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Separating corneal reflections for illumination estimation ☆

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Abstract

Eyes exhibit a significant amount of specular reflection and could be used to derive a detailed estimate of frontal illumination. To determine a more accurate estimate of illumination from the environment, iris color and texture should be separated from the specularly reflected light, since they may substantially obscure reflections of the scene. In this paper, a method is presented for separating corneal reflections in an image of human irises. We consider the iris texture to be diffuse, and the observed image color is produced as the sum of the diffuse component and the specular component. A number of methods have been proposed to separate or decompose these two components. To our knowledge, all methods that use a single input image demonstrated success in only limited cases, such as for uniform colored lighting and simple object textures. They are not applicable to irises, which exhibit intricate textures and complicated reflections of the environment. To make this problem feasible, our method capitalizes on physical characteristics of human irises to obtain an illumination estimate that encompasses the prominent light contributors in the scene. Results of the algorithm are presented for eyes of different colors, including light colored eyes for which reflection separation is necessary to determine a valid illumination estimate.

Keywords: Separting reflection; Human iris; Computer vision

1. Introduction

The difference in behavior between diffuse and specular reflections poses a problem in many computer vision algorithms. Purely diffuse reflections ordinarily exhibit little variation in color from different viewing directions, while specular reflections tend to change significantly in both color and position. The mixture of the two components always results in the inaccuracies of computer vision algorithms, such as stereo [1], image segmentation [9] and object identification [20,22]. Changes in illumination can induce significant variations in the appearance of an object. So, many efforts have been made for the separation of these two components. It is an essential subject in the field of computer vision.

On the other hand, estimating the light conditions in a scene has been intensively investigated for many years, especially in computer graphics. When doing relighting or casting shadows, estimate the illumination environment is the first step [4,5]. However, recovering scene illumination from a given image has proven to be a challenging problem and has only been addressed in rather limited situations. Because of the direct effects of illumination on shading, shadows and specular reflections, people examined these appearance features to infer lighting information. Shading-based methods for single image input generally solve for light intensities from a discrete set of directions by analyzing brightness values according to a given reflectance model [11,42]. Techniques that utilize shadows attached to an object seek to identify pixels that lie along the shadow boundaries, since they indicate the existence of light from a direction perpendicular to its surface normal [37,41]. For cast shadows that fall onto the object's surroundings, brightness values within the shadows have been used in solving a system of equations for light source intensities at sampled directions [28–30]. While these shading and shadow-based methods have produced accurate estimation results, certain assumptions reduce their applicability. Object textures need to be known or uniform, since texture color variations modulate brightness values. The geometry of the object also must be known to analyze image

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intensities or shadow formations. Moreover, methods based on specular reflections are also dependent on known object attributes and similar to shading and shadow-based techniques, they generally handle this problem by introducing a reference object of known shape and reflectance into the scene. Most commonly, the object used is a mirrored sphere [4], on which a detailed image of the illumination environment can be seen. There are, however, many instances where it is not possible to estimate or measure the lighting of the scene. We cannot measure the illumination using a probe when the image has already been captured. In short, obtaining the lighting of a scene from a single image remains a difficult and open problem. It turns out, however, that this problem can be solved when we have a face (hence an eye) in the image, which is often the case with images and videos.

Eyes exhibit a significant amount of specular reflection, and have a geometry that is fairly constant from person to person [8]. From eyes, a detailed estimate of frontal illumination could potentially be derived, and could provide much utility in the analysis of faces, which substantially change in appearance with respect to lighting conditions [22]. A large amount of research has been done on various aspects of the eye in different fields. In computer graphics and human–computer interaction, research has mainly focused on using gaze direction as an interface [12,14], identifying people from their iris textures [3,2] and from photorealistic synthesis of appearance of an eye [18].

Tsumura et al. [36] first made the interesting observation that an image can potentially be used as a "mirrored ball" that conveys information about light sources in the environment. He modeled the eyeball as a sphere and used the highlights on it to estimate the direction of three point light sources at known locations with respect to the camera. Nishino and Nayar [24,25] used eyes for imaging the surrounding environment. From eye images, they demonstrated various uses of the acquired reflections of the environment, such as computing retinal images, binocular stereo and face relighting. Furthermore, Lam and Baranoski [16] give the light transport model for the human iris and simulate the light scattering and absorption processes occurring within the iridal tissues.

In these methods, the color and texture of the eyes are not separated from the reflected environment. Although the subtle texture of dark colored eyes may not significantly distort the appearance of the environment, irises of light color such as blue or green may substantially obscure reflections of the scene. To determine a more accurate estimate of illumination from the environment, iris colors and textures should be separated from the specularly reflected light, and it is this separation in iris images that is the focus of our work.

1.1. Related work

There exists much previous work on separating specular reflections from images. Most separation methods utilize color images and the dichromatic reflectance model proposed by Shafer [32]. This model suggests that, in the case of dielectrics (non-conductors), diffuse and specular components have different spectral distributions. The spectral distribution of the specular component is similar to that of illumination, while the distribution of the diffuse component is a product of illumination and surface pigments. The color of a given pixel can be viewed in RGB color space as a linear combination of a vector for object reflectance color and a vector for illumination color. All image points on a uniform-colored surface lie on a dichromatic plane which is spanned by these two vectors.

Rich literature exists on separation using the dichromatic model. Klinker et al. [15] identify clusters of specular colors in an RGB histogram and project their points onto clusters of diffuse colors to remove specular reflections. Tong and Funt [35] suggest computing the dichromatic planes of several uniform-reflectance regions and finding the line most parallel to these planes. Because of problems that arise from histogram clutter or plane, these approaches are generally effective only for textureless surfaces and a constant illuminant color. Sato and Ikeuchi [27] also employed the dichromatic model for separation by analyzing color signatures produced from many images taken under a moving light source. Lin et al. [21] utilized the epipolar constraint to detect the pixels with specular components and used other views to compute their diffuse components. These approaches have produced good separation results, but they need multiple images input.

Besides color, polarization has also been an effective cue for specular separation. Wolff and Boult [39] proposed a polarization-based method for separating reflection components in regions of constant Fresnel reflectance. Nayar et al. [23] used polarization in conjunction with color information from a single view to separate reflection components, where a constraint is provided by neighboring pixels with similar diffuse color. They identified specular pixels and the illumination color vector in RGB space by utilizing intensity variation produced by a polarizing filter. However, utilizing such an additional filter is impractical in some circumstances.

Recent methods have been proposed for handling surfaces with simple texture [34,33]. Tan et al. [33] detected color discontinuities on chromaticity difference and iteratively compare the intensity logarithmic differentiation with specular-free image. They resolved the separation without explicit color segmentation using local operation. Tan and Lin [34] used TV inpainting technique to apply the highlight removal and the estimation of diffuse color. These approaches demonstrate good performance in their papers, but the limitation is that they require specular reflections to be formed from a single illumination color. Because of these limitations, these previous techniques are not suitable for extracting multi-colored reflections of an illumination environment from a highly textured iris. A general separation method based on minimizing the amount of edges and corners in two decomposed images