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Intrinsic Color Acquisition By Active Color Lighting

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Abstract

Object's color information is not invariant information but is affected by surrounding environments including ambient lights. In this paper, we propsed a new method to acquire intrinsic color information without being affected by ambient lights. In our method, we use a projector as a light source, then capture multiple images with varied color of illumination. Combining these multiple images, we eliminate the influence of ambient lights with avoiding the dark current problem of CCD camera. We show how we treat with other problems caused by specular reflection and interreflection. In the experiments, we show that using our method we can acquire intrinsic diffuse color information without being affeted by ambient lights.

1 Introduction

Color information could be a important visual cue in computer vision (CV). However, visible color information is not invariant information but is affected by surrounding environments. Human visual system has a sophisticated function to cancel these disturbances caused by surrounding environments, and perceive object color as invariant information. This function is called *color constancy.*

There have been many methods proposed to emulate human color constancy by computer or machine[4]. To this date too many papers have been published for machine color constancy to cite in this paper. We only cite [2] as a further reference guide for interested readers. Passive approaches for machine color constancy is inherently under-constrained problem. So in order to get solutions, we often need some additional constraints or prior statistical information. Regardless of many efforts, it is reported that machine color constancy algorithms are not good enough for color-based object recognition[2].

Our approach in this paper is different from machine color constancy approach. In our method we recover intrinsic color information by actively controlling illumination. In many CV fields, it is known that some inherently ill-posed problems become tractable by actively controlling imaging environments. Such problems include depth estimation, shape estimation and so on. We believe that intrinsic color acquisition problem has similar nature.

In the CV applications where color information is crucially important, it is usually to acquire images in highly controlled environments. In these environments, either ambient lights are shut out or we are enabled to use a light intense enough to ignore leaking ambient lights. Although these environments are highly controlled, at the same time being highly restrictive. Constructing highly controlled environments is not always feasible when applying to cultural heritages, human faces, in-plant fruits and so on.

In this paper, we proposed a new method to acquire intrinsic color information. Our proposed method uses a projector as a flexible light source, then captures multiple images with actively varying color of illumination. Combining these multiple images, we eliminate the influence of ambient lights with avoiding the dark current problem of CCD camera. For constructing a practical system, we encounter with some other problems caused by specular reflection and interreflection. We describe how we deal with these problems. Although our method needs to capture multiple images with varied color of illumination, our method is less restrictive than the method with constructing highly controlled environments, Because our method allows ambient lights leek in while our method does not need to use so intense a light. This facility of our method enables the wider applications of color image processing.

2 Properties of Diffuse Color

In this paper, we will use the following notations.

λ Wave length

$S(\lambda)$ The diffuse surface spectral reflectance

$R(\lambda)$ The wavelength sensitivity of the visual sensor

For the present, $E(\lambda)$ means the spectral power distribution of all the lights irradiating the object surface. We will give a more detailed definition later. A sensor quantum catch

$$I = \int E(\lambda)S(\lambda)R(\lambda)d\lambda, \quad (1)$$

where the integral is taken over the entire spectrum.

Ordinarily, we use three kind of sensors, $R_c(\lambda)$, $c = R, G, B$, for color acquisition as following.

$$I_c = \int E(\lambda)S(\lambda)R_c(\lambda)d\lambda \quad c = R, G, B \quad (2)$$

By using *the tristimulus* I_R, I_G and I_B, color information is recognized.

In [8], Shiobara *etal.* indicate that color information can be recognized by varying color of illumination. Their method makes use of the fact that $E(\lambda)$ and $R(\lambda)$ form a symmetrical relationship centered on $S(\lambda)$ in Eq.(1). However it is easily deduced that the varying-illumination-color method is vulnerable against *ambient lights.* Because ambient lights change the color of illumination irradiates object surfaces.

The method using the tristimulus I_R, I_G and I_B is also vulunerable against ambient lights. Eq.(1) and (2) do not include ambient lights (or *global illumination* in Computer Graphics). In actual environment, ambient lights should be taken into consideration. We denote the spectral power distribution of ambient lights as $E_a(\lambda)$. As ambient lights are separated off, hereafter the remaining $E(\lambda)$ means the spectral power distribution of a light, which is directly illuminating the object surface and can be controlled by the photographer. We call such a light as *a camera light*. Using $E_a(\lambda)$ and $E(\lambda)$ as a camera light, Eq.(1) in actual environment becomes

$$I' = \int E_a(\lambda)S(\lambda)R(\lambda)d\lambda + \int E(\lambda)S(\lambda)R(\lambda)d\lambda. \quad (3)$$

Here, we assume that interreflection can be ignored. We will later discuss about the validity of this assumption.

