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Color Cast Correction Mechanisms: Techniques and Innovations for Image Enhancement

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Abstract: This paper presents an in-depth examination of color cast in digital images, elucidating its fundamental principles, generation mechanisms, and real-world implications influenced by light absorption and scattering. The study explores diverse color cast correction methods and provides a detailed analysis of their respective outcomes. Foundational knowledge of color cast, rooted in the principles of light interaction, serves as the basis for understanding its manifestation in various real-world contexts. The research systematically investigates the intricate dynamics of color cast across diverse scenarios, shedding light on its complexities and impact. The paper evaluates a range of color cast correction techniques, including classic approaches such as the Gray World Algorithm, Max–RGB, and White Balance Correction, as well as advanced methods like Gamma Correction, Histogram-Based Method, and the Gray Edge Algorithm. Notably, simulation results underscore the consistent superiority of the Gray Edge Algorithm in effectively correcting color cast, showcasing its robustness across diverse scenarios. This comprehensive exploration contributes to a holistic understanding of color cast, covering its generation, consequences in real-world scenarios, and an in-depth analysis of correction methodologies. The findings provide valuable insights for professionals in image processing and computer vision seeking efficient correction strategies.

Keywords: color cast, image processing, color correction, light interaction, real-world scenarios.

1 INTRODUCTION

Accurate color representation in digital images is crucial for various fields, including photography, design, printing, and digital media. The importance lies in the need for faithful reproduction of colors to ensure that the final output matches the original scene or intended design. Accurate color representation ensures that digital images closely match the colors observed in the real world or the designer's vision. This is essential for conveying the intended visual message and maintaining the fidelity of the original content. Different devices, such as monitors, printers, and cameras, may have variations in their color reproduction capabilities. Accurate color representation helps achieve consistency across these devices, ensuring that users see consistent colors regardless of the device used. For businesses and brands, maintaining consistent and accurate colors is vital for brand identity. Logos, product images, and marketing materials should reflect the brand's color palette accurately to reinforce brand recognition and trust [1].

In fields like photography and medical imaging, accurate color representation is critical for professionals to make accurate assessments and diagnoses. In medical imaging, for instance, accurate representation is essential for identifying and analyzing abnormalities. In the printing industry, accurate color representation is necessary to ensure that printed materials, such as brochures, magazines, and packaging, match the intended design [2]. This helps in maintaining the quality and impact of printed materials. On the internet and in digital media, consistent color representation is important for maintaining the integrity of digital content. This is especially crucial for websites, online advertising, and digital marketing materials. Accurate color representation is also important for accessibility. Individuals with color vision deficiencies rely on accurate representation to comprehend and interact with digital content effectively [3].

Color cast refers to an unwanted tint or hue in an image, often caused by the lighting conditions or the characteristics of the imaging device. The prevalence and impact of color cast are significant in various imaging environments, affecting the quality and interpretation of digital images. Here are key points highlighting the prevalence and impact of color cast:

1. Natural Lighting Conditions: In outdoor photography, the color of natural light can vary throughout the day, causing color casts in images. For example, during sunrise or sunset, the warm sunlight may introduce a reddish or orange color cast, while overcast conditions can result in a cool bluish cast.
2. Indoor Lighting: Different artificial lighting sources, such as incandescent, fluorescent, and LED lights, have distinct color temperatures. This can lead to color casts in images captured indoors. For instance, incandescent lighting tends to produce a warm, yellowish cast, while fluorescent lighting may introduce a cooler, greenish cast.
3. White Balance Issues: Incorrect white balance settings on cameras can contribute to color casts. If the white balance is not adjusted according to the lighting conditions, images may exhibit an undesirable color tint. Auto white balance settings may not always accurately compensate for diverse lighting environments.
4. Photographic Equipment: Variations in the quality and calibration of imaging devices, such as cameras and scanners, can lead to color cast issues. Lower-quality equipment or sensors may struggle to accurately capture colors, resulting in shifts in hue and saturation.
5. Image Editing: During post-processing, improper adjustments can introduce color casts unintentionally. Overediting or using inappropriate color correction techniques may lead to unnatural and distracting color shifts.

6. Printed Materials: Color casts can affect the quality of printed materials. If the colors in a digital image are not accurately represented during the printing process, the final output may exhibit unexpected color shifts, impacting the overall appearance of printed materials.

