CREATION OF THE HDR IMAGE UNDER SUNSHINE
日照下でのＨＤＲ画像の作成

by

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ABSTRACT

The "dynamic range" of a scene is the contrast ratio between its brightest and darkest parts. Low-dynamic range images usually represent pixels, with pixel values ranging as integers between 0 and 255. High-dynamic range pixels are capable of representing light quantities of one to a million and beyond, and can express more exact than the usual dynamic range. But, it was difficult to model an object with high intensity by the usual method using the dynamic range because of the large difference of intensity. In this thesis, we propose a method in which we can avoid this problem and model the sunshine with high-dynamic range.

論文要旨

ダイナミックレンジとは、最も明るい部分と最も暗い部分の間のコントラストの比率である。通常のダイナミックレンジによるイメージにおいては普通、０から２５５の値でひとつのピクセルを表すが、ハイダイナミックレンジは１から１００万（もしくは、それ以上）の値でひとつのピクセルを表すことにより通常のダイナミックレンジより正確な表現を可能にしている。だが、ダイナミックレンジを用いた通常の方法では輝度の差が大きくなりすぎてしまうため、輝度の高い物体をモデル化するのは難しかった。本論文では、その欠点を克服し、ハイダイナミックレンジを用いて太陽光のモデル化を試みる。

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And, I say gratitude also to all the member of the Ikeuchi laboratory.

Contents

Chapter 1

Introduction

1.1Background

Recently, the integration of digital photographs into computer graphic(CG) has been under intense studied. Its application varies from the personal usage to the academic research such as preservation of cultural heritage by 3D data. In order to add the realism into CG, it requires the information on the light source in addition to a model of an object. The model can be virtually constructed as the combination of the CAD primitive. It can also be created from the actual object by measuring it via laser range scanners. Digital photographs are integrated into the system to acquire the information of the light source.

One of the most difficult measurements of light source is when the source is the sun. Under the sun, it is possible to have both the under-exposed and overexposed area as well as the normal area in one image. The estimation of the radiance of the light source(sun) in this condition is not accurate, since the confidency on under-exposed and overexposed area is low. In order to accurately estimate the radiance, it is necessary to increase the dynamic range of the camera. However, the increase by physical adaptation is not always welcomed, since the final cost may be too high for the general public. In this thesis, we propose the method to determine the radiance of the sun light from the photos of CCD camera equipped with filter. Multiple filters and shutter speed are applied to control the exposure. Exposure is used to estimate the radiance. When the reliable radiance is known, it is possible to be virtually constructed the environment with the sun as the light source.

1.2 Our proposed method

As stated in the previous section, digital images have the limited dynamic range. Conventional image processing is not sufficient to create the realism into digital images. In this thesis, the algorithm to create the high dynamic range image is proposed, Radiance of the light source is estimated from the exposure which is the multiplication of irradiance of the light source and the exposure time.

1.3Construction of the thesis

Chapter 2 gives some overview on works about high dynamic range. Works by P.E. Debevec et.al.[1] is then described in more detail. We adopted their algorithm in constructing the high dynamic range radiance map from photographs. Our proposed method is the presented in Chapter 4. Our proposed algorithm is then tested and evaluated(Chapter 5).

Chapter 2

Related works

The "dynamic range" is the contrast of an image(the ratio between the brightest and the darkest intensity). In order to estimate the reliable radiance of the light source, it requires that the dynamic range of the image is sufficient, i.e. no overexposed or underexposed area. In practice, it is difficult to guarantee the sufficient dynamic range. Researches have been done on "high dynamic range" to increase the dynamic range of the camera. In the first half of this chapter, the overview of the research on high dynamic range is presented. The later half is dedicated to the description of the works by P.E. Debevec et.al.[1], since their works is adopted into our system to construct the high dynamic range radiance map from photographs.

2.1 IMAGE ACQUISITION MODEL

The intensity(brightness) on the image does not always relate to the true lighting. Figure 2.1 illustrates the process in taking a photo by digital camera. The light travels through the lens and reaches the laser sensor. The amount of the light the sensor detected varies according to the irradiance(E) and the exposure time(Δt).Total exposure(X) of the sensor is then $E\Delta t$. The data from CCD is then transferred to Analog-digital converter(ADC) and remapped to create the 2D array of image intensity(brightness, color, etc).

The response characteristic of the CCD to the exposure is non-linear. In the underexposed area(the light is too low), there is only a little response. Whereas in the overexposed area(the light is too high), the response becomes saturated. The response is constant when the exposure is higher than some value. Both extreme cases are commonly found when the image is taken under the sun or contains the shiny material under then artificial light.

