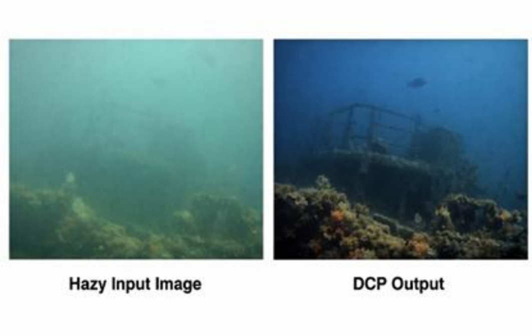
removal.

Finally, the haze-free image is recovered using:

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

The method of DCP is highly effective in improving the visibility and contrast of the image. However, in the case where the image has severe degradation in the color channels, the estimation of the transmission is not accurate. In such cases, preprocessing operations such as Color Channel Compensation (3C) are carried out before the application of the DCP method [1], [2].

The Dark Channel Prior (DCP) method improves the visibility of degraded images by estimating the transmission map and removing haze effects. Although the method enhances contrast and scene details, it may still produce color distortion or dark regions when the input image suffers from severe color channel degradation. Therefore, preprocessing techniques are often required to further improve restoration performance. The result obtained using the DCP method is shown below:



III. PROPOSED METHODOLOGY

3.Hybrid Adaptive Color Recovery(HACR)

3.1 Introduction

In imaging situations such as underwater images, hazy images, or low illumination, images are often characterized by considerable color degradation and loss of visibility. In such imaging situations, one or more color channels are significantly attenuated due to light absorption and scattering effects. Current preprocessing techniques, such as the Color Channel Compensation (3C) method, aim to recover degraded color channels by utilizing the relationship between opponent colors [1]. Though the 3C method can improve color balance, the method is based on predefined compensation factors, failing to effectively cope with images that exhibit different levels of color degradation.

To overcome the shortcomings of the 3C method, this study proposes a novel preprocessing method named Hybrid Adaptive Color Recovery (HACR). This method is an extension of color channel compensation, utilizing adaptive parameter estimation based on statistics. HACR analyzes the intensity statistics in color channels, compensating for the degraded color channel using statistics from other color channels. This method combines color channel compensation with adaptive color recovery, making it more suitable for subsequent color restoration, such as the Dark Channel Prior method [2].

HACR is also designed to be a flexible preprocessing method that can be adapted to cope with different levels of color degradation in images. By adapting the color channel compensation process according to the characteristics of the images, the proposed method can improve the effectiveness of the color restoration process, thereby improving the visual quality of the restored images.

3.2 Methodology

The proposed method for Hybrid Adaptive Color Recovery (HACR) has been conceptualized as a preprocessing stage for the restoration of degraded color information in images captured in unfavorable situations such as haze, underwater scenes, and man-made lighting. In such situations, the intensity of the color channel is significantly reduced due to the absorption and scattering of light, leading to the degradation of the quality of the image and the performance of the restoration algorithm [1], [2].The HACR method begins with the analysis of the color channels in the image I(x). The image is composed of three color channels:

Where R(x), G(x), and B(x) are the intensities of the red, green, and blue channels of pixel x.In order to determine the amount of degradation in each channel, the mean intensity for each channel is calculated as:

$$I(x) = \{R(x), G(x), B(x)\}$$

Let I_c(x) be the intensity of the channel c, R, G, or B, and N be the total number of pixels in the image.After

$$\mu_c = \frac{1}{N}\sum_{x=1}^{N} I_c(x)$$

the detection of the degraded channel, HACR applies

$$I'_c(x) = I_c(x) + \alpha\left(I_a(x) + I_b(x)\right)$$

adaptive color compensation using the remaining channels. The recovered channel is computed as:

The degraded channel is denoted by Ic(x), while Ia(x) and Ib(x) represent the remaining color channels. The term α represents the adaptive compensation factor.The Adaptive Compensation Factor α. The α term is determined by using the standard deviation of the color

$$\alpha = \frac{\sigma_c}{\sigma_r + \sigma_g + \sigma_b}$$

channels :

Where σ_r, σ_g, and $\sigma_b$represent the standard deviations of the red, green, and blue channels respectively.To

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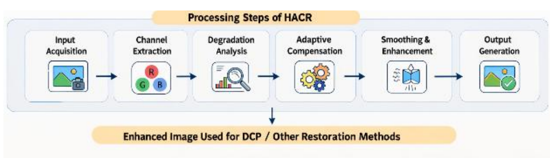
further stabilize the recovered color information, HACR also incorporates local color statistics using Gaussian smoo
thing:

$$G(I_c(x)) = \sum_i w_i I_c(x - i)$$

here w_i represents Gaussian weights and $G(\cdot)$ denotes the Gaussian filtering operation.
Finally, the compensated channel is combined with the remaining channels to generate the recovered image:

$$I'(x) = \{R'(x), G'(x), B'(x)\}$$

The resulting image contains improved color balance and restored channel information. This recovered image serves as an enhanced input for image restoration techniques such as the Dark Channel Prior (DCP), which further improves visibility and contrast in degraded images [2].