The objectives of this paper are the following.

1. Quantify Color Cast Effects: Assess the prevalence and intensity of color casts in digital images under various lighting conditions, considering factors such as natural lighting, artificial lighting, and different color temperatures.
2. Investigate Causes and Origins: Explore the root causes of color casts, including the impact of lighting sources, equipment variations, and environmental factors, to better understand the mechanisms leading to color shifts.
3. Develop Correction Algorithms: Propose and evaluate algorithms for automated color cast correction in digital images. This could involve investigating machine learning techniques or advanced image processing methods to enhance accuracy and efficiency.
4. Assess Impact on Image Quality: Analyze the impact of color casts on the perceived quality and aesthetics of digital images, considering both subjective human assessments and objective quality metrics.
5. Evaluate White Balance Methods: Compare and assess the effectiveness of different white balance methods and algorithms in mitigating color cast issues in various imaging scenarios.

2 ORIGIN OF COLOR CAST

2.1 The Generation of Color Cast

The generation of color cast in digital images can be attributed to a variety of factors, including lighting conditions, environmental influences, and camera settings [4][5]. While mathematical models can help describe some of these phenomena, it's important to note that the complexity of color reproduction involves a combination of physiological, optical, and computational elements [6]. Here's an exploration of factors contributing to color cast with an emphasis on mathematical models where applicable:

1. **Lighting Conditions:**
   - **Color Temperature (Kelvin):** The color of light is characterized by its temperature. Warmer light sources, such as incandescent bulbs, have lower color temperatures, while cooler sources, like daylight or overcast skies, have higher temperatures. The relationship between color temperature and color cast can be expressed using the Planckian locus and correlated color temperature (CCT) models.
   - **Spectral Power Distribution (SPD):** The spectral distribution of light sources influences color perception. Mathematical models, such as the spectral power distribution curve, can describe the spectral composition of different light sources and their impact on color reproduction.
2. **Environmental Factors:**
   - **Surrounding Colors and Reflectance:** The colors of nearby objects and surfaces can influence the overall color cast. Mathematical models like Kubelka-Munk theory can help predict color changes based on the reflectance properties of surfaces and the interaction of light with these surfaces.
   - **Atmospheric Conditions:** In outdoor environments, atmospheric conditions like pollution, humidity, and altitude can affect the scattering of light. Rayleigh scattering, described mathematically, plays a role in the color of the ambient light and may contribute to color cast.
3. **Camera Settings:**
   - **White Balance Adjustment:** White balance settings on a camera compensate for color temperature variations. The simplest model involves a color temperature slider that adjusts the RGB gains. More sophisticated models might involve matrix-based color correction algorithms to account for non-uniform color shifts.
   - **Sensor Characteristics:** The spectral sensitivity of the camera sensor, often represented by a color matching function, influences how the sensor captures and interprets different wavelengths of light. Spectral sensitivity can be modeled using mathematical functions like the CIE standard color matching functions.
   - **Color Filters:** Some cameras use color filters on their sensors to capture specific color information. Bayer filters, for example, use a mosaic of red, green, and blue filters over individual pixels. Mathematical demosaicing algorithms are applied to reconstruct a full-color image from this mosaic.
4. **Combined Factors:**
   - **Color Rendering Index (CRI):** CRI quantifies how accurately a light source renders colors compared to a reference illuminant. Mathematical models associated with CRI can be employed to predict the color rendering properties of different light sources.
   - **Von Kries Model:** The Von Kries model is a linear transformation used in color adaptation and white balance adjustments. It involves scaling the sensor responses based on the assumed changes in illuminant color.

2.2 Light Absorption and Scattering

The physics of light absorption and scattering in different mediums, such as air and water, plays a crucial role in understanding how light behaves in challenging lighting conditions [7]. In underwater environments, the properties of water significantly impact the color and visibility of objects. Let's explore the physics involved, particularly in the context of underwater conditions.

Light Absorption in Water

1. Beer-Lambert Law:

- The Beer-Lambert Law describes the attenuation of light as it passes through a medium. In the context of water, it can be expressed as:

$$I = I_0 . e^{-k.c.d}$$

where:
I is the intensity of light after passing through the medium,
I_0 is the initial intensity of light,
k is the absorption coefficient of the medium,
c is the concentration of the absorbing substance (e.g., chlorophyll, sediments),
d is the path length of light through the medium.