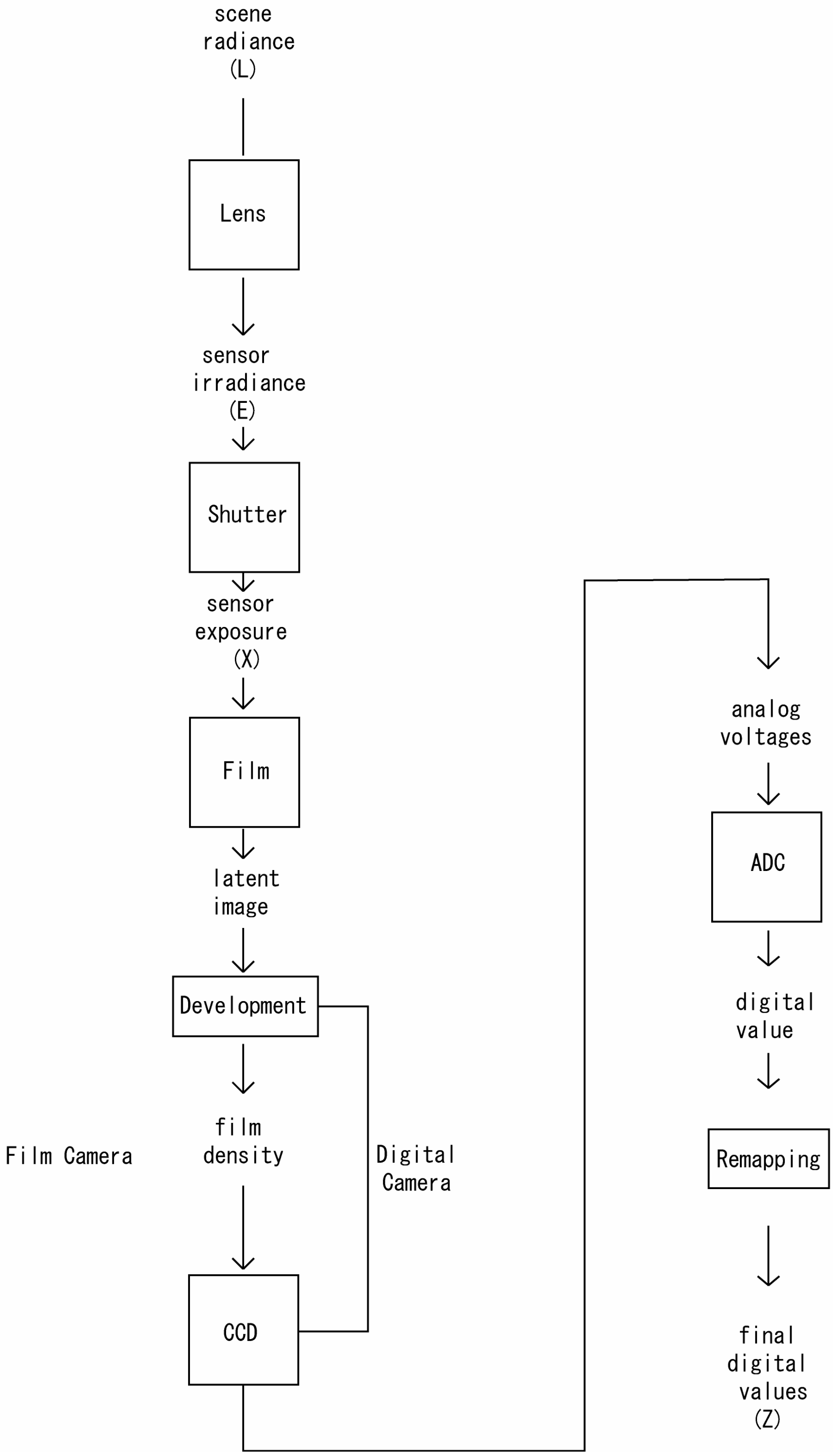


Figure 2.1: Image acquisition model. Nonlinear characteristic is found in exposure, development, scanning, digitalizing and remapping state.

2.2 HIGH DYNAMIC RANGE MAP FROM CAMERA

Film response curve is constructed by utilizing the reciprocity between photochemical and electronic images. It is defined that the exposure(X) is the function of the multiplication of the irradiance(E) and the exposure time(Δt). The exposure does not depend on each parameters separately. That is halving E and doubling Δt gives the same optical density(D) as E and Δt.

Define Z_{ij} as the intensity of pixel with the index i under the exposure Δt_j.

The film reciprocity equation is defined as:

$$Z_{ij} = f(E_i \Delta t_j) \tag{2.1}$$

Assume f be a monotonic function. The exposure($E\Delta t$) can then be estimated by taking the invert of f.

$$f^{-1}(Z_{ij}) = E_i \Delta t_j$$

Take the natural log on both sides:

$$\ln f^{-1}(Z_{ij}) = \ln E_i + \ln \Delta t_i$$

Simplify the notation by defining $g = \ln f^{-1}$. The equation is then rewritten as:

$$g(Z_{ij}) = \ln E_i + \ln \Delta t_j \tag{2.2}$$

Z_{ij} can be approximated directly from the image and Δt is known at the time when the photo was taken. It is possible to estimate E_i and g by least square error. However, the response to the exposure is not linear, condition on overexposure and underexposure must be taken into account for accurate estimation. Define $Z_{\min}$ and $Z_{\max}$ as the maximum and minimum intensity, respectively. Because of the low confidency in underexposed and overexposed area, the weighting function is determined as:

$$w(z) = \begin{cases} z - Z_{\min} \text{ for } z \le \frac{1}{2}(Z_{\min} + Z_{\max}) \\ Z_{\max} - z \text{ for } z \ge \frac{1}{2}(Z_{\min} + Z_{\max}) \end{cases}$$

(2.3)

Rearrange Equation(2.2), the natural log of irradiance can be determined by the following function.

$$\ln E_i = g(Z_{ij}) - \ln \Delta t_j$$

(2.4)

Integrate the weighting function(Equation (2.3)) into Equation 4. More importance is given to the intensity at the midrange(between $Z_{\min}$ and $Z_{\max}$), because the characteristic at the midrange can be considered linear. Equation (4) is then rewritten as:

$$\ln E_i = \frac{\sum_{j=1}^{P} w(Z_{ij})(g(Z_{ij}) - \ln \Delta t_j)}{\sum_{j=1}^{P} w(Z_{ij})}$$

(2.5)

The above equation rejects the low confident data and provides more accurate approximation of E. In addition, it makes use of averaging and is more robust to random noise. Figure 2.2 is the graph showing the relationship between log exposure and pixel value(Z_{ij}). It is impossible to accurately estimate pixel value because the characteristic for each pixel is not the same. On the other hand, by applying Equation (2.5) into the data(Figure 2.3), the relationship of the three pixels comply with one another so the estimation is more accurate.

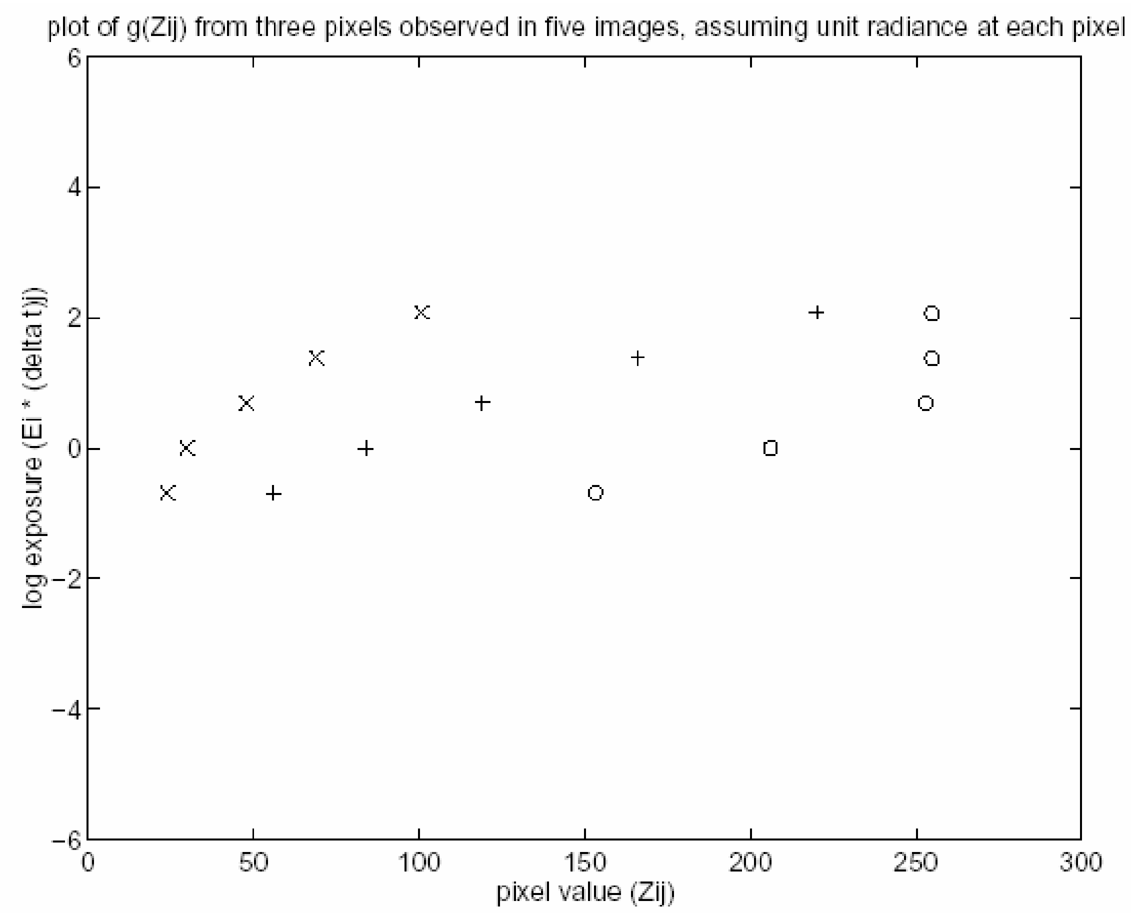


Figure 2.2: Plot of the log exposure to pixel in the intensity (Z_{ij}), of the three pixel, in five image. x ,+, o showed the value of pixel. The evaluation assumes the unit radiance at each pixel.

