Mutual Illumination and Color Constancy

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ABSTRACT

Mutual illumination is the phenomenon in which the light successively bounces on different surfaces of a scene before hitting the retina (or acquisition sensors), so that the color stimulus that hits the sensor is not only a function of the physical properties of the surface from which it is coming, but also of the neighboring surfaces. Since this mutual information has been shown to improve classical computational color constancy algorithms, in this study, we propose to check if it can also improve human color constancy. Our idea is to ask observers to look at colored papers (through one aperture) under unknown light conditions and to name the color of this paper using the elementary color naming method. Two geometric conditions were tested and compared: flattened paper and folded paper where mutual reflections appear between the two paper sides (self-reflections). The experimental results clearly show that the observers do much better in estimating the color of the papers with mutual reflections than without. This is an experimental proof that mutual illumination helps in human color constancy.

KEYWORDS: Mutual illumination, Color constancy, Psycho-visual experiment

INTRODUCTION

The spectral power distributions of the lightings that illuminate a scene strongly influence the light signals received by the retina from the reflecting objects. However, the human visual system is able to "balance" the illumination color and to perceive the color of each object as if it was illuminated by a white illumination, a perceptual phenomenon called color constancy. Computational color constancy algorithms intend to imitate this phenomenon in order to remove the impact of the illumination color in digital color pictures, so that the obtained object colors characterize the object surfaces and not the acquisition conditions. These intrinsic object color properties are used in many computer vision applications such as tracking, object recognition, image registration, etc. Some studies have shown that mutual illumination provides useful information for computational color constancy [1]. Mutual illumination (or inter-reflection) is the phenomenon in which light rays bounce successively on different surfaces of a concave scene before hitting the acquisition sensors (or the observer eyes). In this case, color stimulus which hits the sensor is not only a function the surface from which it is coming, but also of the neighboring surfaces. This mutual information has been shown to improve classical computational color constancy algorithms. In this study, we propose to check if it can also improve human color constancy.

THEORY ABOUT MUTUAL ILLUMINATION

Total irradiance, E, of a concave surface is the sum of direct irradiance, received form the light source, and indirect irradiance, after a collection of light rays reflected once, twice, three times and so on, from each point to each other point of the surface. For Lambertian surfaces, irradiance in a given point P_1, received after one bounce of light from all other points P_i of the surface with respective reflectances r_i, can be related to the irradiance received form direct light, E_0, as followed [2]:

$$E_1(P_1) = \int_{P_i \in S} r_i \frac{E_0}{\pi} K(P_i, P_1)\, dP_i , \qquad (1)$$

where dP_i denotes an infinitesimal area around the point P_i and the function $K(P_i, P_j)$, called geometrical kernel, is defined for every pair of points P_i and P_j and depends on the Euclidean distance between the point as well as on their surface normal [2]. Similarly, taking into consideration the rays reflected twice on every pair of points with reflectances r_i and r_j, we obtain:

$$E_2(P_1) = \int_{P_j \in S} \int_{P_i \in S} r_i r_j \frac{E_0}{\pi^2} K(P_j, P_i) K(P_i, P_1)\, dP_i dP_i ,$$

and for the light rays reflected three times, by following the same reasoning line, we have:

$$E_3(P_1) = \int_{P_k \in S} \int_{P_j \in S} \int_{P_i \in S} r_i r_j r_k \frac{E_0}{\pi^3} K(P_k, P_j) K(P_j, P_i) K(P_i, P_1)\, dP_k dP_i dP_j ,$$

and so on.

We can see, in the above equations, that the resulting irradiance is a multiplication between the input reflectances. Consequently, the resulted colors are not linearly related to the color of the same surface without mutual reflections. This is interesting because it means that mutual illuminations are adding supplementary information that can improve some classical problems, such as (human or computational) color constancy.