2. Absorption Spectrum of Water:

- The absorption spectrum of water shows distinct peaks in the blue and red regions of the electromagnetic spectrum [8][9]. These absorption bands are associated with the absorption of light by water molecules. The mathematical representation of these absorption bands involves complex molecular interactions.

Light Scattering in Water

1. Rayleigh Scattering

- Rayleigh scattering is a dominant scattering mechanism in clear water. The intensity of scattered light (I_s) can be expressed as:

$$I_s \propto \frac{1}{\lambda^4}$$

where:
λ is the wavelength of light.

- This equation highlights that shorter wavelengths (blue light) are scattered more than longer wavelengths (red light). This contributes to the bluish appearance of underwater scenes.

2. Mie Scattering

- Mie scattering becomes more prominent when suspended particles, such as phytoplankton or sediment, are present in the water. The scattering efficiency depends on the particle size and the wavelength of light [10].
- The Mie scattering phase function ($P(\theta)$) for spherical particles is mathematically complex and involves Bessel functions. It describes the distribution of scattered light at different angles (θ).

Challenging Lighting Conditions Underwater

- Attenuation of Light: The combined effects of absorption and scattering result in the attenuation of light with depth in water. The rate of attenuation is influenced by the concentration of dissolved and particulate matter in the water.
- Color Shifts: Shorter wavelengths are absorbed more quickly than longer wavelengths, leading to color shifts in underwater scenes. Reds and yellows are absorbed first, leaving predominantly blue and green light [11].
- Contrast Reduction: Scattering and absorption reduce contrast and visibility underwater. The underwater photographer's formula incorporates these factors:

$$Visibility = \frac{1}{k.d}$$

where:
k is the attenuation coefficient,
d is the distance travelled by light.

2.3 Real-world Scenarios

Color cast can manifest in various real-world scenarios, affecting the appearance of images and potentially impacting the interpretation and communication of visual information [12]. Here are a few examples and case studies that illustrate the presence of color cast in different contexts:

1. Indoor Lighting Variations:
    - Scenario: Consider a scenario where a photographer is capturing images at an indoor event with mixed lighting sources, such as incandescent and fluorescent bulbs.
    - Color Cast Manifestation: Incandescent lighting tends to produce a warm, yellowish cast, while fluorescent lighting can introduce a cooler, greenish cast. Images taken in such conditions may exhibit color imbalances, affecting the overall color fidelity of the photographs.

2. White Balance Issues in Photography:
   - Scenario: A photographer is shooting a portrait session during the golden hour, where the warm sunlight creates a beautiful ambiance. However, the camera's white balance is set incorrectly.
   - Color Cast Manifestation: If the white balance is not adjusted to the warm lighting conditions, the images may appear too cool or blue. The skin tones may lack the desired warmth, and the overall visual impact of the golden hour may be compromised.
3. Underwater Photography:
   - Scenario: An underwater photographer is capturing images at varying depths in a tropical ocean environment.
   - Color Cast Manifestation: As light penetrates the water, it undergoes absorption and scattering. Reds and yellows are absorbed more quickly, resulting in a bluish-green color cast in underwater scenes. Adjusting for this color shift is crucial to restoring the natural colors of marine life and underwater landscapes.
4. Product Photography in Artificial Lighting:
   - Scenario: A designer is photographing products in a studio with artificial lighting, using a mix of LED and tungsten lights.
   - Color Cast Manifestation: Different lighting sources have distinct color temperatures. The images may exhibit color imbalances, with some areas appearing too warm or cool. This can impact the accurate representation of product colors and affect the visual appeal of marketing materials.
5. Architectural Photography in Daylight:
   - Scenario: An architectural photographer is capturing images of a building exterior during midday sunlight.
   - Color Cast Manifestation: The color temperature of natural light can vary based on atmospheric conditions. If the photographer does not account for these variations, the images may exhibit color shifts. For example, a bluish cast might be present on a cloudy day, impacting the perceived warmth of the building's facade.
6. Artificial Lighting in Interior Design Photography:
   - Scenario: A photographer is documenting the interior of a modern office space illuminated by a combination of daylight and artificial LED lighting.
   - Color Cast Manifestation: LED lights often have a specific color temperature. If not balanced correctly, the images may show color inconsistencies, affecting the representation of interior design elements and the overall aesthetic of the space.