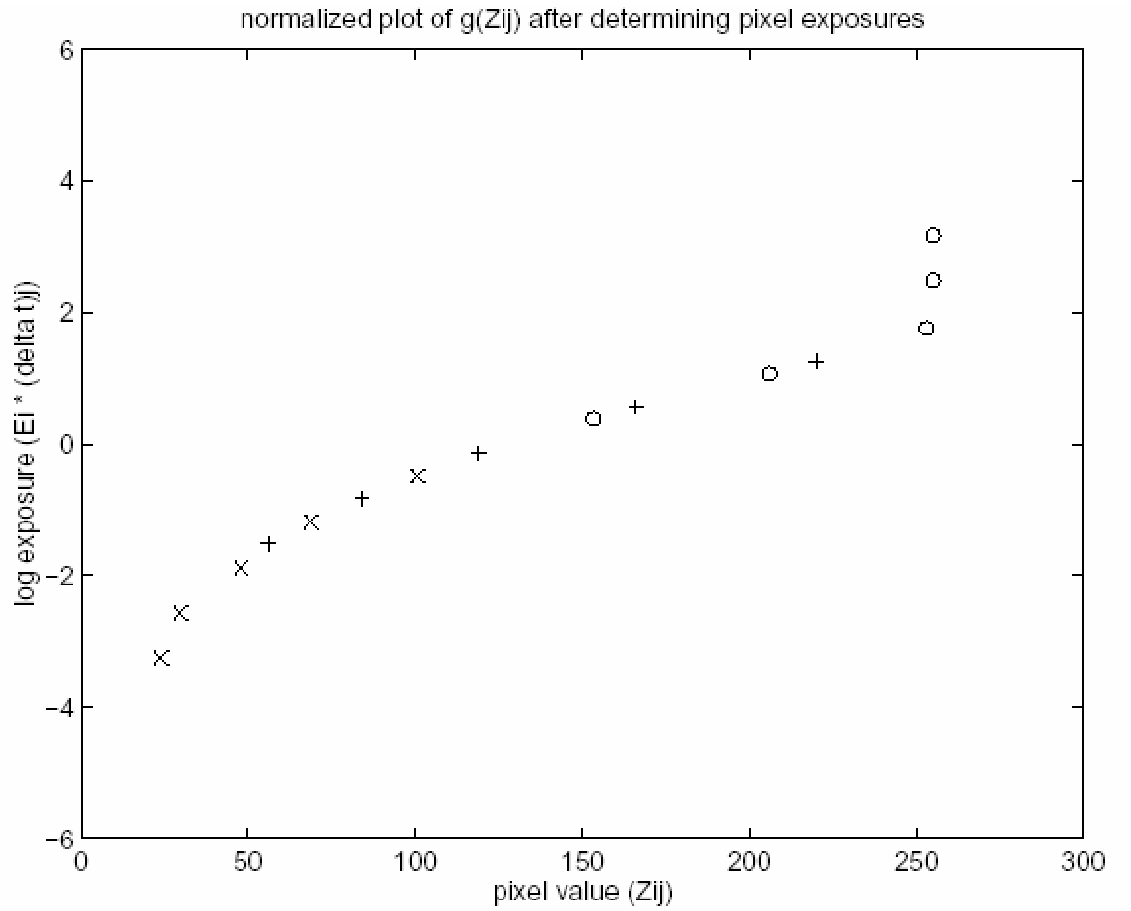


Figure 2.3: Plot of the data in Figure2.2 after applying Equations. The relationship between pixel intensity and log exposure in all 3 pixels has the same line.

Chapter 3

Superimposing Virtual Objects onto a Real Scene

In order to seamlessly integrate the virtual object into the physical environment, light and shadow in the image must appear naturally. That is there is no conflict of lighting on the image. "Radiance" is applied in this thesis because it can correctly calculate the shadow information and divide the image into three individual groups: (1) virtual object, (2) shadow and (3) background. It is necessary to be able to distinguish the different area in the image, because virtual reality often contains the virtual objects. In this chapter, "Radiance" is first described. Then algorithm to superimpose of the virtual object into the real image is presented

3.1 "Radiance" software

"Radiance" is the powerful software for light-source analysis and visualization. In order to calculate the lighting condition on the particular object at the specific time, it requires the following input:(1) 3D co-ordinate of the object(2) Information about the material of the object(3) Time and date(4) Weather condition(E.g. cloudy, sunny).

We assume that the object is taken when the sun is the sole light source. (1) and (2) is used to construct the realistic virtual object while (3) and (4) is used for calculating the shading and lighting of the object and its surrounding. Time of the photo is required to determine the position of the sun, while weather condition is then used to calculate the amount of the radiance from the sun in the image.

From the input, "Radiance" then calculated for the following parameters:

(1) Spectrum radiation luminosity

(2) Radiation illumination

(3) Radiant index.

As its name suggest, spectrum radiation luminosity indicates the luminosity and color. Color information can also be found in radiation illumination. In addition to color, the radiation illumination also provides the information on illumination.

Simulation results from the "Radiance" are presented in both the pictures and the magnitude forms. Example of the rendering by "Radiance" is found in section 2 of this chapter.

The advantage of radiance is on its versatility. Objects can be of various material because users can freely indicates its characteristic in the input[7][8]. Users can manipulate the material characteristic, until it looks real under human perceptions. In addition, calculation and rendering for one lighting state are made easy.

3.2 Rendering

In this section, we test the rendering by "Radiance". We chose the main hall of the Great Buddha as the virtual object(Figure 3.1). The object is created according to the records at the time of the first construction. Its shape is different than the actual hall, because the actual one has undergone various repair/construction. Figure 3.2 showed the image of the light source and the surrounding environment. The location of the virtual object was determined for the accurate optical adjustment. "Radiance" then provides the following four outputs:

(1) Mask image for the virtual object(Figure 3.3)

(2) Mask image for the environment indicating the position of the virtual object. In this experiment, it was the floor where the virtual object lied(Figure 3.4).

(3) Surrounding image when no virtual object exists(Figure 3.5)

(4) Image of the virtual object and its surrounding(Figure 3.6).

In this experiment, Figure 3.6 is the result of superimposing the virtual object on to the ground. It can be seen that shadow on the object is not conflict with human perception.

In order to create realism into the image, it then requires the shadow on the ground as created by the virtual object.

