Active Lighting for Object Brightness Control

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Abstract

We present an active lighting method that can control brightness of multiple objects in a scene to any values on video images. Our approach does not modify pixel values like retouching but changes intensities of multiple lights in the scene. Our algorithm needs little amount of computation to calculate appropriate intensities of the lights because we formulate the brightness of the objects so that the essential parameters in our formulation can be measured in advance. We have implemented a prototype system that can control brightness of faces of two persons in a room to intended values with eight controllable lights as they are walking.

1 Introduction

It is important to control brightness of an object in addition to its location and size in the image for filming purpose. If its brightness goes beyond or under the dynamic range of a video camera, corresponding **image intensity** of its figure turns white-out or black-out. In this case, viewers cannot see anything meaningful and the video is useless. Typical situations in which brightness control is required are a TV studio on filming a person who is talking and walking, video recording of a teacher who is giving classes in a classroom, and so on. When there is more than one person in a scene, it is often asked to film all the people within a camera frame in which each person should be filmed at an appropriate, usually different image intensity respectively. For example, it is a common situation of filming that an important person is set in relatively high intensity while the others are set to be dark on video images.

Another application of brightness control for objects is to emphasize objects in focus. For example, a brightened person on a stage can attract attention of other people while a darkened person will not. This is useful especially in show business.

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We propose a new light control method that can light up each person at any brightness respectively and simultaneously in a scene where more than one person is allowed to walk.

In order to control image intensity of each object in a scene, there are two conventional approaches. One is to modify camera parameters, and the other is to retouch images. These approaches, however, are not good because both of them have crucial defects as described below.

To deal with image intensity of video images, camera parameters such as aperture, exposure time, and gain are usually considered to be used. However, it is not good for our purpose since these parameters will change the image intensity uniformly over the image and can not modify it locally. Suppose there are two persons in a scene and one should be bright and the other should be dark. If we set those camera parameters to make the first person bright, the other person also turns unexpectedly bright and vice versa.

The other approach to change image intensity is retouch, but it sometimes makes discontinuous and unnatural image intensity distribution over the image that may not be accepted on video filming from the viewpoint of image quality. For example, it is hard to retouch surrounding objects naturally based on their true photometric properties.

On the contrary, direct control of multiple lights can light up objects to let each one at a different image intensity in video.

In this paper, we assume that there are more than one objects in a room and they moves freely. A camera is fixed in the room and it films the objects. There are multiple lights of which **light intensity** can be controlled and there are no other lights in the room. Our goal is to find light intensities that set corresponding image region of each object to specified image intensity. As the objects move around, the calculation cost of finding solution should be small in order to keep lighting them appropriately.

An active light control system is introduced by Debevec et al.[6] to replicate a real-world or virtual lighting environment. They control 156 LED lights in *Light Stage 3* and a camera images a person who is lit by the LED lights. As a result, they can obtain consistent image of the person with a given lighting environment. Since their system is designed to composite live performance of a person into a given lighting environment, it can not estimate the image intensity value of the person when a set of light intensity is fed to the system. Therefore, it can not direct the image intensity to an intended value by changing the light intensities.

In order to set the image intensity of an object to an intended value, it is necessary to estimate relationship between light intensity and the image intensity.

Brightness of an object in a scene is generally determined by lighting environment, the shape of the object, and its reflectance property according to model based rendering(MBR) theory because light intensity defines light property in a scene.

Measurement of lighting environment can be done by some recent researches[2][3] [4] that introduce a reference object such as a mirror sphere, and they succeeded in recovering real-world lighting environment by analyzing intensity distribution on the reference object. Although they can estimate lighting environment, it is impossible to estimate how image intensities vary when light intensities are changed. Therefore, the ideas of these approaches cannot be used directly to realize image intensity control of changing lights.

Shape recovery and reflectance estimation of objects are also needed to calculate brightness of object in MBR. Recent researches[7][8] have reported that measurement of geometric and photometric properties of objects are realized and available, but they may need laser spotting or some working time in which objects are not allowed to move. Because of these limitations mentioned here, recent MBR research results are not good to estimate the image intensity of objects when light intensities can be controlled.