In each of these scenarios, addressing color cast issues may involve adjusting camera settings, using color correction tools during post-processing, or employing advanced techniques to enhance color fidelity [13]. Awareness of potential color cast manifestations is essential for photographers, designers, and visual content creators to produce accurate and visually pleasing images.

3 CORRECTION OF COLOR CAST

Color cast correction methods aim to adjust the color balance of an image to achieve accurate and natural-looking colors [14]. These methods range from simple manual adjustments to sophisticated algorithms and advanced image processing techniques. Here's an overview of various color cast correction methods:

1. Manual Adjustments:
   - White Balance Setting: Many cameras allow users to manually set the white balance based on the lighting conditions. This involves selecting predefined settings (e.g., daylight, cloudy, tungsten) or manually adjusting the color temperature.
   - Color Correction Tools: Image editing software like Adobe Photoshop provides manual color correction tools, such as the Levels and Curves adjustments. These tools allow users to modify the color balance by adjusting the intensity of color channels.
2. Automatic Algorithms:
   - Gray World Assumption: Assumes that the average color in an image should be neutral (gray). Adjustments are made to scale and normalize the color channels based on this assumption.
   - Histogram-Based Methods: Histogram equalization and histogram stretching aim to spread color values across the entire spectrum, improving contrast and reducing color bias.
   - Edge-Based Methods: Analyze image edges and apply color corrections to maintain color consistency along edges while adjusting the overall color balance.
3. Advanced Image Processing Techniques:
   - Color Constancy Algorithms:
     - Von Kries Model: A linear transformation model that scales the cone responses in the human visual system to achieve color constancy [15]. It involves adjusting the color gain based on the illuminant.
     - Gray Edge Hypothesis: Considers edges in an image and assumes that edges with similar colors should appear neutral. Adjustments are made to satisfy this hypothesis.
   - Retinex Algorithms:
     - Multi-Scale Retinex: Decomposes an image into multiple scales and adjusts the color at each scale independently [16]. It helps to correct color cast while preserving details.

- Single-Scale Retinex: Simplified version of Multi-Scale Retinex, applying color corrections at a single scale to improve color balance.
- Machine Learning-Based Methods:
    - Convolutional Neural Networks (CNNs): Trained on large datasets, CNNs can learn complex color correction patterns and adjust images based on learned features [17].
    - Generative Adversarial Networks (GANs): GANs can be used for image-to-image translation tasks, including color cast correction, by learning mapping functions from images with color cast to those without.
- Color Transfer Techniques:
    - Global Color Transfer: Adjusts the color distribution of an entire image based on the color distribution of a reference image.
    - Local Color Transfer: Applies color transfer locally, considering the color information within specific regions of an image.

4. Hybrid Approaches:

- Combining manual adjustments with automatic algorithms or incorporating machine learning models into traditional methods to enhance accuracy and efficiency.

Considerations and Challenges:

- Perceptual Quality: Ensuring that color corrections maintain the perceptual quality of the image and do not introduce artifacts or unnatural colors.
- Computational Complexity: Advanced algorithms may have higher computational requirements, influencing their suitability for real-time applications.
- Training Data: Machine learning-based methods often require large, diverse datasets for effective training and generalization to different scenarios.

4 COLOR CAST CORRECTION METHODS

The color cast correction methods can be broadly classified into Color Correction methods and Gray-scale Enhancement methods. Color correction methods and grayscale enhancement methods serve distinct purposes in image processing, and they can be discriminated based on their primary objectives and the aspects of an image they address. The primary goal of color correction methods is to adjust and balance the colors in an image, ensuring accurate and natural color representation [18]. It aims to correct any color biases, casts, or inaccuracies introduced during image capture or processing. Color correction is typically performed in color spaces such as RGB (Red, Green, Blue) or other color models where the color information is represented as a combination of different color channels. Color correction is crucial in situations where accurate color reproduction is essential, such as photography, video production, and graphic design. It helps to compensate for variations in lighting conditions, camera settings, or color inconsistencies.