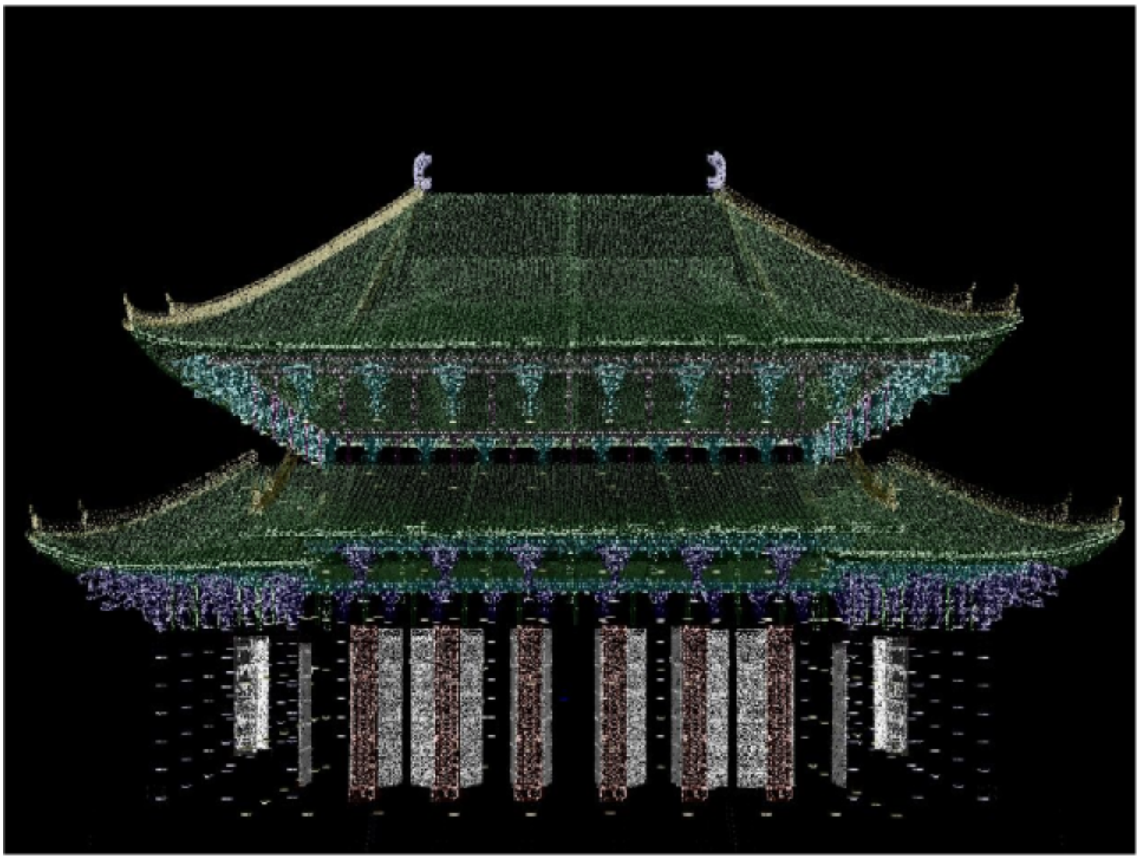


Figure 3.1: The 3-dimensional model of the Hall of the Great Buddha at the time of foundation (virtual object)

3.3 Superimposing Virtual Objects Onto a Real Scene

In order to determine where to create the shadow, "Radiance" classifies the pixels into 3 groups: (1) virtual object, (2) shaded area and (3) background. Background is too far away to be affected by the virtual object so it is unnecessary to create the shadow. Only shaded area is affected and artificial shadow is added into the area.

3.3.1 Virtual Object

Virtual object is depicted in Figure 3.3. The object in Figure 3.6 provides the realistic looking object so it is unnecessary to further process the image. And the object as shown in Figure 3.6 is used.

3.3.2 Shaded area

The area that is affected by the virtual object is depicted in Figure 3.4 as the white area. This area required the artificial shadow to create the realism into the image. The color of the picture after superimposing a virtual object is determined by Figure 3.5, Figure 3.6 and the following equation:

$$M_m = I_m \frac{E_m^2}{E_m^1} \qquad m = R, G, B \tag{3.1}$$

E_m^1 : Illumination in case a virtual object does not exist

E_m^2 : Illumination in case a virtual object exists

I_m : The color of a real scene

M_m : The color of the picture after superimposing a virtual object

Figure3.2: light source image

3.3.3 Background

The remaining area in the image is considered as the background. Virtual objects does not change the image intensity. The original image can be applied without creating the distinguishable conflict in human perception. Figure 3.7 shows the surrounding image which the background was created from.

3.4 Superimposing result

Figure 3.8 shows the superimposing of the virutal objected into the image. The shadow of the surrounding area is no longer conflicted with the light source. In the result, the virtual object is perceived as the actual object existing in the scene instead of the virtual object adding into the scene afterwards. In addition. the object was not perceived as floating above the ground, thanks to the realistic shadow near the object.