Image based rendering(IBR) is an alternative approach that can generate realistic images of objects by synthesizing multiple views of the objects that are taken in advance. Mukaigawa et al.[5] proposed an IBR algorithm that can generate images of arbitrary lighting environment with unknown geometric and reflectance property of an object by synthesizing images taken at different light conditions. Although it can estimate relationship between light intensity and brightness of the object, it needs a set of pre-taken images at every location when the object moves.

In our proposed method, we model influence of light intensity of each light onto an object located at a point $\mathbf{p}$ by a function form of $\mathbf{p}$. We model this function so that it can be measured in advance. A set of light intensities of multiple lights that lets corresponding image regions of objects at specified values can be obtained with little computation cost because of our modeling. Hence our prototype system can keep controlling the lights even when the objects move around.

The rest of the paper is organized as follows. In Section 2, relationship between light intensity and image intensity is described and our model that is suitable for estimating image intensity is presented. We also mention the way of measuring the functions and coefficients that are to be obtained in advance. In Section 3 on-line light control algorithm is shown based on our model. Experimental results are shown in Section 4 and we conclude the paper in Section 5.

2 Image Intensity Control by Changing Light Intensity

In order to set image intensities of objects to target values by controlling light intensities, it is essential to formulate the relationship between light intensity of each light device and image intensity of the objects. We model it so as to realize fast computation when it is used for on-line light control. In this section, we first formulate the relationship, and then we describe the algorithms to measure relevant functions and coefficients. They should be estimated in advance, before the light control starts.

2.1 Formulation of Image Intensity with Light Intensity

Suppose light i ($i = 1 \dots N$) is controlled by light intensity variable v_i ($0 \leq v_i \leq v_i^{MAX}$). With **light intrinsic function** h_i and coefficient a_i, quantity of light I_i of light i can be described as:

$$I_i = a_i h_i(v_i) \tag{1}$$

When light i is turned off, we denote it as $v_i = 0$. The function h_i is a normalized function with the range from 0.0 to 1.0, and $h_i(0) = 0$.

On filming an object under this lighting environment, **scene radiance** L_j, that is radiated from a point on the surface of the object towards the corresponding CCD element at pixel j of the camera, is defined as:

$$L_j = \sum_i b_{ij} I_i \tag{2}$$

In Eq.(2), b_{ij} is a coefficient that is defined by location, surface normal, and reflectance property of the object that corresponds to pixel j, along with location of the light i and that of the camera.

Eq.(2) means that L_j collects all the influences made by any lights in the scene and they are summed. With this equation, L_j can take into account not only diffuse and specular reflectance of the corresponding surface at pixel j but also mutual lighting effects between the object and background objects in the scene.

Then, by substituting Eq.(1) into Eq.(2), we obtain the following equation.

$$L_j = \sum_i c_{ij} h_i(v_i), \quad c_{ij} = a_i b_{ij} \tag{3}$$

In this equation, c_{ij} indicates degree of influence provided by light i at $h_i(v_i)$ onto pixel j. L_j is proportional to $h_i(v_i)$ with coefficient c_{ij} for each light i. **Mutual coefficient** c_{ij} is also determined by the five elements that define b_{ij}. Since the location of the camera and the lights are fixed, c_{ij} changes when location, shape, and reflectance property of the object vary. In other words, if we fix these three elements, c_{ij} becomes constant.

According to [1], image intensity of pixel j denoted by Z_j is formulated as:

$$Z_j = f(L_j \Delta t) \tag{4}$$

In this equation, Δt means exposure time. The function f maps exposure of $L_j \Delta t$ to a certain image intensity and it is considered to be nonlinear and monotonic. We call f a **camera reaction function**. The shape of f depends on camera intrinsic property and varies as we change cameras. The function f has a dynamic range and it returns Z^{MAX} or Z^{MIN} when the exposure exceeds its upper or lower limit.

