Color Constancy Using a Global Nose Camera Attachment

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Abstract

A new color constancy method was recently introduced in [1] using a camera attachment “nose”, which is visible in the image, for spatial measurement of illumination color in the scene. The illumination measurement principle relies on the appearance of highlights or satisfaction of the gray world assumption inside a scene area. However, the nose size was big in the system and its image occupied 25% of the image area.

In this paper, the previous system is modified by reducing the nose size which becomes suitable for measuring uniform illumination color in the scene. In the modified system, the nose image appears continually as a small triangle in an image corner occupying less than 3% of the image area. The color correction algorithm processes the saturated pixels to give them a natural appearance.

A novel technique to balance image colors optically is also introduced that preserves the color resolution in the corrected image. Extensive experiments were carried out which confirmed the effectiveness of the new system.

1. Introduction

Color is a useful cue for identifying an object by humans, but this cue is difficult to use in artificial color vision systems, since the color appearance in an image depends on the illumination color as well as the object surface color itself. Color constancy is the ability to measure a surface color, as it would appear when illuminated by white light, despite the change of actual illumination color incident on the surface.

Several color vision algorithms require that their input color image be processed by a color constancy algorithm prior to their analysis. Therefore, a robust color constancy algorithm is needed and useful for color computer vision research and applications.

Several color constancy algorithms had been proposed in the literature. The simplest method is the use of direct reflection from a single white patch inserted in the scene as the illumination color. A supervised color constancy theory was suggested [6] in which 24 reference color chips were inserted in the scene, which was used to compute the illuminant color. Although the scene-inserted white patch is considered as the most reliable method, it is not applicable in real imaging where a reference patch can not be inserted into the scene.

Another approach search for highlights, since the highlight color in the scene is known to represent the illuminant color on dielectric surfaces. The response of highlighted pixels in the image may be clipped, due to limited sensor range, and it becomes very difficult to measure its real color from the image [4].

The Retinex theory [5] assumed that a weighted convolution of the surface colors inside a window is gray, Gray World Assumption, GWA. Deviation from gray is then attributed to the illumination color change. The Retinex method is quite sensitive to the scene color composition when the GWA is not satisfied [2,3].

A new method was recently introduced in [1] using a camera attachment, “nose”, for spatial measurement of illumination color in the scene. The nose image color represents the illumination color directly when either highlights appear or the GWA is satisfied inside a local scene area. The merit of the nose method is that it makes parallel dependence on two main sources of information about the illumination color and its implementation is extremely fast since the scene convolution is optically implemented. However, the nose size developed in [1] was big and occupied one quarter of the image. The big size results from the need for spatial representation of the illumination color in the scene.

In this paper, the nose system size is reduced by employing the assumption of spatially uniform illumination color in the scene. The color correction algorithm is also modified to handle the saturated pixels, an overlooked problem of color correction, so that they may appear natural. A new technique, for optically compensating image colors, is also presented which preserves the color resolution.

This paper is arranged as follows, Section 2 describes
briefly the scene and nose reflection models. In Section 3, the nose design and the color correction algorithms are described. In Section 4 the results of extensive experimental program for correcting color images of real scenes are presented. Conclusions are finally given in Section 5.

2. Reflection Models

2.1. Scene Reflection and Image Acquisition Model
In Figure 1, the light source is represented in the form of a white lamp surrounded by a color filter which is the same as a variable color lamp.

![Figure 1. Schematic diagram of the scene reflection.](image)