Our aim in this paper is to acquire the information about $S(\lambda)$ without being affected by $E_a(\lambda)$. We call such information as intrinsic color information. As we mentioned, we usually use three kind of sensor, which means varying $R(\lambda)$ to acquire color information. Both varying $R(\lambda)$ and varying $E(\lambda)$ affect I'. However, from Eq.(3) varying $R(\lambda)$ with fixed $E(\lambda)$ affects I' depending on both $S(\lambda)$ and $E_a(\lambda)$. Meanwhile, varying $E(\lambda)$ with fixed $R(\lambda)$ affects I' depending only on $S(\lambda)$. This means that in order to acquire intrinsic color information without being affected by ambient lights ($E_a(\lambda)$), varying $E(\lambda)$ is more reasonable than varying $R(\lambda)$.

3 Color Acquisition by Active Lighting

In this section, we implement a practical system to acquire intrinsic color information of objects using the fact mentioned in the previous section.

For implementation, we have to take characteristics of available cameras and lights into consideration. The simplest way to vary lighting is to turn a light on and off. Although this method is simple, it suffers the dark current problem of CCD camera when ambient lights ($E_a(\lambda)$) are much darker than a camera light ($E(\lambda)$). Dark current means the relatively small electric current that flows through CCD devices when no photons are entering. Due to this dark current problem, readout values of CCD become inaccurate when we can not get enough photons. These inaccurate values may lead to inaccurate estimates of color information. Although this dark current problem may be overcome by using Debevec's high-dynamic-range image acquisition method[1], in which multiple images are captured with varied exposure setting, this method is no longer a "simple" method.

In stead of using the light-on-off method, we propose in this paper a new method in which the spectral power distribution of a camera light is varied, that means color of a camera light is varied. When we use a projector as a camera light, we can easily vary color of the light without altering other settings. In this case, Eq.(3) becomes

$$J_c = \int E_a(\lambda)S(\lambda)R(\lambda)d\lambda + \int E_c(\lambda)S(\lambda)R(\lambda)d\lambda. \quad (4)$$

In Eq.(4), the camera light is expressed as $E_c(\lambda)$ where *c* represents the color of the camera light. In this study, we vary c as W(white),M(magenta),C(cyan) and Y(yellow), then capture four images by a monochrome CCD camera. In additive color process, the equation $W = R+G+B, M = R+B, C = B+G$ and $Y = G+R$ are held. So the following equation are easily derived.

$$J_W - J_C = \int E_R(\lambda)S(\lambda)R(\lambda)d\lambda \quad (5)$$

$$J_W - J_Y = \int E_B(\lambda)S(\lambda)R(\lambda)d\lambda \quad (6)$$

$$J_W - J_M = \int E_G(\lambda)S(\lambda)R(\lambda)d\lambda \quad (7)$$

Eqs.(5) $\sim$ (7) and Eq.(2) are symmetric each other. Notice that right hands of Eqs.(5) $\sim$ (7) contain no ambient lights while $E(\lambda)$ in Eq.(2) may contain ambient lights. This means that by using Eqs.(5) $\sim$ (7) we can acquire intrinsic color information of object without being affected by ambient lights. In addition, when we use a projector as a camera light, the energy difference of the W,C,Y and M lights are so small that our method do not suffer the dark current problem of CCD camera.

Actually, the right hands of Eqs.(5) $\sim$ (7) contain the ambiguity caused by $R(\lambda)$. This ambiguity can be eliminated by the calibration in which some known colored surfaces are used. However, in the following experiments, we omit this calibration step, because our aim is to show that we can eliminate the influence of ambient lights.

4 Artifices for some Problems

There are several assumptions that our method depends on. First, our method assumes that the ambient light ($E_a(\lambda)$) does not change in the period of image acquisition. In addition, our method assumes that the object does not move. These assumptions restrict the usage of our method. There is another assumtion our method depends on; that Eq.(1) or Eq.(3) is held and valid. Some optical phenomenon violate these assumptions. *Specular reflection* and *interreflection* are representatives of these optical phenomena. In this section, we describe artifices to treat with these optical phenomena.

