Image-based Dynamic Lighting Control

Jun SHINGU †, Yoshinari KAMEDA ‡, Masayuki MUKUNOKI ‡,
Koh KAKUSHO ‡, Michihiko MINOH ‡ and Katsuo IKEDA ††

† *Graduate School of Informatics, Kyoto University,*
‡ *Center for Information and Multimedia Studies, Kyoto University*
†† *Osaka Institute of Technology*
† *shingu@mm.media.kyoto-u.ac.jp,*
‡ *{kameda,mukunoki,kakusho,minoh}@media.kyoto-u.ac.jp*
†† *ikeda@is.oit.ac.jp*

Abstract

In taking an image, it is important to shoot target objects under an appropriate lighting. If the lighting is inappropriate, the target objects become too dark or too bright in the taken images and the details of the objects cannot be seen. We propose a method to control lighting automatically to keep the image brightness of the target objects within the dynamic range of the camera. In our method, a background image under arbitrary lighting is synthesized from a set of images obtained under different lighting. The generated background image is used to extract the image regions that correspond to the target object. The intensity of the lights is dynamically controlled so that the target objects are shot under an appropriate lighting by observing the brightness of the extracted foreground pixels. Because this method controls the intensity of the lights based only on the brightness of the taken images, it is needless to recover 3D information and reflectance properties of any objects in the room. We present some experimental results to show the effectiveness of our method.

1. Introduction

When we take video images, it is important to keep the image brightness of the foreground objects, which are target objects, within dynamic range of a camera. When the image brightness of the foreground objects is not taken within the dynamic range, the brightness of the foreground is saturated, which causes white out or black out in the foreground of the resultant image.

Usually, intelligent CCD cameras control its exposure automatically so that the brightness of images is within the dynamic range. Since the exposure cannot change the image brightness of local areas in the image, the image brightness of all pixels in the image is changed as the exposure changes. When the foreground objects are too bright or too dark, it is impossible to keep the brightness of foreground image region within the dynamic range, even if the camera controls its exposure.

In this paper, we propose to a method to control lighting dynamically. Our goal is to keep the brightness of the foreground image region within the dynamic range by changing the intensity of lights in the scene.

To accomplish this goal, we have to be able to control the image brightness of the foreground objects by changing the intensity of the lights. The image brightness of the foreground image region depends on distribution of lights around the foreground objects, plus on shape and reflectance properties of foreground objects. Directly estimating these, image brightness of the foreground image region can be estimated, hence the image brightness of the foreground objects can be controlled. The distribution of lights around the foreground objects can be estimated [3,4,5], but estimating the shape and reflectance properties of the foreground objects is difficult and time-consuming process. Therefore, we control lighting without estimating the three-dimensional information and the reflectance properties of each object in the scene explicitly. Instead, we extract the foreground image region and control lighting by observing the brightness of the extracted foreground region.

In order to extract the foreground image region, the background subtraction method is often used. However, this method cannot extract the foreground correctly, when a background image is changed against the lighting. Ivanov et al.[2] proposed a lighting independent background subtraction method by using a stereo camera, but it does not work well if background objects have specular reflection. In our work, we assume that there are no uncontrollable lights in the room, and we can obtain the intensity of each light in the room. We introduce a method that can synthesize a background image under any intensity of lights, even if there are specular reflections and interreflections in the scene. When the intensity of the lights is changed dynamically as we control, the foreground image region is extracted by the conventional background subtraction method using the background image that is synthesized as the intensity of the lights changes.

By observing the image brightness of the extracted foreground image region, we can know whether the image brightness of the region is within the dynamic range or not. We control the lights so that the foreground image region is within the dynamic range, by verifying the result from the image brightness of the foreground region.

The rest of this paper is organized as follows. In the next section we describe the environment that we assume in this paper. Section 3 introduces how to extract the foreground image region, and section 4 presents the dynamic lighting control method. In section 5, we present the result of our method and conclude in Section 6.