IV. COMPARATIVE STUDY OF 3C, DCP, AND HACR FOR IMAGE RESTORATION

4.1 Introduction

In this chapter, a comparative analysis of the different preprocessing and restoration techniques used to improve degraded images is presented. The results obtained by using well-established techniques, such as Color Channel Compensation (3C) and Dark Channel Prior (DCP), are analyzed and compared with the results obtained using the proposed method, namely Hybrid Adaptive Color Recovery (HACR). The main goal is to compare the results obtained by using each method in the context of color balance recovery and improving the visibility of degraded images.

4.2 Performance Evaluation

4.2.1 Performance Metrics

To evaluate the performance of different image restoration methods, Peak Signal-to-Noise Ratio (PSNR) and Structural Similarity Index (SSIM) are commonly used quality metrics. PSNR measures the reconstruction quality of the processed image compared to the reference image by calculating the ratio between the maximum possible pixel value and the mean squared error between the images. SSIM measures the perceptual similarity between two images by comparing their luminance, contrast, and structural information. Higher PSNR and SSIM values indicate better image restoration performance.

The Peak Signal-to-Noise Ratio (PSNR) between the reference image (I) and the processed image (K) is given

$$PSNR = 10 \log_{10}\left(\frac{MAX^2}{MSE}\right)$$

by:
The Mean Squared Error (MSE) between the reference image (I) and the processed image (K) is given by:

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

4.2.2 Comparison Using 3C, DCP, and HACR

A fair comparison between the restoration methods is performed using the same input image and identical evaluation metrics such as PSNR and SSIM. The experimental results show that the 3C + DCP method improves image visibility by compensating the degraded color channels before applying haze removal, resulting in better color balance compared to basic restoration methods. However, the compensation in 3C relies on fixed parameters and may not adapt well to different levels of image degradation. The proposed HACR + DCP method demonstrates improved restoration performance by adaptively recovering the degraded color channels using image statistics. The adaptive color recovery mechanism helps HACR provide more consistent color compensation and improved contrast, resulting in clearer images and better restoration quality compared to the 3C + DCP method.

Table : Qualitative comparison of 3C+DCP and HACR+DCP:

Method	PSNR	SSIM
3C + DCP	10.51	0.564
HACR + DCP	12.06	0.604

4.2.3 Classifier Analysis

the performance of different restoration methods is evaluated using quantitative image quality metrics. The processed images obtained from each method are compared with the reference image using PSNR and SSIM values. These metrics measure the similarity between the restored image and the reference image in terms of pixel intensity and structural information. The method that produces higher PSNR and SSIM values is considered to provide better restoration performance. This evaluation approach highlights the effectiveness of the preprocessing and restoration techniques without introducing additional complexity in the evaluation process. The comparison mainly focuses on analyzing how well each method restores image visibility, color balance, and structural details.

4.3 Results and Discussion

The experimental results demonstrate that the proposed HACR + DCP method provides improved image restoration performance compared to the 3C + DCP approach. The 3C + DCP method enhances image visibility by compensating degraded color channels before haze removal; however, it relies on fixed compensation parameters and may not perform consistently under varying degradation conditions. In contrast, the proposed HACR method introduces adaptive color recovery based on image statistics, which enables more effective restoration of degraded color information. This adaptive mechanism helps maintain better color balance, improved contrast, and clearer visual details in the restored images. The quantitative evaluation using PSNR and SSIM metrics further supports the effectiveness of the proposed approach, demonstrating competitive or improved restoration quality compared to existing methods. Moreover, the HACR preprocessing step is computationally simple and can be easily integrated with restoration techniques such as DCP without significant computational overhead. Therefore, the HACR framework provides a balanced combination of improved color recovery, enhanced visibility, and efficient preprocessing, making it a suitable solution for image restoration in degraded visual environments.

CONCLUSION AND FUTURE WORK

5.1 Conclusion

This study proposed a Hybrid Adaptive Color Recovery (HACR) method to improve the restoration of degraded images captured under challenging environmental conditions such as haze and underwater scenes. The proposed approach focuses on recovering weakened color channels through adaptive color compensation before applying image restoration techniques. By improving the color balance of degraded images, the method provides better input for subsequent restoration processes. The experimental results demonstrate that the proposed framework enhances image visibility and color consistency while maintaining computational simplicity. Therefore, HACR can be considered an effective preprocessing technique for improving the quality of degraded images in practical image restoration applications.

5.2 Future Scope

In future work, the proposed HACR method can be further improved by combining it with advanced image restoration techniques and deep learning models. The approach can also be tested on larger and more diverse datasets. In addition, optimizing the method for real-time applications could make it useful in areas such as surveillance, underwater imaging, and autonomous systems.

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