4.1 Specular Reflection

In [7], Shafer indicated that the observed color of specular highlights is expressed by the linear sum of the color of the light and that of the diffuse reflection component (*Dichromatic Reflection Model*). This model states that the color of specular highlights does not follow Eq.(1).

Fortunately, when objects are dielectric materials, such as plastic, fruits and so on, specular reflection component of the camera light can be removed optically[5]. In our system, two polarization filters are placed in front of both the camera and the camera light. When the relative polarization angle of these filters is adjusted, we can remove specular reflection optically.

4.2 Interreflection

Interreflection[6] (or *mutual illumination*) caused by a camera light may alter the ambient light ($E_a(\lambda)$) of the scene, which violates our assumption that ambient light ($E_a(\lambda)$) does not change in the period of image acquisition. Our approach is to keep the influence of interreflection as small as possible.

When a surrounding scene is directly illuminated by the camera light, the change of ambient lights ($E_a(\lambda)$) becomes no negligible. So in order to keep the effect of interreflection to be small, we need to narrow the beam of the camera light so that only the object is directly illuminated. In this case, as the surrounding scene is indirectly illuminated by the interreflection of a camera light, the change of ambient lights ($E_a(\lambda)$) is thought to be small.

As we mentioned, we use a projector as a camera light. A projector as a camera light is flexible[3] so that we can control the area to be illuminated. When we conform the axis of the camera to the axis of the projector, the correspondence between the image area where the target object occupies and the area where the projector is illuminating is straightforward. This axis-conformation can be realized using a beam splitter (or a half-mirror). In this way, we can exclusively illuminate the object area by the camera light without the need of acquiring 3D information.

5 Experiments

We applied our method to the real scene which consists of four wooden block pigs whose painted colors are red, yellow, green and blue (Fig.1). These wooden pigs have no prominent specular reflection. Except for four wooden block pigs, the scene consists of a white desk and a white wall. As the white desk surface is the only prominent source of interreflection, we deemed the influence of interreflection is negligible, because the color of interreflection from the white desk surface is the same color of the camera light. For all of these reasons, we did not use the artifices described in Sec.4. We used a half-mirror, in addition to a projector (SANYO Pro-X) as a camera light and a camera (Sony XCD-X700 monochrome camera). Using a half-mirror, objects are illuminated from the same direction of the camera.

Figure 1: The scene used in the experiments

The objects are placed at a distance of about 2m from both the camera and the camera light. As ambient lights, we used four kinds of lights; a 100W incandescent lamp, a LED Red spot light, a LED Green spot light and a LED Blue spot light. According to the manufacturer, the brightness of these LED lights are as following. The LED Red light; 200 lux at 2000mm distance. The LED Green light; 300 lux at 2000mm distance. The LED Blue light; 100 lux at 2000mm distance.

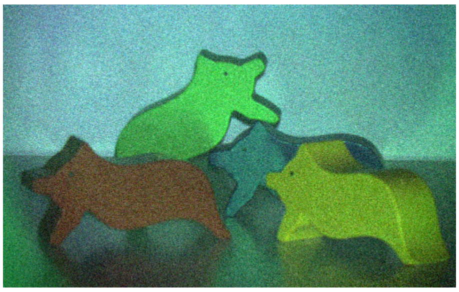
Figure 2: Objects illuminated by both green ambient lights and cyan camera light

The incandescent lamp is placed in nearly same direction of the camera and at a distance of about 1.5m from the objects. The LED lights are placed at a distance of about 3m from the objects, and about 45 degree yawed to the direction of the camera. Under these ambient lights environments, we captured four images with varied color of the camera light; white, magenta, yellow and cyan. Fig.2 shows the one segment of the experiments where the objects are illuminated by both the green LED ambients light and the cyan camera light. Although the LED lights are not so bright as the incandescent lamp, we see that the LED green light is not so dark as compared with the cyan-colored camera light. To the captured four images we applied the left-hand calculations of Eqs.(5) $\sim$ (7), then we got RGB values.