2. Assumptions for the Environment

Our method is based upon the following assumptions:

- **Light**: Position and orientation are fixed. The intensity is controlled by *light control parameter* (LCP) (e.g. voltage). All the light sources in our environment are these controllable lights.
- **Camera**: Position and orientation are fixed. Intrinsic parameters of camera, such as the iris, exposure time and focal length etc. are fixed.
- **Background object**: Shape and reflectance properties, which include both diffuse and specular reflections, are fixed.

These assumptions are easily satisfied in the environment of an indoor room.

3. Synthesizing Background Images and Foreground Extraction

3.1. Photometric Model of Image Shooting

In order to discuss how to synthesize background image, we need to model a relation of image brightness of each pixel with LCPs of lights.

First, we construct a model of a light. Based upon the assumptions in section 2, the intensity of light i is controlled by LCP v_i. The intensity I_i is described as follows:

$$I_i = a_i h_i(v_i)\,, \qquad (1)$$

where h_i is a response function of light i. It is a normalized function ranging from 0 to 1. The coefficient a_i is the scaling factor.

The scene radiance $L_{j(p)}$ of object surface $j(p)$ that corresponds to pixel p in the image defined as follows:

$$L_{j(p)} = \sum_i (b_{ij(p)} I_i)\ , \qquad (2)$$

where $b_{ij(p)}$ is a coefficient, which depends on the shape and the reflectance properties of object surface $j(p)$, the position of the camera and light i. $b_{ij(p)}$ includes both diffuse and specular reflectance properties. Equation (2) is based on an idea that the scene radiance of an object surface can be described as a linear operation of the intensity of all lights in the environment. Therefore, $L_{j(p)}$ is correctly calculated even in an environment where there are specular reflections and interreflections.

Image brightness Z_p is derived from the scene radiance $L_{j(p)}$ as follows [1,7]:

$$g(Z_p) = \ln(c_p L_{j(p)})\ , \qquad (3)$$

where c_p is a camera parameter that depends on intrinsic parameters of the camera, in particular, iris, exposure time, focul length and position of pixel p in the image. g is a response function of camera.

Equations (1),(2),(3) lead a formula for the image brightness Z_p of pixel p with the LCP v_i of light i.

$$Z_p = \begin{cases} Z^{MIN} & (\textit{under dynamic range}) \\ g^{-1}(\ln(\sum_i w_{ip} h_i(v_i))) & (\textit{within dynamic range}) \\ Z^{MAX} & (\textit{over dynamic range}) \end{cases} \qquad (4)$$

where $w_{ip} = a_i\, b_{ij(p)}\, c_p$, which depends on position of the camera and the lights, shape and reflectance properties of the object surface and intrinsic parameters of the camera.

3.2. Synthesizing Background Images under Various Lightings

In this section, we describe the method how to synthesize background images by using images that are taken under different lighting.

Because we assume that the position of the camera and the lights, the shape and the reflectance properties of the surface of the background objects and the intrinsic parameters of the camera are all fixed, coefficient w_{ip} in equation (4) is fixed. By estimating response function h_i of light i, response function g of the camera and coefficient w_{ip} beforehand, image brightness of pixel p in a background image is determined from the LCP v_i of light i. This means background image under any LCP of light i is synthesized.

The response function h_i of light i, the response function g of the camera and coefficient w_{ip} are able to be estimated from images that are taken under different lightings and with different exposure times of the camera.

First, response function *g* of the camera is estimated by sampling image brightness of pixels in a set of still images that are taken in different exposure times of the camera. In the set of images of different exposure times, every pixel is supposed to be within the dynamic range at least once. Thus, the value of $\sum_i w_{ip} h_i(v_i)$ in equation (4) is derived from the estimated response function *g* and image brightness Z_p [1].

Second, response function h_i of light *i* is estimated. When only light *i'* is turned on, $\sum_i w_{ip} h_i(v_i)$ in equation (4) becomes to $w_{i'p} h_{i'}(v_{i'})$.
When positions of the camera and light *i'*, as well as shape and reflectance properties of the object surface, are fixed, $w_{i'p}$ is fixed. By estimating $w_{i'p} h_{i'}(v_{i'})$ at every $v_{i'}$, the response function $h_{i'}$ is estimated.