Grayscale enhancement methods focus on improving the quality, contrast, and perceptual clarity of grayscale (black and white) images. While they may not directly address color correction, they enhance the visual features in monochromatic images. Grayscale enhancement is applicable to images that are inherently monochromatic, where color information is absent or irrelevant [19]. It often operates in luminance or intensity representations of images. Grayscale enhancement is commonly employed in medical imaging, computer vision, and certain types of image analysis where the emphasis is on extracting features from intensity variations rather than color information. In this paper, the following methods are used to correct color cast.

Color Correction Methods:

1. Gray World Algorithm
2. Max - RGB
3. Von Kries Hypothesis
4. White Balance Correction
5. Gamma Correction

Gray-Scale Enhancement Techniques:

1. Histogram-Based Method
2. Grey Edge Algorithm
3. Gray Pixel World
4. White Patch Retinex Algorithm

The Gray World Algorithm assumes that under a neutral light source, the average color in an image should be Gray. The algorithm calculates the average intensities (Ravg, Gavg, Bavg) and determines a scaling factor for each channel. The corrected color channels are given by:

$$R_{corrected} = \frac{1}{R_{avg}} \times R$$
$$G_{corrected} = \frac{1}{G_{avg}} \times G \qquad (1)$$
$$B_{corrected} = \frac{1}{B_{avg}} \times B$$

The Gray World Algorithm is a simple yet effective method for color balancing, particularly in situations where a scene has a dominant color cast. However, it assumes a neutral average color, which may not hold true in all scenarios, and it might not perform well in the presence of extreme color imbalances.

The Max - RGB method enhances intensity values by selecting the maximum among the red, green, and blue channels. The corrected intensity is given by Iout=max(R,G,B). Max - RGB is a simple and computationally efficient method for enhancing color intensity, particularly useful for creating visually vibrant images. However, it may oversaturate certain color channels, leading to potential loss of detail and color accuracy.

The Von Kries Hypothesis adapts the color space based on luminance values, utilizing an adaptation matrix M_{adapt} to scale the color channels.

$$\begin{bmatrix} R_{corrected} \\ G_{corrected} \\ B_{corrected} \end{bmatrix} = M_{adapt} \times \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (2)$$

Von Kries adaptation is a robust approach for maintaining color constancy under changing lighting conditions, contributing to consistent color perception. However, it assumes that the color adaptation is linear, which may not hold true in all scenarios, and it may not handle extreme color changes effectively.

White balance correction adjusts color channels based on the color temperature of the light source. One common method involves using a correction matrix M to scale the RGB values:

$$\begin{bmatrix} R_{corrected} \\ G_{corrected} \\ B_{corrected} \end{bmatrix} = M \times \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (3)$$

The matrix M is determined based on the known color temperature of the light source. White balance correction is crucial for ensuring accurate color representation in images captured under different lighting conditions, contributing to natural-looking results. However, its effectiveness relies on accurate color temperature estimation, and it may struggle in challenging situations with mixed lighting sources.

Gamma correction involves a non-linear adjustment to the intensity values of an image. The equation $I_{out} = I_{in}^{\gamma}$ signifies the correction, where I_{in} is the input intensity, I_{out} is the corrected intensity, and γ is the gamma factor. This method compensates for the nonlinear response of display devices, offering improved control over brightness and contrast. Gamma correction is computationally efficient and straightforward to implement. It is particularly useful for adjusting the overall tonal response of an image. However, gamma correction might not fully address color imbalances or intricate color correction needs, as it primarily focuses on brightness adjustments.

Histogram-based methods, such as histogram equalization, enhance contrast in grayscale images by redistributing intensity values based on the cumulative distribution function (CDF) of the image histogram. Histogram equalization effectively improves contrast and is widely used for enhancing the visibility of details in grayscale images. However, it may exaggerate noise, and its performance can be sensitive to the image content and distribution.

The Grey Edge Algorithm enhances the perceptual quality of grayscale images by emphasizing edges and details. Convolution with edge-detection kernels is often employed to enhance intensity gradients. Grey Edge Algorithm is effective in highlighting image features, making it useful for applications requiring edge emphasis. However, it might enhance noise along with details, and the choice of the edge-detection kernel can influence results.