According to Eq.(3) and Eq.(4), we can estimate Z_j of pixel j when we set $\{v_i\}$ for the lights. In these equations, $\{v_i\}$ and Δt are control parameters, and Z_j can be obtained from a captured image. Therefore, if we measure the rest of the unknown terms of f, h_i, and c_{ij}, it is possible to find $\{v_i\}$ that makes Z_j to a target value. We describe the method of measuring f, h_i, and c_{ij} in the following sections.

2.2 Measurement of Unknown Functions and Coefficient

First we measure camera reaction function f. Light intrinsic function h_i of light i can be measured based on f. As these two functions do not depend on what is shown to the camera, we can measure these two functions in a scene where no objects move.

As it is difficult to obtain precise values of mutual coefficient $\{c_{ij}\}$, we approximate it by using the mean of $\{c_{ij}\}$ for all the pixels $\{j\}$ that belong to the same object.

2.2.1 Camera Reaction Function

When all the objects and $\{v_i\}$ are fixed to be stable, L_j is constant according to Eq.(3). The function f can be obtained by observing the change of Z_j as we change exposure time Δt in Eq.(4)[1]. Note that a set of $(Z_j, \Delta t)$ should be eliminated if Z_j is Z^{MAX} or Z^{MIN} because it breaks the assumption that f is monotonic.

2.2.2 Light Intrinsic Function

When only light i is turned on, we can rewrite Eq.(3) as:

$$L_j = c_{ij} h_i(v_i) \tag{5}$$

Because of the definition, c_{ij} is constant and independent from v_i when all the objects in the scene are stable. Therefore, relationship between v_i and L_j can be observed by changing v_i where all the objects are stable and all the other lights except for the light i are turned off. We can obtain h_i by normalizing the relationship between v_i and L_j into $(0.0, 1.0)$. Scene radiance L_j can be estimated by rewriting Eq.(4) into Eq.(6) because f is monotonic and Δt and Z_j are given.

$$L_j = \frac{1}{\Delta t} f^{-1}(Z_j) \tag{6}$$

2.2.3 Mutual Coefficient

Mutual coefficient c_{ij} depends on location, surface normal, and reflectance of the corresponding object. In other words, the mutual coefficient depends on the object itself and its location and direction in the scene.

In this paper, we take up human faces as our target objects because human face is one of the most valuable objects on filming. A human face is usually recognized as a whole, so the target image intensity for the face is instructed as the mean intensity of the face region. Therefore, we think mean image intensity $\bar{Z}$ and corresponding mean scene radiance $\bar{L}$ of an object.

As $\bar{L}$ is calculated by averaging L_j of pixel $\{j\}$ that belong to the region $\Re$ of the object, it can be written as

$$\begin{aligned} \bar{L} = \frac{1}{n} \sum_{j \in \Re} L_j &= \frac{1}{n} \sum_{j \in \Re} \sum_i c_{ij} h_i(v_i) \\ &= \sum_i (\frac{1}{n} \sum_{j \in \Re} c_{ij}) h_i(v_i) \\ &= \sum_i \bar{c}_i h_i(v_i) \end{aligned} \tag{7}$$

from Eq.(3). Coefficient $\bar{c}_i$ indicates the mean of c_{ij} in $\Re$ and n is the number of pixels in $\Re$.

As the object is allowed to move, we consider $\bar{c}_i$ as a function of the location $\mathbf{p} = (x, y, z)$. We denote it as $\bar{c}_i(\mathbf{p})$.

When the object is at $\mathbf{p}$, from Eq.(7) the scene radiance $\bar{L}(\mathbf{p})$ is denoted as:

$$\bar{L}(\mathbf{p}) = \sum_i \bar{c}_i(\mathbf{p}) h_i(v_i) \tag{8}$$

The scene radiance $\bar{L}(\mathbf{p})$ can be estimated by Eq.(6) with $\bar{Z}$.

Suppose all the lights except for light i are turned off. Then, Eq.(8) can be rewritten as:

$$\bar{c}_i(\mathbf{p}) = \frac{\bar{L}(\mathbf{p})}{h_i(v_i)} \tag{9}$$

We obtain the complete $\bar{c}_i(\mathbf{p})$ by interpolating sampled data that are taken in the place where the object moves around. Repeat the same process for all the lights in order to obtain $\bar{c}_i(\mathbf{p})$ for each light i.