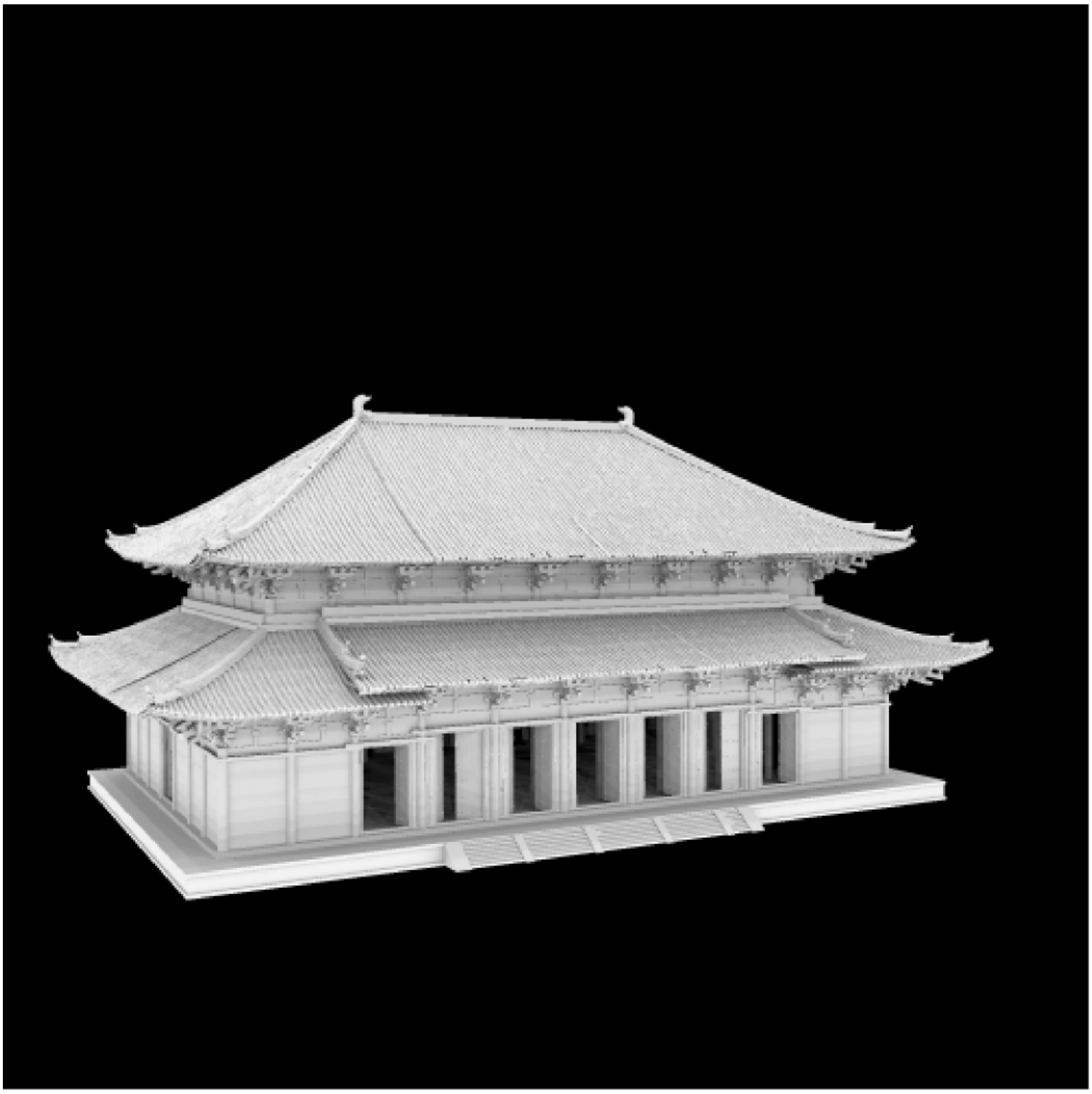


Figure3.3: mask image of virtual object

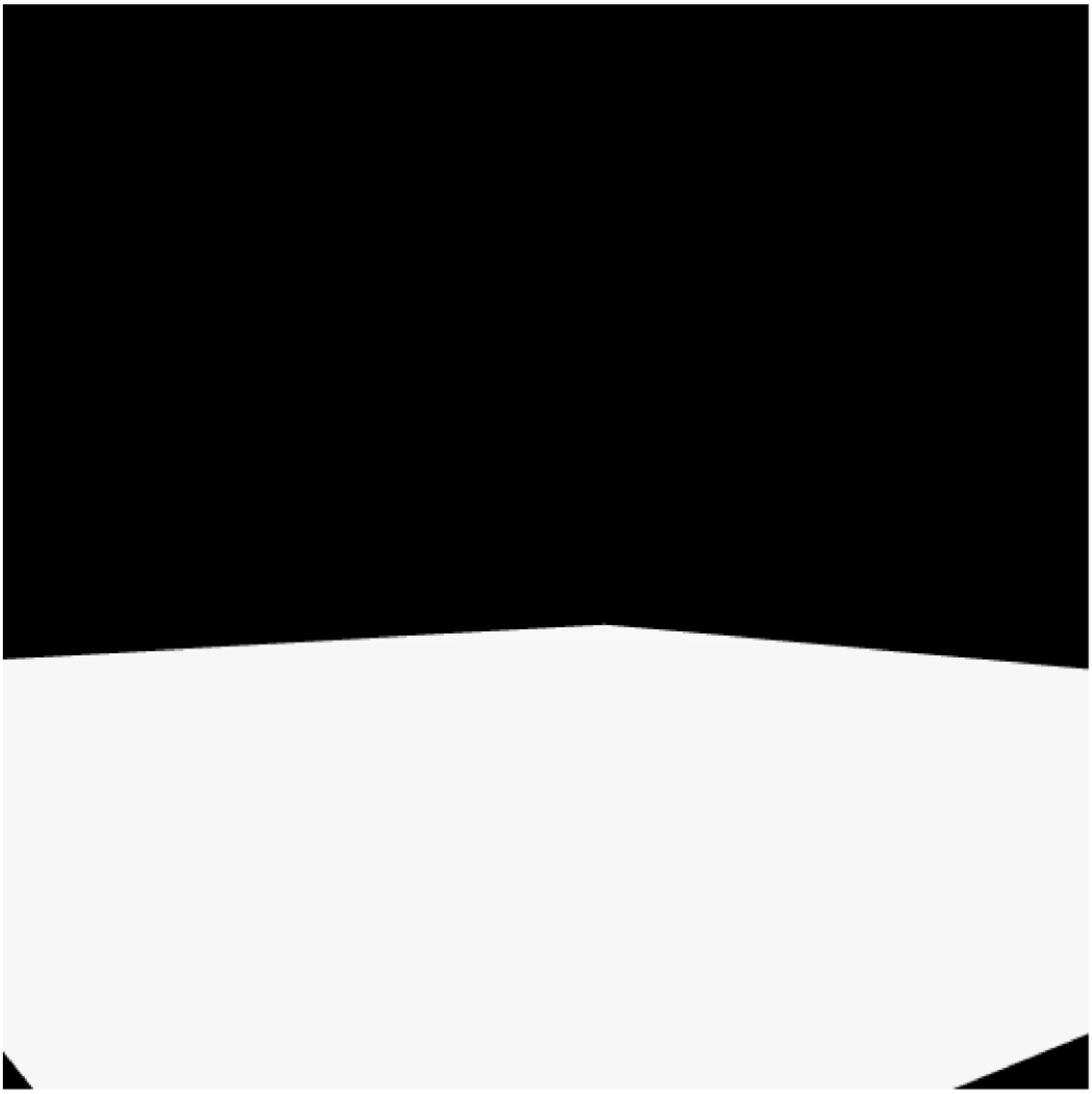


Figure 3.4: mask image of the ground

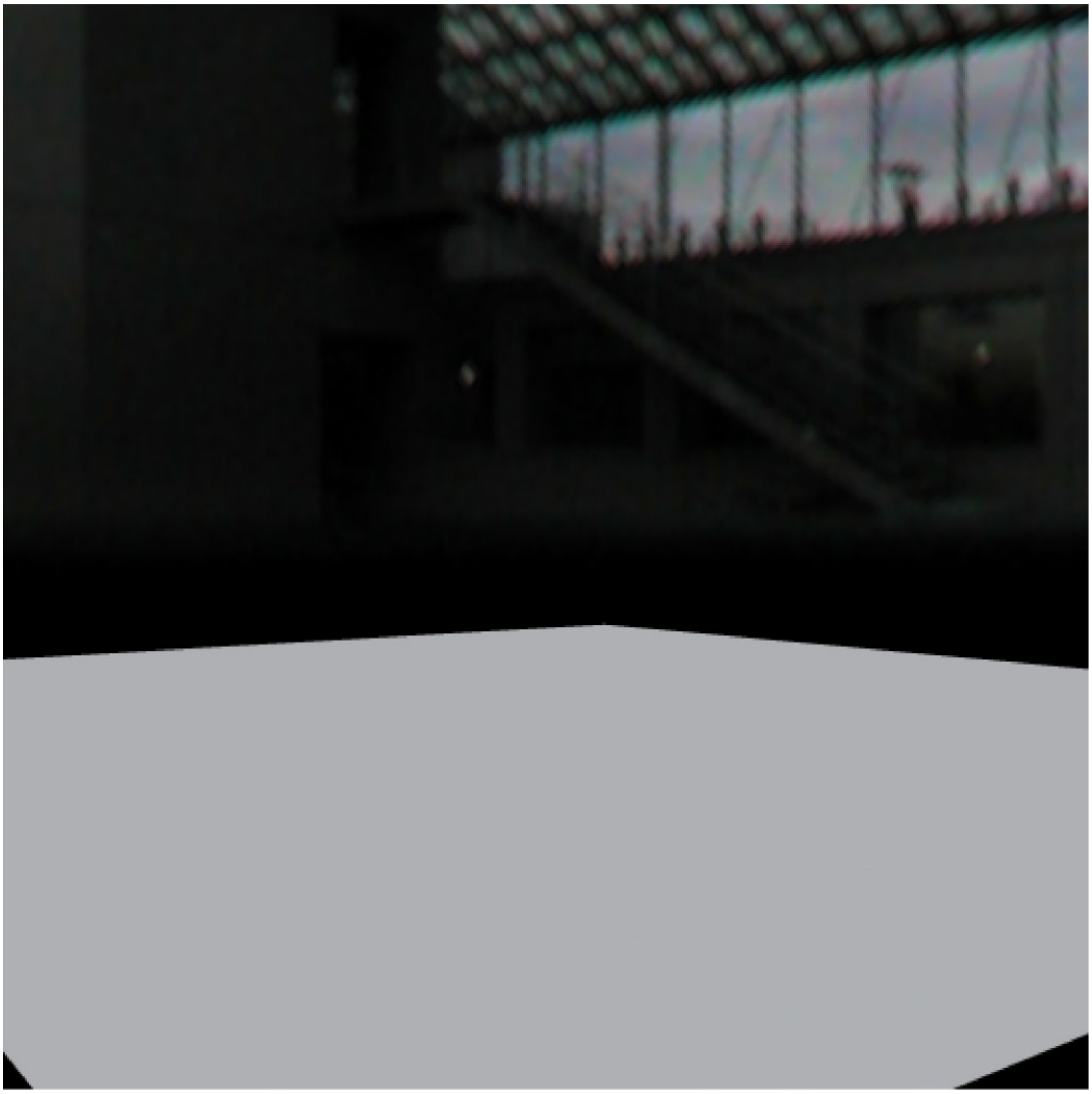


Figure3.5: Illumination of the ground in case there exists no virtual object

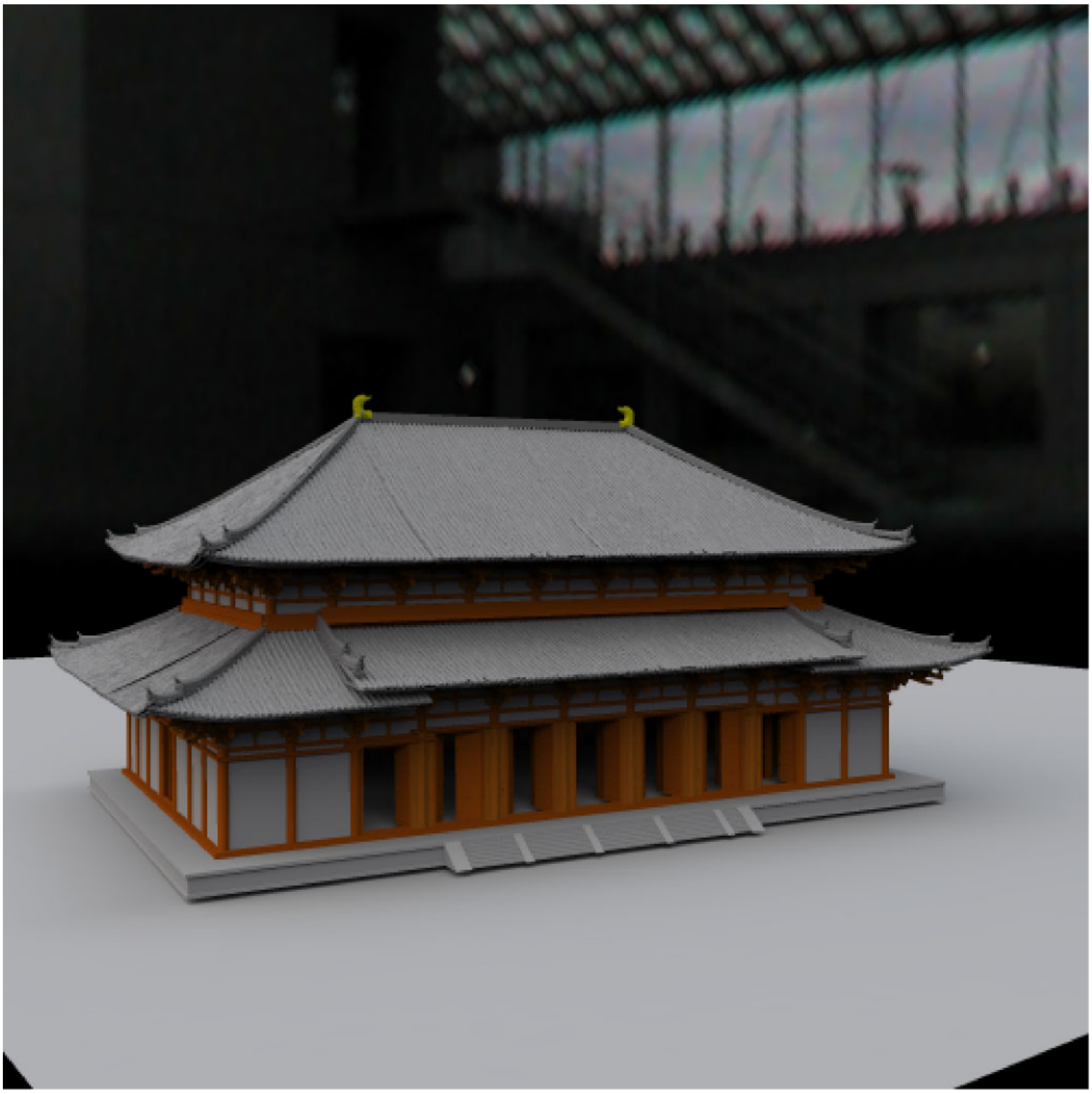


Figure 3.6 Illumination of the ground and virtual object in case there exists virtual object

Fig 3.7: Real scene

Figure 3.8 result of superimposing virtual object onto a real scene

3.5 Deletion of shadow in a real image

In order to superimpose the virtual Hall of the Great Buddha into the actual place, it is necessary to remove the shadow created by the actual hall from the image. The shadow of the virtual hall is then later added into the shadowless image. In this section, we propose the algorithm to remove the shadow of the to-be removed object. Our algorithm is the reverse engineer of the process in "Radiance".

3.5.1 Rendering

The image is rendered in the same manner as "Radiance"(Section 2). The rendering process is described here by mean of th example. The photo of the cube of the size 12x12x12 m3 was taken(Figure 3.9). In addition, the 3D model of the cube was measured and is showed in Figure 3.10. Light source image is shown in Figure 3.11. The viewpoint of the object is selected according to the our calibration on the object and the calculated information of the camera. Information of the camera used in the algorithm are:(1) position, (2) direction and (3) degree between the camera and the object. From the input, four images(as in "Radiance") was created. Figures 3.12 and 3.13 show the mask image of an object and the shaded area, respectively. The surrounding without and with virtual object are shown in Figures 3.14 and 3.15, respectively.

