Estimation of the Size and Location of Multiple Area Light Sources

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Abstract

Most illuminant estimation algorithms worked on point light sources or directional light sources. Little attempt has been made, however, to estimate area light sources. In this paper, we present a novel scheme that estimates the size and location of multiple area light sources using a set of stereo images of a sphere with a shiny surface. The parameters of the area light source are estimated by a novel algorithm which minimizes the matching error between the corresponding specular patches. Experiments on real images show that our method is accurate and robust in estimating the parameters of the area light source.

1. Introduction

Most illuminant estimation techniques worked on directional light sources or point light sources. For example, lots of schemes have been proposed in the context of shape from shading [1] to calibrate a single directional light source. Many attempts have been made recently to detect multiple directional light sources by exploring different cues, e.g. shadows cast by an object with known shape[6], specular properties of a shiny surface[4], or critical points on a Lambertian sphere[5][7].

All the above works assume directional light source, which is a reasonable approximation to real scene illuminants provided that the distances between the light sources and the illuminated objects are large enough compared against the sizes of both the light sources and the illuminated objects. This approximation may not be valid in some cases, especially when light sources are within a limited range, e.g. a small room. The point source model could be used in this situation such as in [3] [8], by introducing another parameter, i.e. the distance of the light source. In real applications, the situation could be more complex, having extended or large panel lights within a limited distance. Apparently, it is more appropriate to model it as the area light source, which has been widely used in computer graphics with the advantages of more realistic rendering over using the directional source or the point source. However, area light source calibration is more challenging due to the fact that more parameters have to be estimated. To the authors' knowledge, there still remains a void in the computer vision literature in explicitly estimating the size and location of the area light source. In this paper, as an effort on this complicated problem, a novel scheme is designed to estimate the area light sources.

The rest of this paper is organized as follows. In section 2, an appropriate model is built for the area light source which facilitates the estimation process. The whole estimation framework is outlined in section 3. In section 4, we discuss the estimation algorithm in detail, and in section 5, we present experimental results on real images.

2 Area Light Source Modeling

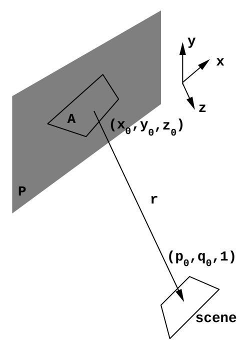

Figure 1: area light source modelling

Inspired by the 4D lighting hypercube model proposed in [2], we model the area light source as follows. As shown in figure 1, put a plane P between the light source and the scene, a source ray r piercing the plane through a point (x_0, y_0, z_0) in direction $(p_0, q_0, 1)$ is parameterized as $(x_0, y_0, z_0, p_0, q_0)$. We choose the plane P to be one of the tangent planes of the light source oriented in such a way that it maximizes the alignment of its normal with all the rays emitting from the light source to the scene. Since the plane is extremely close to the light source, we make an approximation that the light source lies on the plane. Therefore, a ray $(x_0, y_0, z_0, p_0, q_0)$ can be described as originated from point (x_0, y_0, z_0), and emitting in direction $(p_0, q_0, 1)$. Based on this approximation, a light source can be defined in terms of the set of rays emitting into the scene:

$$M_{src} = \{(x, y, z, p, q) : (x, y, z) \in A, (p, q) \in Q\}, \quad (1)$$

where A represents the source region on the plane P, and $Q \in \Re^2$ is the set of the directions of all the rays emitting from the light source. According to this definition, the estimation process includes estimating the source region A and detecting the directional range Q. Usually, the space between the light source and the scene is a free space (i.e. nothing in between blocks the rays), and the source rays emit in all directions. We simplify the estimation process by making an approximation that the direction range Q spans the whole direction space: $Q = \Re^2$, and put our efforts mainly on estimating the source region A.

3 Framework Outline

In our framework, images are taken by a pair of well calibrated stereo cameras with known focal length and baseline. A sphere with a shiny surface is used as the calibration object. The whole framework is outlined in figure 2.