2.2.4 Coefficient with Reference Model

To facilitate measurement of $\bar{c}_i$, we introduce a reference object and measure mean mutual coefficient $\bar{m}_i$ instead of measuring $\bar{c}_i$ itself. In the case of filming a human face, the reference object is a human shaped 3D head model. If we use the reference object, the target person is not needed while we measure $\bar{m}_i$. On the other hand, $\bar{m}_i$ should be adjusted to fit the target person as they have different properties.

Mean mutual coefficient $\bar{m}_i$ of the reference model is obtained in the same approach as the one for $\bar{c}_i$ described in Section 2.2.3.

If the geometric difference between the reference object and the target person is small enough, difference between $\bar{m}_i(\mathbf{p})$ and $\bar{m}_i(\mathbf{p})$ is derived only from difference of their reflectance properties. Suppose both surfaces of the model and the person can be modeled by diffuse reflection model and they have similar distribution of reflectance. We denote the ratio between these two reflectances as r. Since the reflection model is independent from $\mathbf{p}$,

$$\bar{c}_i(\mathbf{p}) = r\bar{m}_i(\mathbf{p}) \tag{10}$$

is satisfied for arbitrary $\mathbf{p}$.

From Eq.(7), Eq.(8), and Eq.(10), r can be calculated by :

$$r = \frac{\bar{c}_i(\mathbf{p})}{\bar{m}_i(\mathbf{p})} = \frac{\sum_i \bar{c}_i(\mathbf{p})h_i(v_i)}{\sum_i \bar{m}_i(\mathbf{p})h_i(v_i)} = \frac{\bar{L}(\mathbf{p})}{\bar{L}_m(\mathbf{p})} \tag{11}$$

This equation lets us estimate r by obtaining $\bar{L}(\mathbf{p})$ and $\bar{L}_m(\mathbf{p})$ with the same lighting condition at the same place. As a result, we need to obtain $\bar{L}(\mathbf{p})$ only once or a few times in order to estimate r.

By $\bar{m}_i(\mathbf{p})$ along with r, we obtain approximated $\bar{c}_i(\mathbf{p})$ by Eq.(10).

3 Light Control Algorithm

In this section, we describe a light control algorithm that sets mean image intensities of the multiple objects to the target value of $\hat{Z}$ respectively. To let the mean image intensity $\bar{Z}$ to the target value $\hat{Z}$ is equivalent to let mean scene radiance $\bar{L}$ to target scene radiance $\hat{L}$ that corresponds to $\hat{Z}$ by Eq.(4). Therefore, we describe our algorithm based on $\bar{L}$.

For the object $k(k = 1, \ldots, M)$, we denote mean image intensity of the object k as $\bar{Z}_k$ and mean scene radiance as $\bar{L}_k$. The scene radiance $\bar{L}_k$ can be approximated as follows based on Eq.(6).

$$\begin{aligned}\bar{L}_k = \frac{1}{n_k}\sum_{j\in\Re_k} L_j &= \frac{1}{n_k}\sum_{j\in\Re_k}\frac{1}{\Delta t}f(Z_j) \\ &\simeq \frac{1}{\Delta t}f(\frac{1}{n_k}\sum_{j\in\Re_k} Z_j) \\ &= \frac{1}{\Delta t}f(\bar{Z}_k)\end{aligned} \tag{12}$$

In this equation, n_k indicates the number of pixels that belong to the object region $\Re_k$.

Since the camera reaction function f is considered to be smooth, this approximation is reasonable when the variance of Z_j is small enough.

Hence we can calculate $\hat{L}_k$ by Eq.(12) as follows.

$$\hat{L}_k = \frac{1}{\Delta t}f(\hat{Z}_k) \tag{13}$$

The light control is conducted so that $\bar{L}_k$ has the same value of $\hat{L}_k$.