The illumination from the light source, $E(\lambda)$, can be modeled by the relation

$$H(\lambda) = L(\lambda)F(\lambda)$$

where $L(\lambda)$ is the Spectral Power Distribution, SPD of a neutral virtual light source, and $F(\lambda)$ is the spectral characteristics of the filter. When the colored illumination hits a rough surface, it reflects a light spectrum, $I(\lambda)$ that can be described by

$$I(\lambda) = S(\lambda)H(\lambda)$$

where $S(\lambda)$ is the surface color. It can be observed that the surface reflection is a multiplication of surface color by the light source color. Since the color of light source is subject to random changes, the reflection $I(\lambda)$ need to be processed to eliminate the effect of light source color. The reflection entering to the camera sensor usually passes through a front filter which is represented by

$$I_C(\lambda) = F_{I_{II}}(\lambda)$$

where $I_C(\lambda)$ is the scene reflection entering to the camera sensor and $F_{I_{II}}(\lambda)$ is the spectral characteristics of the camera front filter. Each sensor element integrates the incident spectrum and deliver an output signal given by

$$K(x,y) = \int \int [I_C(\lambda)\cdot R(x,y)\cdot dX\cdot d\lambda]$$

where $K$ may take three values corresponding to Red, Green and Blue color bands, $(x,y)$ are the image coordinates, $(X,Y)$ are the world coordinates referred to the image center, $F_{I_{II}}(\lambda)$ is the spectral response of spectrum sampling filter for the $k$th observation.

2.2. The Nose Inter-Reflection Model
The assumptions of the nose method are:

1. The illumination color is spatially uniform all through the imaged scene.
2. The scene reflect highlights that follow the Neutral Interface Reflection model [7], and angled to appear in the image or the colors inside a control area of the scene are following the GWA.
3. Adequate responses can be measured in the image for both main and nose sections, so that the responses are neither week nor saturated, except for the highlighted pixels.

The first assumption is true for a large class of scenes which is illuminated by a single color light source. The surface reflection from inhomogeneous dielectric surfaces can be described using the dichromatic reflection model [7]. The model proposes a Body reflection (B) which carries surface color modified by light source color and an Interface (I) reflection which carries light source color only.

The nose image represents image of the scene subject to two blurring processes. The first is due to the dispersed reflection pattern on the nose surface. The second blurring results from the defocusing of the nose surface image since the camera is focused to the relatively distant scene [1].

The reflected components from object surface are reflected again from the nose surface, thereby giving four components (I-I), (I-B), (B-I) and (B-B) as shown in Figure 2.

Component (I-I) represent the illumination color while component (I-B) represent the illumination color modified by nose surface color. The nose surface color is spectrally neutral, then (I-B) represents the illumination color. (B-I) represents object surface color and (B-B) represent object surface color modified by nose surface color. Component (B-B) is very weak in intensity due to successive dispersion and hence can be ignored.

Then, the nose image color is composed of three main components (I-I), (I-B) and (B-I). The components (I-I) and (I-B) represent the illumination color and they will dominate the nose reflection color when strong intensity highlights appear in the scene. When no highlights appear, the representation depends on the satisfaction of the GWA which makes component (B-I) to represent the illumination color. Therefore, the nose image color represents the illumination color when the assumptions are satisfied.
2.3. Color Correction Model

The second process to achieve color constancy is to derive the image colors in its canonical appearance, given the illuminant color in the scene and the direct image. The canonical color appearance is defined to be the image colors had it been captured under a white canonical illuminant. The previous techniques derive the colors by dividing image colors by the illuminant color. Using this model, the corrected surface color, in each pixel, can be described by:

\[ \frac{C}{\bar{C}} = K \frac{u}{\bar{u}} \]

where \( K \) denote the color responses in a main image pixel, \( \bar{C} \) denote the illumination color, and \( \bar{u} \) is a fixed scale factor adjusted to expand the color values linearly in the frame buffer. This formula is well known as the Von Kries Coefficient Rule, VKCR, and when it is used, the color sampling filters should have disjoint spectral transmission curves in the visible spectrum [3].

In the state of the art video cameras, the VKCR is implemented in an analog form by changing the gain of video amplifiers in color channels. While in research, the VKCR is digitally implemented by multiplying the digitized color signals with numerical gain factors by software. Both the analog and digital methods share the following disadvantages:

a) Noise amplification, especially when the scene reflection is weak.

b) Un-natural appearance of highlighted pixels because its relation with neighboring pixels is altered in a non-physical way. This phenomenon results from the fact that saturated pixel color is not physically related with the scene reflection and therefore, correction can not remove the color of the pixel nor to maintain its natural appearance as in the original un-corrected image.