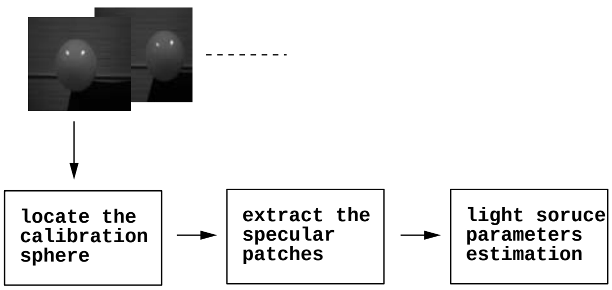

Figure 2: Framework outline

First, a set of stereo image paris are taken with the calibration sphere placed in different locations of the scene. Then the size and the locations of the sphere are detected using each image pair. Since the sphere has a shiny surface, the light sources in the scene will create sharpe specular patches on the surface of the sphere. After extracting the specular patches from the images, we can retrace the rays from the camera center through the specular patches, which should be retraced back to the light sources. Based on this observation, we proposed an algorithm which effectively locates the area light sources.

4 Area Light Source Estimation

4.1 Locate the Calibration Sphere

In order to calibrate the illuminants accurately, the parameters of the calibration sphere (i.e. the radius and the center location of the sphere) should be estimated accurately because the estimation errors of the sphere will be doubly propagated to the estimations of the illuminants. (see [3]) In [4], authors found that the lines passing through the camera projection center and the boundary points of the sphere image form a tangent cone to the sphere. Since a pair of stereo images are taken, two tangent cones can be determined and the sphere can be located by intersecting the two cones. Based on this idea, a non-linear minimization algorithm was proposed in [4] to locate the calibration sphere. In our framework, we use the same method as proposed in [4] because it requires rather relax experimental setup and the calibration results are robust and satisfactory.

4.2 Specular patch extraction

Various algorithms have been proposed to extract the specular patches in the sphere image. In [3], a simple thresholding algorithm was used to segment the specular intensities out. In [4], the intensities of the corresponding pixels between the stereo image pair were compared to distinguish the diffuse intensities and specular intensities. In [8], authors located the specular patches by ellipse fitting. In our framework, we noticed that the specular reflection will cause a sudden increase in intensity, so it is easy to detect the boundaries of the specular patches by a general edge detector. Then, the specular patches are extracted by grouping the pixels inside the boundaries. To increase the robustness of our algorithm, we used a calibration sphere with uniform reflectance surface which avoids the false edges caused by the reflectance variation. Also, the average intensities of the patches are checked to ensure that the specular patches have relatively higher intensities. Experiments on real images are shown in figure (4). We can see in the second row that the specular patches are extracted successfully.

4.3 Estimation of The Area Light Sources

Lots of light source calibration algorithms utilize the specular reflection property to locate the light sources, such as [3][8]. They first establish the correspondences between the specular patches, then the 3D locations of the light sources are triangulated by a simple geometric calculation. In their works, the point light source with limited distance is assumed, therefore, one pixel is chosen out of the specular patch to represent the reflection point of the point light source. Usually, the centroid point of the specular patch is chosen as a reasonable one.

The situation of the area light source calibration is more complex. As described in section 2, the area light source is modelled as a set of rays originated from a region A instead of one point in the 3-D space. Therefore, a set of locations instead of one should be estimated. Recall from section 2, the source region A was defined as a region on the plane P. So, if the plane P is determined, the source region A can be estimated by a simple ray retracing process (see figure 3). Now, the question is how to estimate the plane P. In section 2, the plane P was defined as one of the tangent planes of the light source oriented in such a way that its normal aligns with the average of the directions of all the source rays. In our method, the average of the directions of all the retraced rays is used as an initial guess of the plane normal. Therefore, the distance d between the plane P and the specular patch on the sphere surface should be estimated in order to get the initial estimation of the plane P (see figure 3).