Suppose the object k is found at $\mathbf{p_k}$. In order to set the corresponding $\bar{L}_k$ to the target value of $\hat{L}_k$, we need to find $\{X_i\}$ that satisfies the following equations for all k.

$$\hat{L}_k = \sum_i \bar{c}_{ik}(\mathbf{p_k})h_i(v_i) = \sum_i \bar{c}_{ik}(\mathbf{p_k})X_i \tag{14}$$

Each $X_i = h_i(v_i)$ is regarded as a dependent variable of light intensity v_i of light i.

As there are M equations of Eq.(14), the number of control variables N should be equal or more than M. In other words, the number of the objects should be no more than the number of the lights to find a solution.

Note that there will be a situation that no solution exists even in the case the number of the objects is smaller than that of lights. One of the reasons is that domain of X_i is limited within $(0.0 \leq X_i \leq 1.0)$.

After we find $\{X_i\}$ that satisfies M equations of Eq.(14), light intensity variable $\{v_i\}$ can be calculated by $v_i = h_i^{-1}(X_i)$. Light control is conducted by sending $\{v_i\}$ to light equipment.

Calculation of $\{v_i\}$ and light control are conducted every time after at least one of these two situations is detected.

1. Location $\mathbf{p_k}$ of the target k is changed. It means the value of $\bar{c}_{ik}(\mathbf{p_k})$ should be modified accordingly.
2. New target image intensity $\hat{Z}_k$ of the object k is specified.

As $\{v_i\}$ is solved by linear simultaneous equations in Eq.(14), our algorithm enables us to change lighting environment rapidly just after one of the two situations 1. and 2. are detected.

4 Results

4.1 Environment

We have conducted experiments in a classroom with two persons. A snapshot of the classroom is shown in Figure 1 and the floor plan of the classroom is shown in Figure 2. Walking area size of which is 300[cm] by 155[cm] is set in the frontal area of the room and it is also shown in Figure 2.

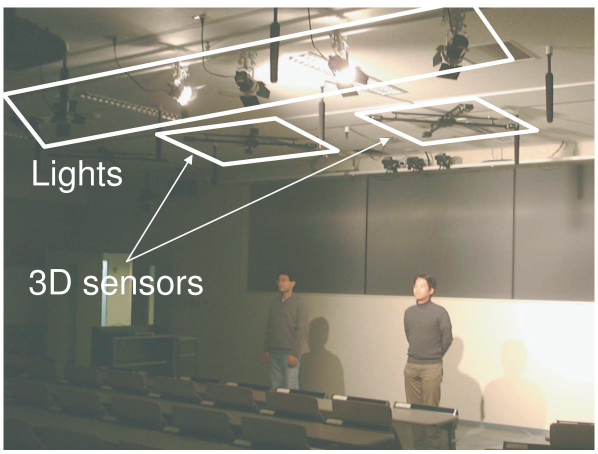


Figure 1: Experiment overview

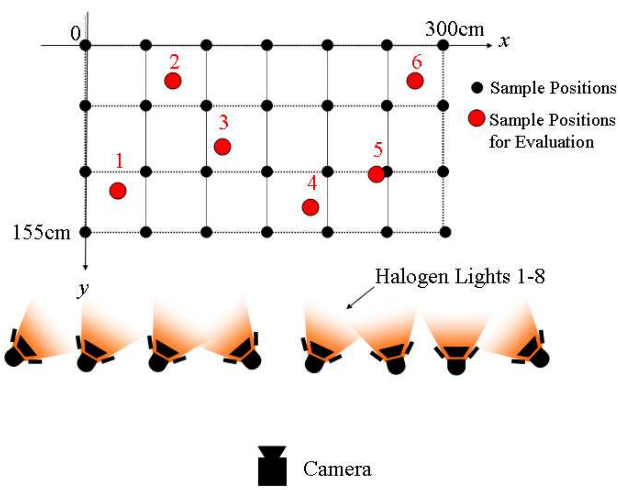


Figure 2: Floor Plan of the room

We use 8 halogen 500W lamps made by LPL. They are fixed onto the ceiling so as to light up the frontal area of the classroom. The directions of the lights are not severely set because our approach does not need any geometric calibration of the lights. Each light can be controlled with 128 step ($v_i = 0 \ldots 127$) by light control equipment made by Effect Arts.