The Gray Pixel World technique adjusts the intensity of each pixel based on the average intensity of the entire image. The corrected intensity $I_{corrected}$ for each pixel is calculated as:

$$I_{corrected} = \frac{\sum I_{pixels}}{Number\ of\ pixels} \quad (4)$$

This approach contributes to overall image enhancement by ensuring a consistent average intensity across the image. Gray Pixel World is easy to implement and provides a quick enhancement of overall image quality, particularly for images with uneven lighting. However, it may not be suitable for images with significant local variations or specific intensity patterns.

The White Patch Retinex algorithm applies the Retinex algorithm, emphasizing local color changes in an image. The corrected intensity $I_{corrected}$ is computed using the Retinex formula, which involves the logarithm of the ratio of the original intensity to an estimated illumination value. White Patch Retinex is effective in improving color and contrast, particularly in low-light conditions, by normalizing local illumination. However, it may lead to color overemphasis in certain situations, and computational complexity can be a consideration for real-time applications.

5 SIMULATION RESULTS

In this section, simulation results of different color cast correction schemes are presented. First, four levels of color cast are applied to a ground truth image: first level with lesser effect of color cast and fourth level with severe effect of color cast. Fig. 1 and Fig. 2 show the color cast corrected images with each scheme.

The first column of images is with respect to level – 1 color cast and the remaining level – 2, level – 3, and level – 4 respectively. In each case objective measurement is carried out using Absolute central moment (ACMO), Brenner's focus measure (BREN), Squared gradient (GRAS), Modified Laplacian (LAPM), Variance of Laplacian (LAPV), Diagonal Laplacian (LAPD), and Wavelet variance (WAVV) [20][21]. These values are tabulated separately for each level of color cast. Table 1 presents these metrics in level – 1 case, and Table 2, Table 3, and Table 4 present the focus metrics associated with level – 2, level – 3, and level – 4 respectively [22][23].

Table 1. Focus metrics in Level – 1 Color Cast case

	ACMO	BREN	GRAS	LAPM	LAPV	LAPD	WAVV
Gray World Algorithm	71.553	0.057	0.022	0.146	0.057	0.311	0.053
Max – RGB	52.706	0.016	0.006	0.076	0.015	0.163	0.027
Von Kries Hypothesis	51.720	0.015	0.006	0.076	0.015	0.161	0.026
White Balance Correction	71.553	0.036	0.015	0.126	0.045	0.266	0.048
Gamma Correction	53.224	0.015	0.006	0.067	0.015	0.141	0.029
Histogram-Based Method	69.124	0.033	0.013	0.118	0.040	0.250	0.045
Grey Edge Algorithm	74.473	0.042	0.019	0.159	0.065	0.329	0.059
Gray Pixel World	71.553	0.036	0.015	0.126	0.045	0.266	0.048
White Patch Retinex Algorithm	52.706	0.016	0.006	0.076	0.015	0.163	0.027

Table 2. Focus metrics in Level – 2 Color Cast case

	ACMO	BREN	GRAS	LAPM	LAPV	LAPD	WAVV
Gray World Algorithm	74.820	0.276	0.118	0.324	0.458	0.680	0.177
Max – RGB	46.045	0.009	0.003	0.052	0.007	0.112	0.017
Von Kries Hypothesis	44.225	0.008	0.003	0.051	0.007	0.110	0.017
White Balance Correction	74.820	0.077	0.036	0.222	0.138	0.462	0.090
Gamma Correction	33.831	0.007	0.003	0.047	0.007	0.101	0.019
Histogram-Based Method	76.291	0.086	0.042	0.242	0.174	0.498	0.103
Grey Edge Algorithm	80.598	0.100	0.053	0.295	0.225	0.600	0.114
Gray Pixel World	74.820	0.077	0.036	0.222	0.138	0.462	0.090
White Patch Retinex Algorithm	46.045	0.009	0.003	0.052	0.007	0.112	0.017

Table 3. Focus metrics in Level – 3 Color Cast case

	ACMO	BREN	GRAS	LAPM	LAPV	LAPD	WAVV
Gray World Algorithm	75.044	0.660	0.278	0.442	1.144	0.925	0.294
Max – RGB	38.644	0.006	0.002	0.039	0.004	0.084	0.013
Von Kries Hypothesis	36.300	0.005	0.002	0.038	0.004	0.081	0.012
White Balance Correction	75.044	0.096	0.046	0.247	0.187	0.509	0.106
Gamma Correction	22.906	0.003	0.001	0.031	0.003	0.066	0.013
Histogram-Based Method	57.480	0.067	0.030	0.183	0.122	0.379	0.087
Grey Edge Algorithm	86.719	0.115	0.058	0.303	0.250	0.617	0.121
Gray Pixel World	75.044	0.096	0.046	0.247	0.187	0.509	0.106
White Patch Retinex Algorithm	38.644	0.006	0.002	0.039	0.004	0.084	0.013