Finally, because the functions h_i and *g* are estimated, by using equation (4), coefficient w_{ip} is simply estimated from a set of images that are obtained by taking background objects under different LCP v_i and with different exposure times of the camera.

3.3. Foreground Extraction

Using the synthesized background image, foreground image regions are extracted by the conventional background subtraction method. First, image brightness Z_p is obtained by taking the scene where both foreground and background objects exist. Second, background image brightness Z_p^{back} under current LCPs is synthesized by the procedure described above. Finally, based on the difference in the image brightness between the shot image and the synthesized background image, we classify each pixel of the shot image into the following 3 categories:

(i) $Z_p \neq Z_p^{back}$

The pixels in this category correspond to the foreground or background shaded by the foreground objects.

(ii) $Z_p = Z_p^{back}$

(a) $Z_p = Z^{MIN}$ or $Z_p = Z^{MAX}$

As we explained at equation (3), the image brightness of pixels in this category is not within the dynamic range. Because Z_p does not reflect the scene radiance accurately, we cannot determine whether the pixels correspond to foreground or background objects.

(b) Otherwise

The pixels in this category correspond to the background.

We extract pixels that are classified into category (i) and (ii)-(a) as *extracted foreground pixels* and control lights by observing their image brightness. The *extracted foreground pixels* exactly include a foreground image region. When our lighting control succeeds in keeping the image brightness of the *extracted foreground pixels* within the dynamic range, our goal to keep the brightness of the foreground image region that corresponds to the foreground objects within the dynamic range is accomplished. Therefore, we control lights by observing image brightness of the *extracted foreground pixels.*

4. Dynamic Lighting Control

Based on the foreground extraction that is described in section 3, we propose a dynamic lighting control method by observing image brightness of the *extracted foreground pixels*. The basic idea is to repeat evaluating the image brightness of the *extracted foreground pixels* and changing the intensity of the lights based on the results of the evaluation.

In this section, we present how to evaluate the image brightness of the *extracted foreground pixels* and the algorithm of our dynamic lighting control method.

4.1. Evaluation of the Image Brightness

Since our goal is to keep the image brightness of the *extracted foreground pixels* within the dynamic range, we need to evaluate whether it is within the dynamic range or not. When the image brightness of the *extracted foreground pixels* is out of the dynamic range, lighting needs to be modified.

Equation (4) shows that when brightness Z_p of pixel *p* is out of dynamic range, it becomes Z^{MIN} or Z^{MAX} . By counting the number of pixels whose image brightness is Z^{MIN} or Z^{MAX}, we evaluate the image brightness of a set of pixels as follows:

- Under the dynamic range [U]:
  $N_{under} > \tau$ and $N_{under} > N_{over}$
- Within the dynamic range [W]:
  $N_{under} < \tau$ and $N_{over} < \tau$
- Over the dynamic range [O]:
  $N_{over} > \tau$ and $N_{over} > N_{under}$

Where N_{under} and N_{over} are numbers of pixels whose image brightness is Z^{MIN} and Z^{MAX} respectively and τ is a threshold. In case [U], the intensity of lights must be increased, whereas in case [O], the intensity of lights must be decreased. Otherwise, that of lights needs not to be changed.

4.2. Algorithm of Dynamic Lighting Control

Using the foreground extraction method proposed in section 3 and evaluation of the foreground image region defined at section 4.1, the algorithm of our dynamic control method is described as follows:

(Step1) Construct a light-table and initialize all lights in the light-table as “unselected”.

(Step2) If there is no light that is marked “unselected”, End.

(Step3) Extract the *extracted foreground pixels*

(Step4) Evaluate the image brightness of the *extracted foreground pixels*. Based on the result of the evaluation, one of the following step is taken:

- (a) [W]: The goal is achieved. End.
- (b) [U]: Go to (Step5).
- (c) [O]: Go to (Step5) (since the following steps in this case are almost the same as in case [U], we omit explaining)

(Step5) Select a light *i’* whose intensity is darkest and marked as “unselected” in the light-table. Mark light i’ in the light-table “selected”.