The camera we used is SONY EVI-D30 and it is located in the rear side of the classroom so as to cover the frontal area. All the camera parameters except for exposure time Δt are fixed. The exposure time can be changed at 28 steps from $\frac{1}{60}$[sec] to $\frac{1}{10000}$[sec]. Input image to the system is gray and the size is 640×480 pixel. Image intensity varies from 0 to 255.

In order to obtain 3D location of target objects and a reference object, we used ultrasonic 3D sensor equipment of InterSense IS-600mkII. The sensor part is installed on the ceiling to cover the walking area. Ultrasonic beacons are attached to the people and the reference object. The head position of them is reported in real time.

4.2 Camera Reaction Function, Light Intrinsic Function, and Mutual Coefficient

We show experimental results of measuring camera reaction function f, light intrinsic function h_i, and mutual coefficient c_{ij}.

4.2.1 Camera Reaction Function and Light Intrinsic Function

We measured camera reaction function f and light intrinsic function h_i by the method in Section 2.2.1 and Section 2.2.2.

Figure 3 shows inverse form f^{-1} of camera reaction function f and Figure 4 shows light intrinsic function h_i. In this experiment, we found all the h_i's have the same shape.

4.2.2 Mutual Coefficient by Human Model

We measured the mutual coefficient $\bar{c}_i$ by the method presented in Section 2.2.4.

The reference model is a human-shaped head model of which the geometric property is similar to that of the persons in the scene. Surface of the model is painted by diffused white color. A snapshot of the model is shown in Figure 5.

We measured coefficient of the reference object $\bar{m}_i$ and the reflectance ratio r. As the height of the head of people is regarded as constant while they are walking and standing, we set the height z of the target object as $z = 180$[cm].

As shown in Figure 2, we set 28 sampling points to estimate $\bar{m}_i(\mathbf{p_s})$ $(s = \{1 \cdots 28\})$. Sampling was done at 7 positions along x axis at an equal spacing for 0–300[cm].