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Fig. 1. Simulation results of Gray world algorithm, Max RGB, Von Kries Hypothesis algorithm, White balance algorithm, and Gamma correction algorithms

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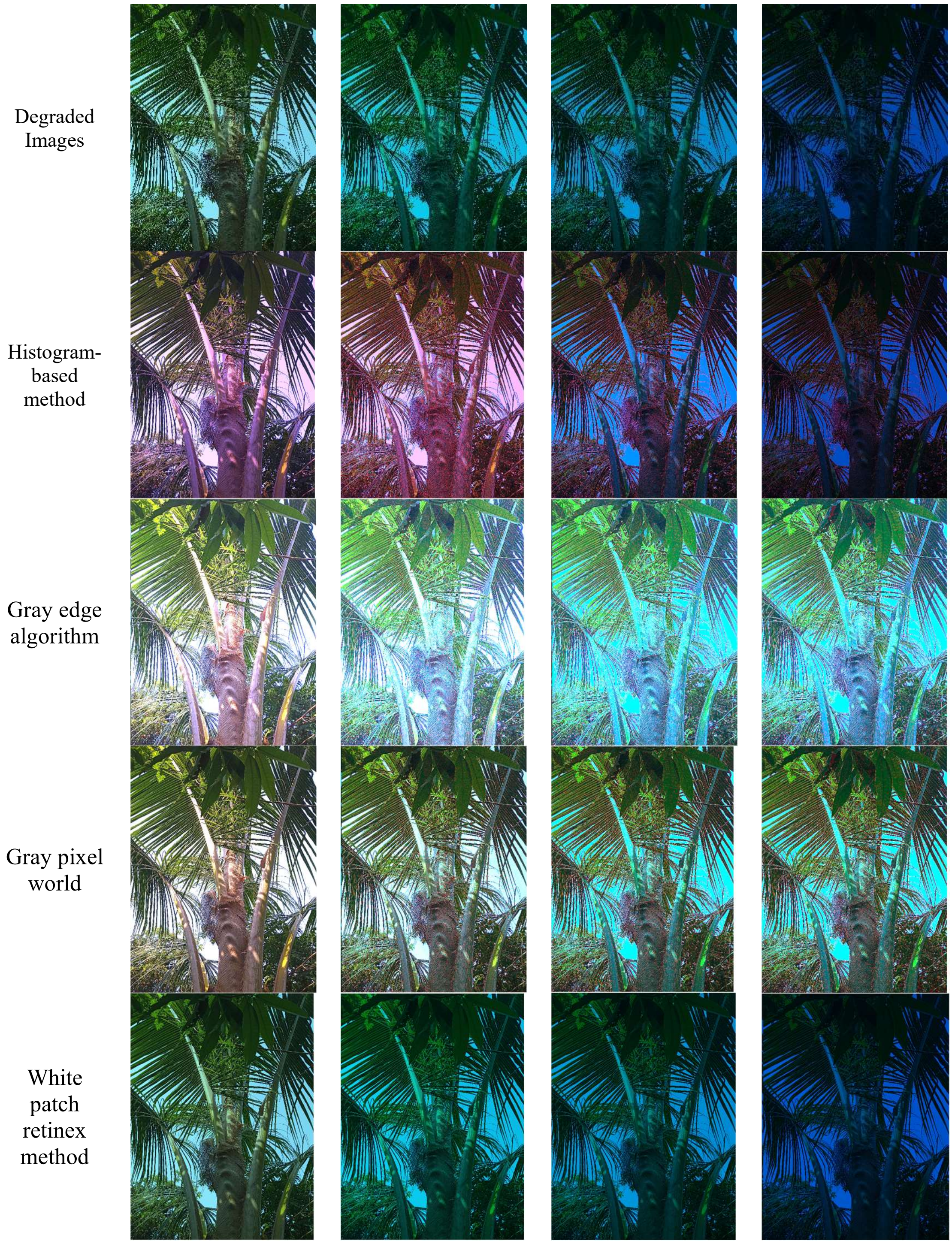