(Step6) Change the intensity of light *i’* into its maximum.

(Step7) In the *extracted foreground pixels*, mark the pixels whose image brightness increase by the change of the intensity of light *i’*. We call these pixels as *effective foreground pixels* of light *i’*.

(Step8) Evaluate the image brightness of the *effective foreground pixels*. Based on the result of the evaluation, one of the following step is taken:

- (a) [W]: The intensity of light *i’* is appropriate.
- (b) [U]: Because intensity of light *i’* is maximum, it is impossible to make the *effective foreground pixels* of light *i’* in brighter by light *i’*.
- (c) [O]: Because there is appropriate intensity of light *i’* between the maximum value and the original intensity, the appropriate intensity is searched by using binary search, repeating changing the intensity and evaluating the *effective foreground pixels* of light *i’* .

(Step9) Back to (Step2).

5. Experiment

We evaluated the validity of our foreground extraction and dynamic lighting control methods by experiments in a real environment.

We used three halogen lights (LPL, 500W). These lights can be controlled by a dimmer (T5, Effectarts) and their LCPs are $v_i = \{0, 1, \ldots 127\}$. We set the environment to satisfy the assumptions in section 2. The image size shot by the camera (SONY, EVI-D30) is 512x440 pixels. When a pixel becomes under or over the dynamic range, the image brightness of the pixel is forced to be $Z^{MIN}=15$ or $Z^{MAX}=252$. Figure 1 shows the environment.

Figure 1: Environment for the experiments

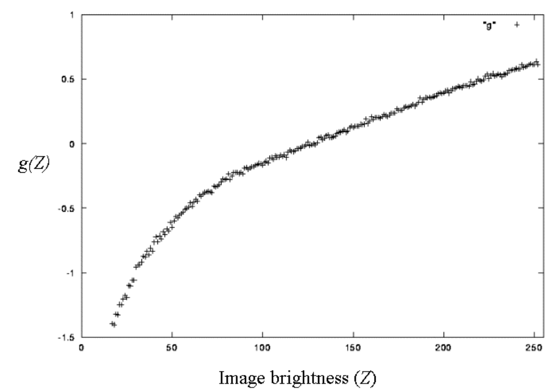


Figure 2: The response function *g* of the camera.

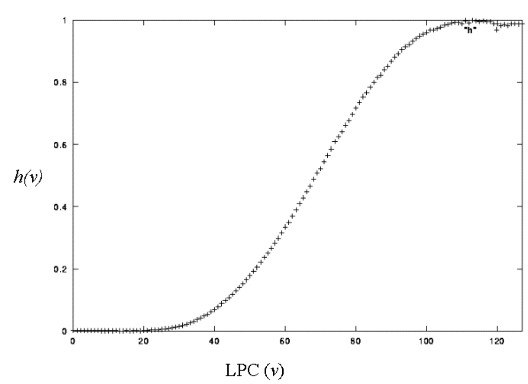
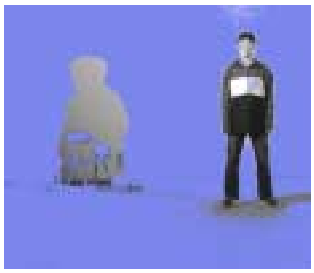


Figure 3: The response function *h* of the halogen light

(a) (b)



(c)

Figure 4: (a) An image taken by setting the LCPs of the Halogen light 1, 2, 3 to be 60, 20 and 90, respectively, (b) synthesized background image for the lighting of (a), (c) *extracted foreground pixels* by subtracting (b) from (a).