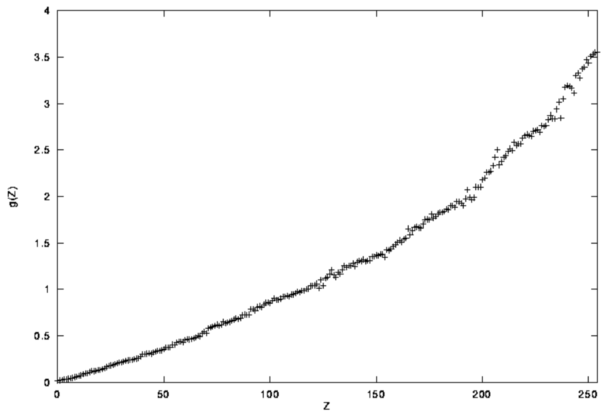


Figure 3: Camera Reaction Function in f^{-1}

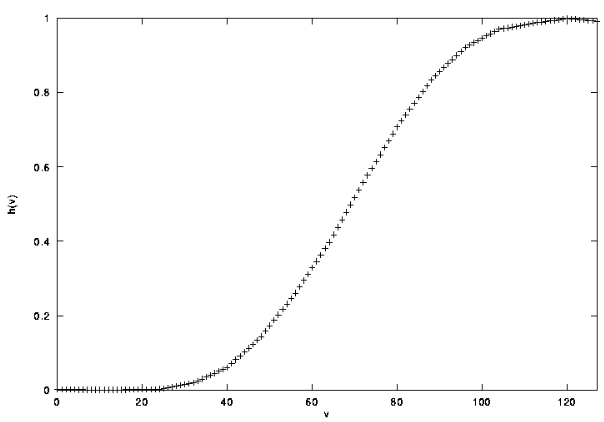


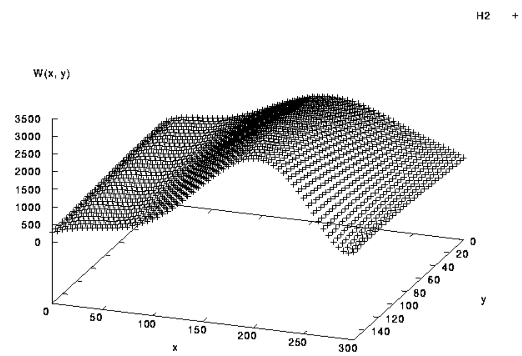
Figure 4: Light Intrinsic Function

It was also done at 4 positions along y axis for 0–155[cm] in the same way. Therefore, the total is $7 \times 4 = 28$ points. Precision of location of the model is within 5[cm]. Image region $\Re$ of the model is manually defined to estimate $\bar{L}_m$.

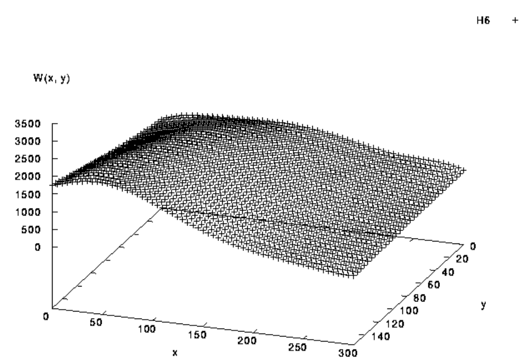
We obtained $\bar{m}_i(\mathbf{p})$ for all i's by interpolating the data. Figure 6 shows two of the estimated $\bar{m}_i(\mathbf{p})$.

To evaluate the error of $\bar{m}_i$, we set the reference model at 6 different points which are shown in Figure 2 and calculated the difference between the estimated value $\bar{m}_i$ and the measured value. Table 1 shows the result. Figures in the column of average are obtained by averaging the measured values for all the lights. Absolute error is obtained by averaging the absolute error between $\bar{m}_i$ and the measured

Figure 5: Head Model



(a) Halogen Light No.2



(b) Halogen Light No.6

Figure 6: $\bar{m}_2$ and $\bar{m}_6$

Table 1: Estimation of $\bar{m}_i$

Location (x,y)	Average	Absolute Error	Error Rate
1 (35, 110)	802.3	50.0	6.24 %
2 (70, 50)	801.9	36.0	4.49 %
3 (115, 80)	1036.6	40.7	3.92 %
4 (185, 130)	1287.8	37.0	2.87 %
5 (245, 100)	965.2	69.4	7.19 %
6 (275, 35)	694.1	29.9	4.30 %

Table 2: Ratio r of Reference Model and Person-1

Location (x, y)	r	$\lvert\bar{r} - r\rvert/\bar{r}$ (%)
1 (0, 0)	0.2284	7.08
2 (155, 0)	0.2258	5.88
3 (300, 0)	0.2307	8.16
4 (0, 155)	0.2024	5.11
5 (155, 155)	0.1976	7.37
6 (300, 155)	0.1948	8.64
Ave. $\bar{r}$	0.2133	

value for all the lights. Error rates of our approach are less than 7.2%.

We estimated reflectance ratio r by setting the object (a person) in the same location where the reference object was set to estimate $\bar{m}_i$. We extracted the corresponding face regions manually for both the reference object and the persons. Table 2 shows the result of estimating r for person-1. We obtained r at 6 different locations.

The differences between the estimated r at each location and the total average of $r = 0.2133$ are all within 8.7% and its standard deviation is 0.0152.

This result shows that r is considered to be constant through different locations. In this experiment, we adopt the ratio $r_1 = 0.2133$ for person-1. We also conducted the same estimation for person-2 and person-3, and we obtained $r_2 = 0.2033$ and $r_3 = 0.2851$.

4.3 Active Light Control

We implemented a prototype system that can control 8 lights actively based on our proposed method described in Section 3.

Light control experiment was conducted for two persons. The system controlled the 8 lights so as to let both faces keep specified brightness while they sometimes moved freely within the walking area. We used 3D position sensors to know their locations.