To estimate the distance d, the correspondences of the specular patches between images should be established first.

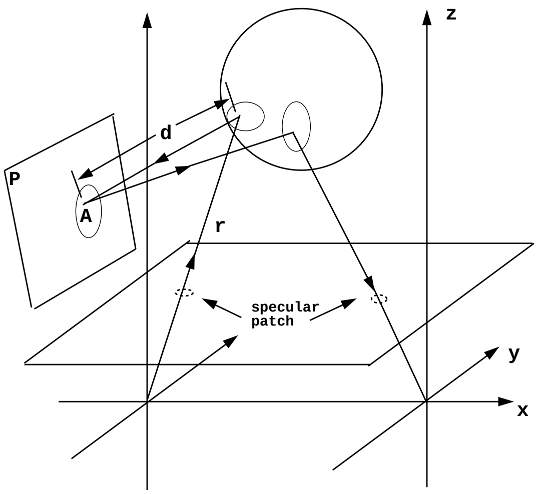

Figure 3: Specular imaging geometry

Suppose n images are taken, and one of which is chosen as the refrence image. Similar to [4], we can group the specular patches by their relative locations to determine which patches result from the same illuminant. The specular patches are sorted first by their horizontal coordinates and then by their vertical coordinates for each image, which effectively groups the corresponding specular patches together. Suppose a specular patch S_{re} in the reference image corresponds to a specular patch S_j in the $j^{'}th$ image. Given the distance d, we can determine the plane P using the initial guess of its nomal. Then, the source region A can be determined by the ray retracing process: For a pixel $p_{rei} \in S_{re}$, a ray originated from camera center is retraced through it; once it hits the surface of the sphere, the ray is further reflected back towards the light source and intersects with the plane P. The intersection point should be the location of the light source. Repeat the process for all the pixels inside the specular patch S_{re}, we can determine the location of the source region A. To check the validness of the location, we reverse the retrace process to create a specular patch in the $j^{'}th$ image, which should coincide with S_j if the distance d is correct. The whole process described above can be formulated as a mapping function: $\Xi(d, S_{re}, j) = S_{mj}$, i.e, given distance d, the specular patch S_{re} in the reference image is mapped to the patch S_{mj} in the $j^{'}th$ image. Define a function $\chi(S_{mj}, S_j)$ to measure the matching error between the mapped patch S_{mj} and the specular patch S_j:

$$\chi(S_{mj}, S_j) = \|C(S_{mj}) - C(S_j)\|^2 - \lambda \frac{S_{mj} \cap S_j}{S_{mj} \cup S_j} \quad (2)$$

Where $C(\bullet)$ is a funtion which calculate the centroid point of a patch. The function χ includes two items: the first item measures the distance of the two patches, while the second item measures the overlapping of the two patches. Considering all the corresponding specular patches, we define a matching error function with respect to the distance d:

$$\Psi(d) = \sum_j \chi(\Xi(d, S_{re}, j), S_j) \quad (3)$$

The optimal estimation of distance d can be achieved by minimizing the matching error function.

Now, we have an initial estimation of the plane P. The result can be further refined by defining the matching error function with respect to the plane $P(a, b, c) = \{(x, y, z) : ax + by + cz = 1\}$:

$$\Psi^{'}(a, b, c) = \sum_j \chi(\Xi^{'}(P(a, b, c), S_{re}, j), S_j) \quad (4)$$

Finally, minimizing the matching error funciton with the initial estimation gives us the optimal estimation of the plane P. Once the plane P is determined, the area light source region A can be easily estimated by the ray retracing process described above.