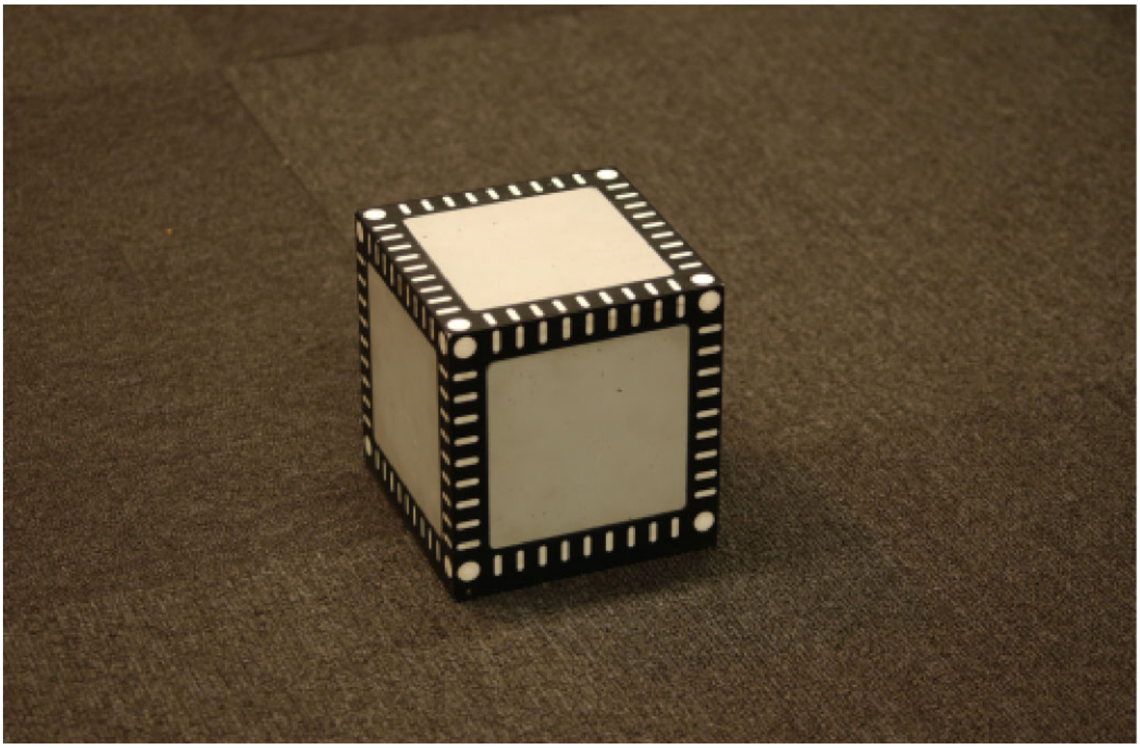


figure3.9: Object

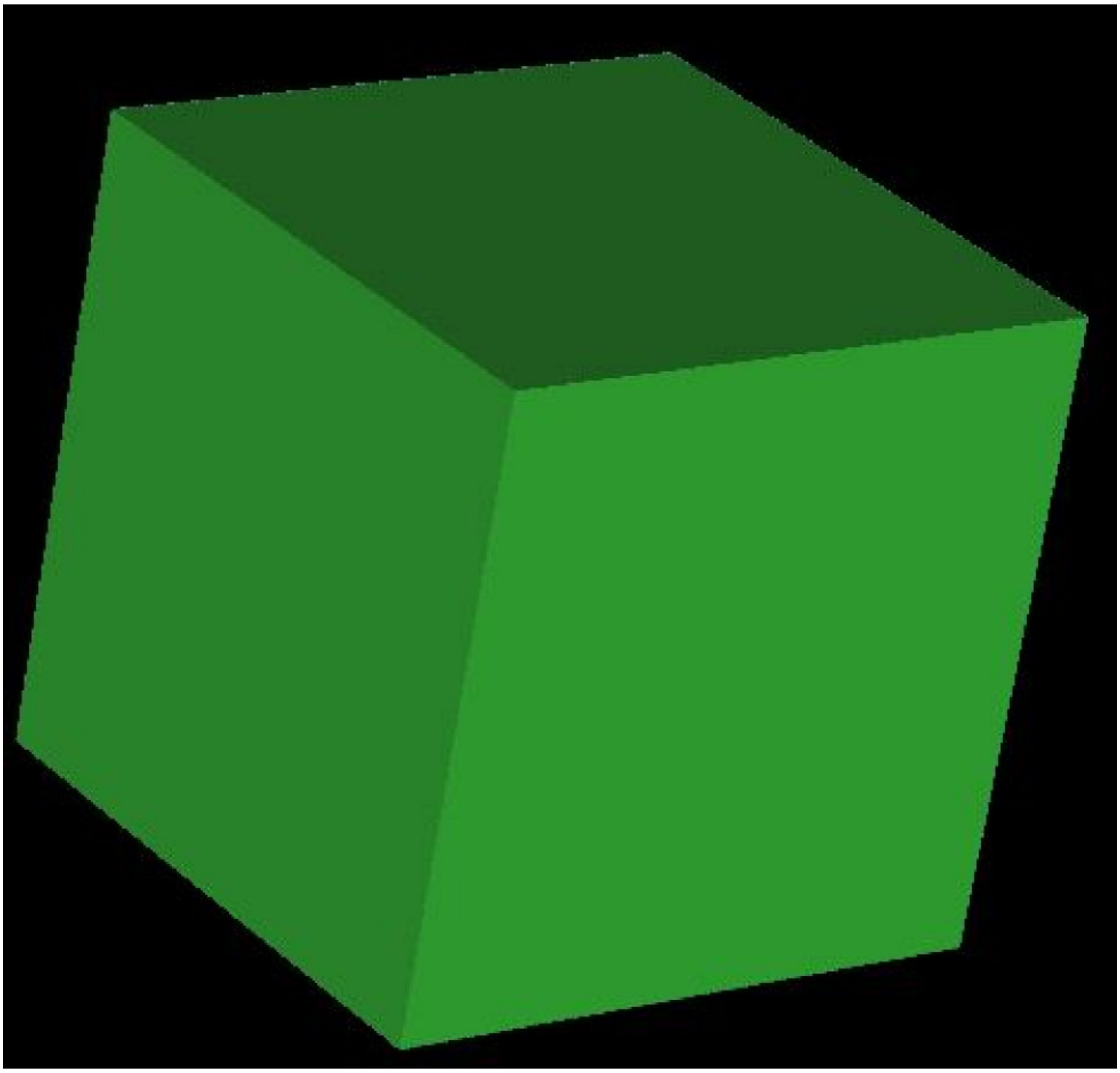


Figure3.10: 3D model of the object

3.5.2 Elimination of shadow in a real image

In the same manner as in "Radiance", pixels in the image are classified into 3 groups: (1) virtual object, (2) shaded area and (3) background. In this example, the model of a virtual object is shown in Figure 3.12 and its texture is shown in Figure 3.9. It is unnecessary to process the virtual object and background because there is no effect of the shading from the actual object(to be deleted). Only the shaded area which contains the shadow as created by the to-be deleted object is considered.