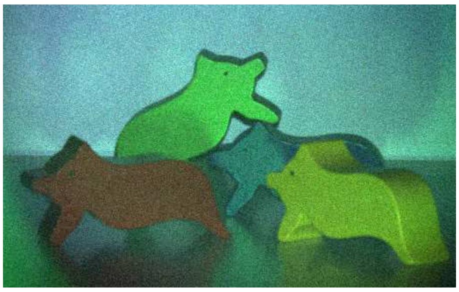
Table 1: Averages of the caluculated RGB values

RED Region			
ambient lights	R value	G value	B value
incandescent lamp	13.8	11.3	7.3
LED Red light	12.8	11.4	7.9
LED Green light	13.4	12.0	7.7
LED Blue light	13.3	11.8	7.5
GREEN Region			
ambient lights	R value	G value	B value
incandescent lamp	9.8	24.9	11.6
LED Red light	8.7	23.8	10.2
LED Green light	8.9	24.0	10.4
LED Blue light	9.3	24.1	10.7
BLUE Region			
ambient lights	R value	G value	B value
incandescent lamp	7.5	18.2	15.9
LED Red light	6.5	18.3	15.4
LED Green light	6.7	18.3	15.5
LED Blue light	6.9	18.3	15.6
YELLOW Region			
ambient lights	R value	G value	B value
Incandescent lamp	16.0	23.5	6.1
LED Red light	14.8	24.4	6.9
LED Green light	15.7	25.1	6.4
LED Blue light	16.1	24.9	6.4

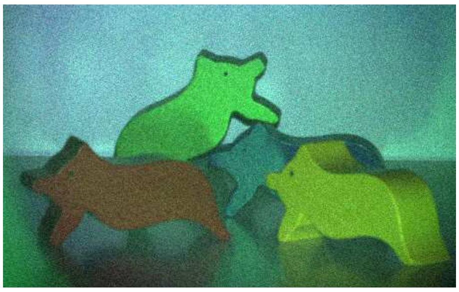
Table 1 shows the average values of the pixels which belong to RED Region, GREEN Region, BLUE Region and YELLOW Region. We manually selected these four regions inside four wooden block pigs. Despite the difference of ambient lights, we see that the averaged R,G and B values are almost the same in each colored region. We calculated the RGB vector angles of all possible combinations in each colored region. Out of 24 possible combinations, the maximum value was 3.25 degree. The average value was as small as 1.48 degree. Considering the quantization noise which is caused due to the RGB small values, these results are considered to be quite well.



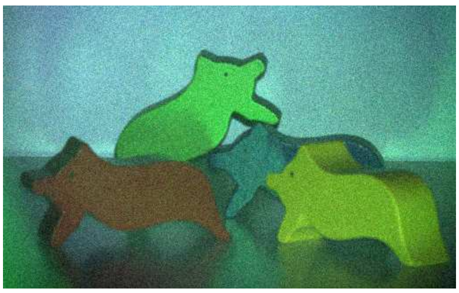
(a) Incandescent lamp



(b) LED Red light



(c) LED Green light



(d) LED Blue light

Figure 3: Acquired intrinsic color images

We visually certify these results. We map these calculated RGB values into RGB color images, then display them. As Table 1 shows that the calculated pixel values are so low that plainly converted RGB color images will have no visual effects. So we magnified these values by seven times in a single uniform way, then converted into RGB color images. Fig.3 shows the converted color images. Note that we did not adjust color balance, so the white wall does not look white. Although these RGB color images are quite noisy, we see that these images look almost the same. From these results, we see that the influences of ambient lights were eliminated, and we successfully captured intrinsic color images without being affected by ambient lights.

6 Conclusions

In this paper, we proposed a new method to acquire intrinsic color information without being affected by ambient lights. In our method, we use a projector as a flexible light source, by which we vary color of illumination. Combining multiple images captured with varied color of illumination, we eliminate the influence of ambient lights with avoiding the dark current problem of CCD camera. A projector as the light source is so flexible that we can narrow the beam of the light, which enable us to directly illuminate only the object surface. In this way, we can avoid the interreflection problem. In the experiments, we showed that we can acquire intrinsic diffuse color information without being affected by ambient lights.

Although our method needs to capture multiple images with varied color of illumination, our method is less restrictive than the method using highly controlled lighting environments. So we expect that our method widens the applicability of the color image processing where accurate color estimation is needed.

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