5 Experiment results

In order to test and evaluate our framework in practice, we have performed experiments on real images. The images were acquired with Bumblebee camera: a 2-eye stereo camera designed by PointGrey Inc. This device provides us rectified images and camera calibration parameters. Figure (4) shows an example of the estimation process. The first row shows a image pair with the calibration sphere illuminated by two ceiling fluoresent lamps. After locating the calibration sphere, the specular patches are extracted from the images as shown in the second row. Then, the area matching algorithm described in the last section is used to estimate the light source. The last row shows two matching results. The left column shows the case when the estimation of the plane P is not optimal. We can see that the mapped patch is not wholly overlapped with the original specular patch. Minimizing the matching error gives us the correct estimation of the plane P, and the best match will be acheived as shown in the right column.

Sixty light sources located in different locations in total were used to create different kinds of images. The locations and the sizes of the light sources were manually measured as ground truth. Here, we use the location of the centroid point of the area source region in order to simplify the measuring process. As shown in Figure 5, the average error of the estimated locations is about 4% and the average error of the estimated sizes is about 6% when the distance of the light source is within $2m$.

As an application to Augmented Reality, our light source calibration algorithm can be used to render virtual objects into a real scene. Figure (6a) shows a real scene, our goal is to render a synthetic teapot on the top of the table in the scene. We first placed the calibration sphere on the table to calibrate the light sources, then the estimated light source is used in the rendering process. We have used the Blue Moon Rendering Tools (BMRT) to render the scenes containing

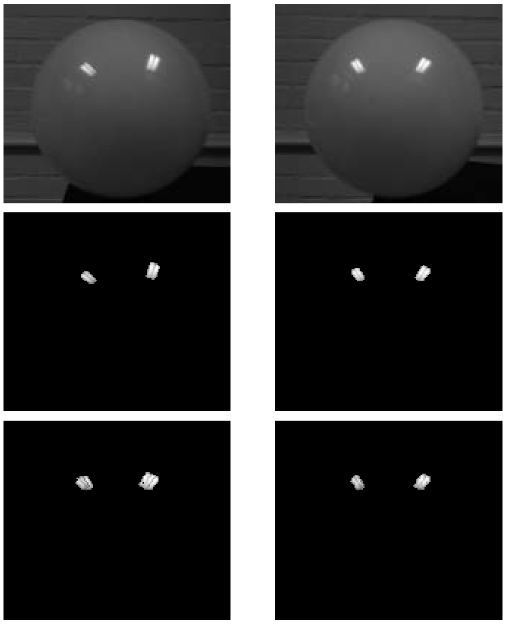

Figure 4: Light source calibration using real images

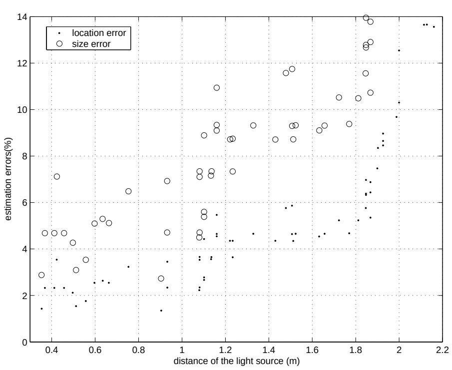

Figure 5: Error estimation for real image

a mixture of real and artificial objects. Figure (6b) shows the rendering result. We can see that the shading and the shadow of the synthetic teapot are correctly rendered. Since the area light source is used in the rendering, some effects such as blur shadows can be rendered as shown in figure (6b), which is impossible if point light sources or directional light sources are used.

6 Conclusion and future work

This paper presents a novel scheme for calibrating the area light sources from a set of stereo image pairs of a sphere. The parameters of the area light sources are estimated by a novel algorithm which matches the corresponding specular patches between the images. Our experiment results show both of efficiency and accuracy of our algorithm.

Our work can be further extended in two directions. First, instead of using a sphere as the calibration magic object, more general objects could be used. However, reconstructing the shape of a general object in the presence of specular intensity is a tough problem by itself which needs more efforts. Another direction of pursuit involves the calibration of the intensities of light sources, which is of equal importance as the light source locations in Augmented Reality.

(a) (b)

Figure 6: (a) original scene; (b) a synthetic teapot is rendered into the scene

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