Displays 35 (2014) 6–17

Contents lists available at ScienceDirect

Displays

journal homepage: www.elsevier.com/locate/displa

Color constancy for visual compensation of projector displayed image

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ARTICLE INFO

Article history:
Received 24 July 2013
Received in revised form 13 October 2013
Accepted 25 October 2013
Available online 1 November 2013

Keywords:
Computational color constancy
Image display
Projector
Viewing conditions
Projection screen
Von Kries

ABSTRACT

The color of a displayed image by a projector can be distorted by features of the device, the ambient light, the projection screen, and also the observer. This has raised the need to correct the image during the display to eliminate these effects and to ensure a constancy of the color appearances. In this paper, we propose models for controlling the appearance of the displayed image. We argue that depending on the target application, the computational color constancy can be specified at different steps of the formation scheme of the sensed image by a human. Based on that observation and the image formation models, we reformulate the problem of the color constancy and we show that the resulting transformations cannot be explained by von Kries theory. Two compensation algorithms are deduced. The first allows preserving the appearance of the original image, and it can be used for the constancy of the acquired image whatever the environment conditions. The second algorithm allows to simulate appearances of a sensed image in a specific conditions. It can be used for the compensation of the screen reflectance or to create special effects or the camouflage. In addition, we propose a complementary operation for the contrast compensation which is derived from the Weber's law. Experimental results show the merits of the proposed models and algorithms.

1. Introduction

Projectors become more proliferate and integrated in multiple areas. However, the quality of the displayed image can be adversely affected by the device used and the real viewing conditions. The displayed image under bright conditions may appear with washed colors and attenuated contrast. The appearance of an image captured under illuminant D65, will be also affected when it is perceived under another illuminant. The mismatch between the display environmental illuminant and the illuminant of the image acquisition may influence the perception of the image. In addition, the displayed image onto an ordinary surface will be affected, where its appearance will be modulated by the color and the geometry of the surface. The projector features could also affect the quality of the displayed image. The transfer function, and the embedded color signal processing influence the color generation. Moreover, the sensed image quality depends on the spectral abilities of the human visual system (HVS). As it is characterized by its nonlinear response to the intensity of the ambient light [1], this means that the perceived contrast of the image will be necessarily affected.

The use of a projector anywhere is a challenging task that requires controlling the appearance of the sensed image. Indeed, we need for some applications, an image appears for a normal viewer the same regardless of the display conditions. Similarity is desired between the image as it was created and its sensed version. For other applications, we prefer to control the display conditions in order to cancel out or to create some distortion effects such as in cases of visual effects or digital art.

Controlling effects of the viewing conditions can be done through two approaches: material and computational. The materiel approach consists in monitoring the projector settings according to the environmental features, such as the ambient light which can be measured by a photometer [2,3]. Some specific screens are designed in the manner that the ambient light will be reflected out of the observer direction [4], the area where viewers can be placed needs to be specified during the installation phase. In the materiel based approach, the concern is the measure of the light present in the environment rather than its perceptual impact [2], where the compensation is considered as a global phenomena. However, the local compensation of the ambient light intensity, the light color, and the projection screen are not available. This is the basis of the computational approach [5–11]. Our work falls within the last approach, in which we propose the transformation of the image according to the viewing conditions before sending it to the projector. The viewing conditions can be recovered through acquiring images of the projection screen. Indeed, the modified image displayed by the projector can create the desired appearance by interacting with the environmental parameters.

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http://dx.doi.org/10.1016/j.displa.2013.10.003

This paper is organized as it follows. In the next section, we present the problem statement. After, in Section 3 we detail our proposed models of the compensation of viewing conditions. Then, Section 4 provides details on the method used in parameters estimation. In Section 5, the experimental results are presented. Finally, we conclude this paper with a summary of the work.

2. Problem statement

As it is indicated above, several factors influence the appearance of the displayed image, among them, there is the projection surface and the surrounding lights. Consequently, the projected image will undergo two transformations noted S and L, respectively. Furthermore, the effect generated by a projector can be represented by a transformation D. Moreover, we note the effects due to HVS by a transformation O. Indeed, for an original image I that will be displayed by a projector, its corresponding image sensed by a viewer noted I_O, can be written as:

$$I_O = O(L(S(D(I)))). \quad (1)$$

We note that the limitations of the HVS in terms of contrast perception and ambient conditions should be considered. Therefore, a correlation can be deduced between the intensity of the surrounding light, the response of the human eye and the perceived contrast. This can be expressed by a model which will be described later. Indeed, controlling the desired appearance of an image requires to be aware of all effects of viewing conditions that adversely influence the appearance.