Fig. 2. Simulation results of Histogram-based method, Gray edge algorithm, Gray pixel world, and White patch retinex algorithm

Table 4. Focus metrics in Level – 4 Color Cast case

	ACMO	BREN	GRAS	LAPM	LAPV	LAPD	WAVV
Gray World Algorithm	75.378	0.613	0.247	0.398	0.949	0.842	0.259
Max – RGB	30.566	0.003	0.001	0.028	0.002	0.061	0.008
Von Kries Hypothesis	25.136	0.002	0.001	0.024	0.001	0.051	0.007
White Balance Correction	75.378	0.087	0.041	0.223	0.165	0.464	0.100
Gamma Correction	12.636	0.001	0.000	0.017	0.001	0.036	0.007
Histogram-Based Method	33.812	0.023	0.009	0.084	0.034	0.179	0.045
Grey Edge Algorithm	85.869	0.100	0.050	0.264	0.206	0.544	0.110
Gray Pixel World	75.378	0.087	0.041	0.223	0.165	0.464	0.100
White Patch Retinex Algorithm	30.566	0.003	0.001	0.028	0.002	0.061	0.008

In the Level – 1 color cast case, all techniques exhibit relatively high ACMO values, indicating a moderate level of focus. The Gray Edge Algorithm consistently outperforms other methods in BREN, GRAS, LAPM, LAPV, LAPD, and WAVV metrics, suggesting better sharpness and focus in images corrected using this approach.

As the color cast level increases to Level – 2, ACMO values continue to rise, reflecting a decrease in overall focus. Focus metrics such as BREN, GRAS, LAPM, LAPV, LAPD, and WAVV consistently decrease across all techniques. Notably, the Gray Edge Algorithm maintains its superiority in preserving image sharpness, emphasizing its effectiveness under higher color cast conditions.

In the Level – 3 color cast case, ACMO values reach higher levels, indicating a further decrease in focus. Similar trends are observed in focus metrics, with a decrease across all techniques. Once again, the Gray Edge Algorithm stands out as the most effective in maintaining focus, showcasing its robustness in challenging color cast scenarios.

At the highest color cast level (Level – 4), ACMO values peak, suggesting the lowest overall focus. Focus metrics consistently decrease, emphasizing the difficulty of preserving sharpness in highly color-casted images. The Gray Edge Algorithm remains the top-performing technique, underscoring its resilience in extreme color cast conditions.

Across all color cast levels, the Gray Edge Algorithm consistently proves to be the most effective technique in maintaining image focus, outperforming other methods such as Gray World Algorithm, Max – RGB, Von Kries Hypothesis, White Balance Correction, Gamma Correction, Histogram-Based Method, and White Patch Retinex Algorithm. The general trend indicates that as color cast levels increase, there is a notable decrease in focus metrics for all techniques, highlighting the importance of robust color correction methods, with the Gray Edge Algorithm showing remarkable stability and reliability in challenging conditions.

6 CONCLUSIONS

This paper comprehensively explores the phenomenon of color cast in digital images, delving into its fundamentals, generation mechanisms, and real-world scenarios affected by light absorption and scattering. The study investigates various color cast correction methods and presents their detailed results. The foundational understanding of color cast, rooted in the principles of light interaction, provides a robust basis for comprehending its occurrence in real-world contexts. The paper meticulously analyzes the impact of color cast across different scenarios, shedding light on its complexities. Furthermore, the research investigates a range of color cast correction techniques, unveiling their effectiveness through simulation results. From classic methods like Gray World Algorithm, Max – RGB, and White Balance Correction to advanced techniques like Gamma Correction, Histogram-Based Method, and Gray Edge Algorithm, the paper evaluates their performance in diverse scenarios. The results showcase that the Gray Edge Algorithm consistently outperforms other methods, emphasizing its robustness in color correction. This paper contributes a comprehensive overview of color cast, covering its generation, impact on real-world scenarios, and a detailed exploration of correction methodologies. The findings not only deepen our understanding of color cast but also provide valuable insights for practitioners in image processing and computer vision seeking effective correction strategies.

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