Many methods have been proposed in the literature in order to handle inter-reflections in computer vision applications. Some approaches focused on removing the effect of inter-reflections [2-7], whereas others used it as extra information that may help in solving other problems such as light SPD estimation or surface spectral reflectance estimation [1,8,9]. The work of Funt et al. clearly shows how mutual reflections can help in the computational color constancy problem [1].

On the other side, inter-reflections were also used for psycho-visual experiments. Harding et al. [10] tested shape perception in scenes that contained illumination gradient such as shading and inter-reflections. They show that observers are able to use these gradients to make consistent shape judgements. Likewise, in [11], Bloj et al. demonstrated that the human visual system incorporates knowledge of mutual illumination at an early stage in color perception.

In this paper, we propose to test if humans are better in color constancy when looking at flattened surfaces (without mutual reflections) than when looking at folded surfaces (with mutual reflections). The experiment is explained in the next section.

EXPERIMENT

Our idea is to ask observers to look at colored papers (through one aperture) under unknown light conditions and to name the color of this paper using the elementary color naming method. Two geometric conditions were tested and compared: flattened paper, where no mutual reflections can be observed, and folded paper, where mutual reflections appear between the two paper sides (self-reflections). For the psycho-visual experiment, 16 observers were asked to name the colors of 4 different colored papers: red, green, yellow and blue under 3 different colored lightings: red, green and blue. The observers stated the amount in percentage of blackness, whiteness and chromaticness of the colored paper they perceived. Subsequently, if they perceived chromaticness in the it, hue: red-yellow or yellow-green or green-blue or blue-red, of colored paper must be approximated in percentage. The hue angle was calculated according to percentage of red, green, yellow and blue. Subsequently, xy coordinates were computed according to hue angle and percentage of chromaticness.

The physical configuration of experimental setup is illustrated in Figure 1. We have created a box in which we placed some (flattened or folded) colored papers. This box was in a dark room and we put a light source with colored filters just above the box, so that the observer could not see this light source but only the reflection of this source on the paper, through an aperture. The observer was 80 cm from the aperture and was asking to name the color of the paper he was seeing. If the observing conditions allow color constancy, the observer should name the color as the current paper color without impact from the colored light source.

RESULTS AND DISCUSSION

Figure 2 is showing the results obtained from our psycho-visual experiment. Since we have used 4 different colored surfaces, we provide 4 different plots. The elementary color naming method provides a chromaticity point for each tested stimulus. Since we have 16 observers, we have 16 points for each tested stimulus. Instead of displaying 16 points, we prefer to show ellipses that represent the distribution of these 16 color naming. The dashed ellipses represent the color naming results for the flattened papers (without inter-reflections) and the solid ellipses represent the results for the folded papers (with inter-reflections). On each plot, the black asterisk is the chromaticity point of the considered paper under white light. This is the point where all the color naming should be in case of perfect color constancy. The green, blue and red stars represent the chromaticity of the light source used to construct the green, blue and red ellipses, respectively.

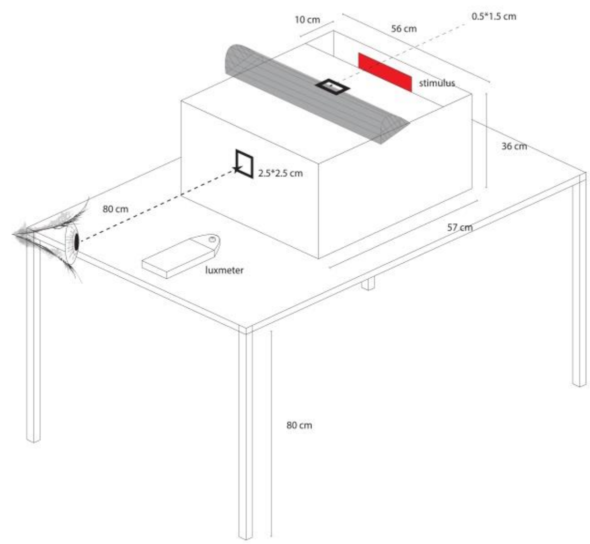

Figure 1. Experimental configuration.