The digital implementation of the VKCR have the further disadvantage of introducing numerical gaps in the image histogram, implying loss of color resolution.

A simpler method for color correction can be considered when we observe that cameramen use color filters in front of their camera lenses to compensate for the illumination color changes. The placement of a color filter, having a complementary color to the illumination color is an optical division by the illumination color. Therefore, it is suggested that an efficient optical compensation can be realized by inserting a filter, in front of the camera lens, with spectral characteristic described by \( F_{\lambda} \), which can be determined from the relation

\[ I_{i} = \frac{I_{i}}{\lambda} \]

Referring to Figure 1, the compensation filter, \( F_{\lambda} \), should have the complementary color to the illumination color as described by the virtual filter \( F_{\lambda} \). The optical compensation method does not suffer the problems of both the analog and the digital methods. It should be noted that changing the filters to balance image colors is an existing human art experienced by photographers, but the novelty here is to control the filter according to a signal from the illumination color sensor.

3. System Design

3.1. Nose surface design

The spatial nose introduced in [1] has the following limitations:

1) The nose length is 16 cm (big).
2) Nose image occupies 25% of the image area.
3) The nose profile needs to be carefully machined.

The nose image relatively big area was needed to allow sufficient spatial resolution for representing illumination color variations in the main image. It was then realized that the nose image area could be reduced by employing the constraint of spatial uniformity of the illumination color in the scene. Figure 3 shows the steps to reach the final design of a short global nose. In Fig.3.a, the spatial nose appeared as a rectangle with sharp edge separating the nose image from the main image. When the nose edge depth was reduced, as shown in Fig.3.b, the nose image decreased, but its edge was severely blurred and the area to the right of the nose edge was not clearly focused. The rectangular nose is not efficient in preserving the clear focused main image area. The nose surface is then rotated to appear as a triangle in the image corner, as shown in Fig.3.c. The final nose affects the main image area in a very small region. Only a small part of the nose image area is used to calculate the illumination color which can be mapped to a control area in the main image as seen in Figure 4. The global nose is short and its surface is flat and easy to install and adjust. The new global nose need not be carefully machined. The small nose also eliminated the need for exact pixel-by-pixel mapping and its installation and adjustment is simple.
3.2. Digital Color Correction Algorithm

The corrected pixel color may be saturated from computational aspects of the correction algorithm and can be avoided by careful choice of the scaling factor $SF$. When the pixel is saturated in the original image itself, special treatment is needed, otherwise the appearance of such pixels in the corrected image is unnatural. One color channel, two or three color channels may be saturated in the original caption.

The real scene reflection in the saturated pixel color channel can not be physically recovered. Highlights are generally small parts in the image area, but if they become major part of the image, the solution is to reduce the iris opening, since true color can not be recovered in the image for saturated pixels.

The three cases are treated here as follows:

a) When one color is saturated, the third one is estimated by extrapolation employing a spectral smoothness constraint. The common case is that one extreme end of the visible spectrum [blue or red] may be saturated. The saturated color is estimated by assuming a linear or curved relation between the color integrals and wavelength.

b) When two colors are saturated, it becomes difficult to recover the two colors. Therefore, the pixel is called a corrupted one and the decision is that it should lose its color and be sacrificed to look white. The histogram of the unsaturated color of such pixels is evaluated so that the value of $SF$ is chosen so that minimum of this histogram is mapped to the brightest value.

c) When the three colors of a pixel are saturated in the original image, it is mapped to the white color [gray scale]. The intensity of the white color of the highlighted pixels appear as a very bright white while its surround is relatively darker, the highlights will look unnatural and seen as a scratch. Therefore $SF$ is set to expand the color histograms so that highlights appear natural.

In the experiments, it was observed that the human eye appreciates the natural appearance of highlights in the image.