In this paper, we address the control of the viewing conditions for projector-based display system through the color constancy concept. The goal is to make the displayed images invariant to some factors depending on the use purpose. In the literature, the von Kries theory based computational color constancy has been widely studied for a chromatic adaptation and for white balancing [12]. But, to the best of our knowledge, it was never explicitly broached for projector-based display systems. For images displayed by a projector and viewed by a normal viewer, we show that the color constancy concept can be extended and used in different ways. As it is shown in Fig. 1, we categorize applications into two possible scenarios; (1) preservation of the image appearance and (2) simulation of the image appearance as it will be detailed later. By the first scenario, we propose to preserve the appearance of the displayed image sensed by a viewer to appear similar to the original image as it was created. Consequently, the sensed image should be invariant to the response of the projector, the ambient light, the projection screen and also the response of the viewer. For example, we can perceive a sunset image as it was captured by a camera independently of how or where it is displayed. By the second scenario, we were interested to make two images viewed under two different conditions appear identical. This scenario was particularly designed in the perspective of simulation, whereby, we can simulate other effects that can be produced under specific environments of visualization. For example, this can be used for visual arts and camouflage, where we can create some artistic effects. Therefore, the illuminant of the display environment and the target illuminant are introduced by the proposed model for this scenario, similar to the current and the target screen reflectance. In addition, aiming to produce the desired visual contrast of the displayed image under bright conditions, the Weber law is used for the image contrast enhancement according to the intensity of the surrounding light.

In the field of the environmental conditions compensation, there exist in literature two families of methods: the heuristic methods and the image formation based methods. These methods were designed principally in order to reduce some effects of the environmental conditions, where the above transformations have been studied. For the heuristic methods, works [10,9,13] proposed frameworks considering the preceding transformations separately. In [11], the method was based on power law function to map the input range to the output range, considering the contrast enhancement. We note that the compensation algorithms based on heuristic arguments are different from ours. For image formation based methods, all are designed to deal with the color constancy between the original image and the image captured by a camera (first scenario). The transformation S is considered in [6,5], and L in [5]. They [6,5] proposed a set of parameters higher to a matrix 3×3 of color mixing for every pixel of the image. Authors in [7] proposed a method based on one color mixing matrix for the entire image. However, in a dark environment, this matrix is eliminated in [14] by using a color filter for both the projector and the camera. Note that the second scenario described above is not tackled before. Unlike these approaches, the one we propose deals with both scenarios in addition to the use of one global estimated matrix 3×3 for all images. More precisely, Table 1 summarized the similarities and differences between different approaches including ours. We can resume contributions of the paper as the followings. (1) We reformulate and exploit the computational color constancy concept for projector systems which can be seen as a fundamental founding; (2) we propose models for both scenarios that are appearance preserving and appearance simulation; and (3) we take into account four transformations.

3. Proposed model

In this section, we provide details of each model corresponding to two scenarios described above, by modeling the spectral response of the projector, the screen reflectance, the surrounding lights and the spectral response of the viewer. Transformations could be linear [5,6,8,10] or nonlinear [11]. In this work, we consider all transformations as linear.

To this end, we need to further develop the model of the sensed image formation in Eq. (1). Then, we will explain how we can employ the color constancy between the sensed image and the original image (scenario 1), as well as two sensed images under two different environments (scenario 2). After that, as the HVS is affected by the surrounding light, it becomes harder to see details of the displayed image in bright conditions. Consequently, the visual contrast of the sensed image will be attenuated. To overcome this limitation, we propose a method to enhance the contrast of the displayed image according to the surrounding light intensity. Note that the projector has three-color channels R, G and B.

The projector input pixel I_k of the k^{th} band of an image is modulated by its spectral response $t_k(\lambda)$, which includes all spectral responses of the projector optical components such as the lens and the physical processing operations. The k^{th} light band $E_k(\lambda)$ generated by the projector through its lens is given by Eq. (2) [5,6], where λ represents the wavelength of the visible spectrum. A linear transformation D is considered, since the DLP projectors used are assumed digital linear systems [7,15].

$$E_k(\lambda) = I_k(\lambda)t_k(\lambda). \quad (2)$$

Note that the colored point of the projection screen has a spectral reflectance represented by $\rho_{kc}(\lambda)$, where k in $\{R, G, B\}$, it is considered as the color channel of the screen. Let $l_a(\lambda)$ be the spectral distribution of the actual surrounding illumination. The human eye receives a mixture of lights that are reflected by the projection screen. These lights come from the projector and the surrounding illumination. Yet the radiance R_k of the scene point in the direction of the viewer's eye is written as it follows:

$$R_k(\lambda) = (I_k(\lambda)t_k(\lambda) + l_{ak}(\lambda))\rho_{kc}(\lambda). \quad (3)$$