The experimental results clearly show that the observers are much better in estimating the color of the papers with mutual reflections than without. Indeed, most of time, the solid ellipses are closer to the black asterisk than the dashed ellipses. This is an experimental proof that mutual illumination helps for human color constancy.

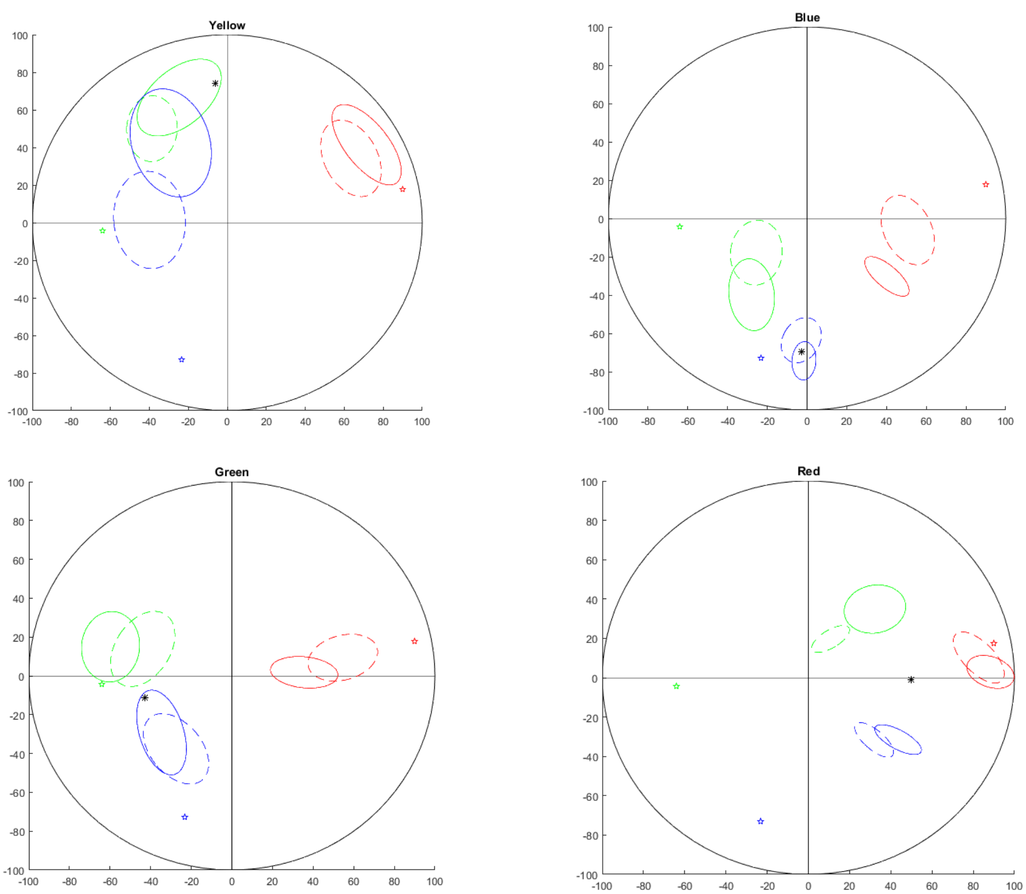

Figure 2: Chromatic shift due to mutual illumination, from dashed to solid ellipses. See text for details.

CONCLUSION

In this paper, we have tested the color constancy perceived by human visual system when looking at flattened and folded colored papers under colored illumination. The results clearly show that the mutual reflections that occur in case of folded colored papers help to maintain color constancy, compared to the case without mutual reflections when the observers are seeing only flattened colored papers. Future works would consist of integrating such mutual reflections in order to help solving some critical problems such as computational color constancy or spectral reflectance estimation from RGB data.

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