4. Experiments

The camera used is a 3 CCD Sony XC-001 color camera module which is calibrated to produce linear responses of the CCD sensor element with respect to scene irradiance. The spectral response curves of the camera are relatively disjoint. The lens is 8mm fixed focal length and the automatic gain control option is not used and the gamma correction is also not utilized. The camera image is digitized by a frame grabber attached to a PCI slot of the host computer. The digital color correction program is written by the author in C-code and run through Visual C/C++ programming environment. The global nose is mounted in front of the camera over an adjustment mechanism. The mechanism allows for manual adjustment of the nose in front of the camera lens. The mechanism consists of an x-y table mounted over a rotating table. The nose surface is flat and its width is 5 mm. The nose is made from a steel rod and its surface is pasted with an aluminum foil. A small size protection hood was mounted.

The experimental program focuses primarily on the real imaging situations and outdoor imaging in particular. Extensive experiments were carried out and the digital correction results are quite satisfactory, since the image color are restored and look as if imaged in white light. The highlighted regions are not yellow in the output image but its white appearance is preserved.
The nose system performance may be compared with two previous methods, the Scene White Patch, SWP, and the Retinex method. The SWP is a good reference but it is inapplicable in real imaging situation. Therefore, only the comparison with the Retinex method will be made, since it is the only applicable method in the scenes.

A statistical measure was devised which shows the quality of color maintenance, which is based on the volume of color gamut. Good correction expands the color gamut of the image colors in the RGB color space. Change of the light source vector has the effect of compressing the color gamut and skewing it in the direction of light source color vector [3]. Therefore, the area of color gamut in the two-dimensional chromaticity space (r,g) is calculated and the ratio of this area after and before correction is evaluated and considered as a reliable metric for expressing the correction quality. Increased area ratio means expansion of color gamut.

The problem of the Retinex is its excessive reliance on the satisfaction of the GWA. When the Retinex is used to correct scenes with large areas of single color, it fails to correct such areas and the output image looks gray. Figure 6 shows the area ratio for three sample outdoor images, where symbol R refers to the Retinex and symbol N refers to the Nose. The ratio for the nose-corrected images is higher than the ratio for the Retinex corrected images. The graph shows clearly the observation of color correction quality and confirms that the nose method correction maintains the colors while the Retinex causes coloration loss in the corrected images and thus causes significant reduction in the color gamut.

The issue of color correction implementation discussed in subsections (2-3) and (3-2) of this article was also experimented. The modified digital color correction algorithm works successfully to render natural images regarding highlight appearance. However, it is clear that digital correction produces gaps in the corrected image histogram and thus causes reduction of color resolution and this phenomenon gets more severe when the original images are taken in a relatively dark lighting. Optical correction was experimented using complementary color filter which preserves the color resolution. The implementation of optical color compensation in an automatic way can be achieved when the illumination colors can be categorized in a number of colors, therefore, a number of gelatin or glass filters, having the complementary color to that of the set of illumination colors, can be selected in advance and stored permanently inside the camera.

The selection of filters is made upon the signal of the illumination color (separately fed to the camera). One or more filters may be selected to become active at one time by cascading them in the optical path of incident rays.

5. Conclusion

In this paper, the nose-camera imaging system is significantly improved. The new system is capable of stabilizing color appearance in the image when the illumination color is changed. Employing the assumption of a spatially uniform illumination color in the scene, both the nose size and nose image area were reduced to suit practical applications. The results of the experiments can be summarized as follows:

1- The system works and provides clear and stable color images for outdoor scenes.

2- The saturated pixels were handled in such a way that they look natural in the corrected images.

3- The nose system outperformed the Retinex method regarding the accuracy of color recovery.

The proposed system combines the advantages of having a practical size, high speed, and robust color correction performance.
References


Biography

Mohamed Abdellatif received his PhD in intelligence technology from Okayama University, Japan in 1998. Upon completion of his degree, he has been appointed as the director of the Mechatronics laboratory in Ain Shams University in Egypt. He holds three international patents in nose-camera color imaging systems. His current interests now include color vision research and development of autonomous vehicle perception devices. He is a member of the Egyptian Engineer Syndicate and the IEEE computer society.