(a) (b)

(c)

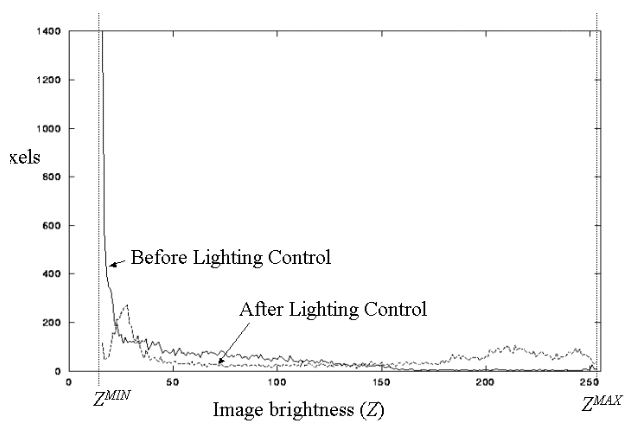
Figure 5: (a) An image taken by setting the LCPs of the Halogen light 1, 2, 3 to be 20, 100 and 70, respectively, (b) synthesized background image for the lighting of (a), (c) *extracted foreground pixels* by subtracting (b) from (a).

5.1. Background Synthesis and Foreground Extraction

Figure 2 and 3 show the response function g of the camera and the response function h_i of the halogen light. These functions are estimated as is explained in section 3.2.

Figure 4(a) is an image that includes a foreground object (human) and background objects. The background image synthesized for the same lighting condition is shown in Figure 4(b). Although there are specular reflections on the ball that is one of the background objects, and interreflections are supposed to exist in this environment, the background image is accurately synthesized. By using the synthesized background image, the *extracted foreground pixels* (the foreground region with the shaded background region) is successfully extracted as shown in Figure 4(c). Under a different lighting, the *extracted foreground pixels* are also accurately extracted as shown in Figure 5.

(a) (b)



(c)

Figure 6: (a) An original image, (b) An image after the lighting control, (c) histogram of image brightness in the foreground image region.

5.2. Dynamic Lighting Control

We tested our dynamic lighting control method. Figure 6(a), (b) are the images that are taken before/after using our dynamic lighting control method respectively. By extracting a foreground image region (human, 11417 pixels) manually, we confirmed that the numbers of the pixels whose brightness is out of the dynamic range in the foreground image region are reduced from 1406 to 152 by our method. Figure 6(c) is the histogram of the brightness in the foreground image region.

6. Conclusions and Future work

In this paper, we proposed a dynamic lighting control method by extracting the foreground region using background synthesis. The experiments show that the foreground image region is successfully extracted under controllable lighting, and the lighting is dynamically changed so that the brightness of the foreground image region is within the dynamic range.

However, some further works are required for applying our dynamic lighting control method into real time video shooting. Our lighting control method takes a long time, even a minute, for searching an appropriate lighting, because this method uses only images and searches an appropriate lighting by evaluating foreground image region and changing lighting repeatedly. For making this search faster, some additional work could be done, for example, using three-dimensional information including the position of the foreground objects, lights and camera, which can be estimated easily or can be given beforehand.

[1] Paul E. Debevec, Jitendra Malik "Recovering High Dynamic Range Radiance Maps from Photographs" SIGGRAPH97 Proceedings, pp.369-378, 1997

[2] Yuri Ivanov, Aaron Bobick, John Liu "Fast Lighting Independnt Background Subtracion" International Journal of Coumputer Vision 37(2), pp.199-207, 200

[3] Sato, Y. Wheeler, M.D. and Ikeuchi, K. "Object Shape and Reflectance Modeling from Observation" SIGGRAPH97 Proceedings, pp.379-387, 1997

[4] I.Sato, Y.Sato and K. Ikeuchi "Illumination distribution from shadows" Proceedings of IEEE Conference on Computer Vision and Pattern Recognition (CVPR'99), pp.306-312, June 1999

[5] Imari Sato, Yoichi Sato, Katsushi Ikeuchi "Acquiring a radiance distribution to superimpose virtual objects onto a real scene" IAPR Workshop on Machine Vision Applications '98, pp. 19-22, 1998

[6] Paul E. Debevec "Rendering Synthetic Objects into Real Scenes: Bridging Traditional and Image-based Graphics with Global Illumination and High Dynamic Range Photography" SIGGRAPH98 Proceedings, pp.189-198, 1998

[7] B. Horn "Robot Vision" MIT Press, 1986