In the first experiment, we specified that the face of person-1 should be lit up at 150 and person-2 at 50. In the second experiment, the face of person-1 is set to 80 and that of person-3 is set to 170. Note that what we concern is the brightness of the faces only.

Table 3: Image Intensity Result for Person-1 at 150 and Person-2 at 50

Snapshot		person-1	person-2
1	Average	157.0	58.4
	Abs.Error	7.0	8.4
2	Average	159.6	57.7
	Abs.Error	9.6	7.7
3	Average	158.8	43.9
	Abs.Error	8.8	6.1
4	Average	165.4	61.3
	Abs.Error	15.4	11.3
5	Average	165.2	57.7
	Abs.Error	15.2	7.7
6	Average	158.1	43.9
	Abs.Error	8.1	6.1

Table 4: Image Intensity Result for Person-1 at 80 and Person-3 at 170

Snapshot		person-1	person-2
1	Average	80.3	169.1
	Abs.Error	0.3	0.9
2	Average	95.6	154.9
	Abs.Error	15.6	15.1
3	Average	89.8	158.2
	Abs.Error	9.8	11.8
4	Average	86.9	160.7
	Abs.Error	6.9	9.3
5	Average	84.8	170.1
	Abs.Error	4.8	0.1
6	Average	96.5	157.0
	Abs.Error	16.5	13.0

We took 6 snapshots to estimate the errors at each experiment. The results are shown in Table 3 and Table 4, and two snapshot images are shown in Figure 7.

The results show that our prototype system can control the brightness of the target objects within the error of about 10%. When the target image intensity is dark, the control tends to be difficult. We think this is because the shape of f is slanted more steeply for the small values.

The processing time to find the solution of $\{v_i\}$ was 1.5[ms] in average. As our prototype system needs about $1,000$[ms] to obtain 3D location of the objects and to change the light power, currently our system can control lights at about 1Hz. We think we can shorten the cycle time dramatically if we introduce quick response devices.

(a) Snapshot No.1 of Person-1(right):150 and Person-2(left):50

(b) Snapshot No.1 of Person-1(left):80 and Person-2(right):170

Figure 7: Snapshots of Active Light Control

5 Conclusion

In this paper, we presented an active lighting method that can control brightness of multiple objects in a scene by changing light intensity variables $\{v_i\}$.

We introduced a new formulation of brightness estimation that requires little computation cost on controlling the lights because all the unknown functions and coefficients are estimated in advance in our approach. We especially focused on human face as target object and described the method to estimate coefficients $\bar{c}_i$ effectively by using a reference object.

In the experiments, our prototype system could light up two persons of whom the face brightness was kept at different image intensity. The experimental results showed that active light control can be achieved based on our approach and we discussed the preciseness and errors of the results.

It is our hope to track more than two persons by adding more light units in our hardware equipment. We are also planning to control exposure time Δt to eliminate the situation in which no solution is found.

References

[1] P. E. Debevec and J. Malik, "Recovering High Dynamic Range Radiance Maps from Photographs", *Proceedings of SIGGRAPH97*, pp.369-378, 1997

[2] 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, 1999.

[3] I. Sato, Y. Sato, and K. Ikeuchi, "Acquiring a radiance distribution to superimpose virtual objects onto a real scene," *Proceedings of IAPR Workshop on Machine Vision Applications*, pp.19-22, 1998.

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

[5] Y. Mukaigawa, H. Miyaki, S. Mihashi, and T. Shakunaga, "Photometric Image-Based Rendering for Image Generation in Arbitrary Illumination," *Proceedings of International Conference on Computer Vision (ICCV2001)*, Vol.II, pp.652-659, 2001.

[6] P. Debevec, A. Wenger, C. Tchou, A. Gardner, J. Waese, and T. Hawkins, "A Lighting Reproduction Approach to Live-Action Compositing," *Proceedings of SIGGRAPH2002*, pp.547-556, 2002.

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

[8] K. Nishino, Y. Sato, and K. Ikeuchi, "Eigen-Texture Method: Appearance Compression and Synthesis based on a 3D Model," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol.23, No.11, pp.1257-1265, 2001.