The shaded area is the white area in Figure 3.13. The color of the image after superimposing the virtual object is estimated from Figure 3.14, Figure 3.15 and the following equation:

$$I_m = M_m \frac{E_m^1}{E_m^2} \qquad m = R, G, B \tag{3.2}$$

E_m^1 : Illumination in case the object does not exist

E_m^2 : Illumination in case the object exists

I_m : The color of a real scene

M_m : The color of the image in case the object existing

Besides the shaded area, the information on the surrounding is taken from the real image(Figure 3.9) without further processing.

Figure3.11: light source image

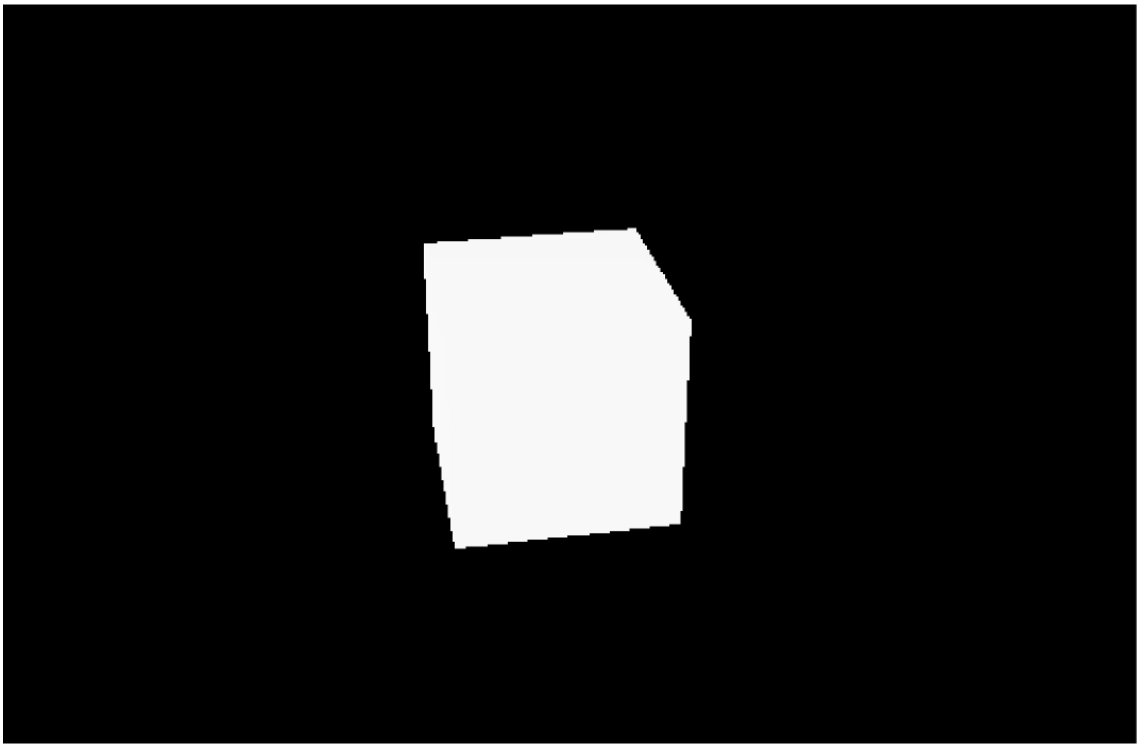
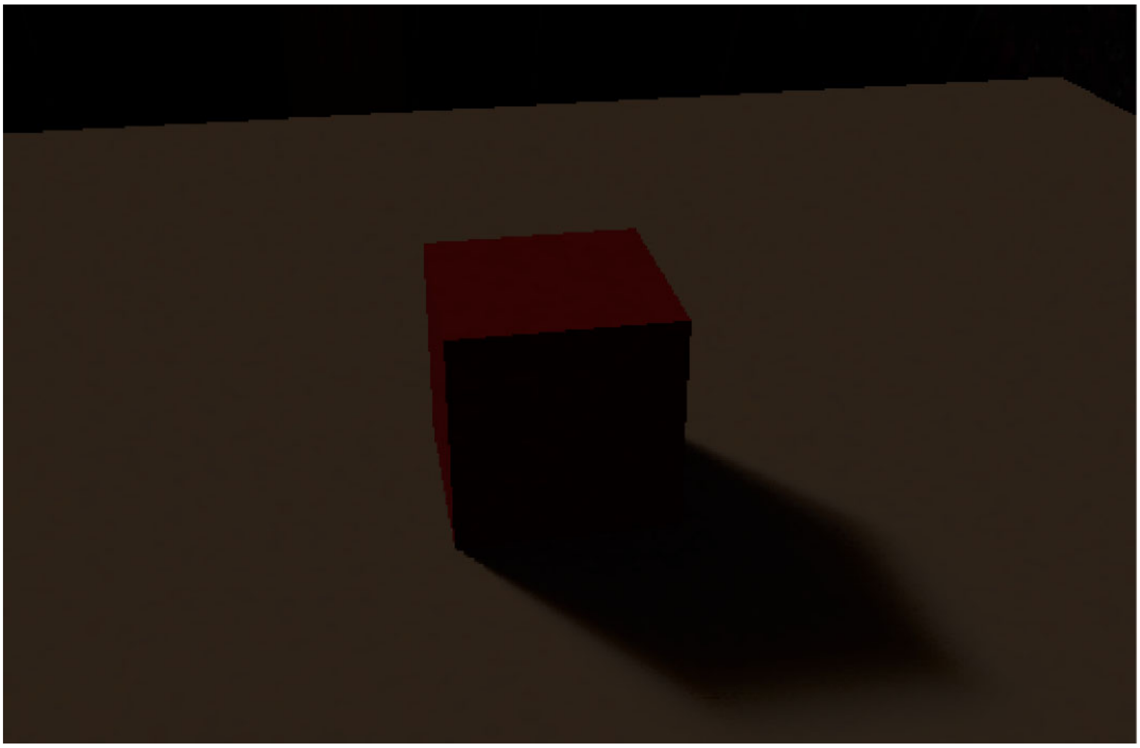


Figure3.12: mask image of the object

Figure3.13: mask image of the ground

Figure3.14: Illumination of the ground in case there exists no object



Chapter4

Experiment and Evaluation

The image taken when the sun is the light source has a very high dynamic range. It is difficult to find the actual camera which has the sufficient range to cover the dynamic range required in this condition. Instead of improving the camera physically, we propose the method to increase the dynamic range without really changing the camera. Different shutter speeds and filters are applied and a sequences of an images are taken via digital camera NIKON D1X. FUJI filters are used to block the sun from the image. A stop is used to simplify the calculation of the exposure.

4.1 Modeling the radiance maps of the Sun

4.1.1 Multiple exposures.

The radiance map of the sunshine is estimated by taking the photos under different exposure. The effect of the intense intensity of the sun is coped by multiple images. In this experiment, the photos are taken under 5 conditions where each condition has different kind of the filter.

(1) No filter.

The exposure time ranged from 1/16000s to 1/30s. The exposure of a image was twice the one taken before. Some results are shown in Fig.4.1. Saturation due to overexposure is found in every result.

Figure4.1: Sample image whom no filter is applied.

(2) ND1 filter. The exposure time is similar to "no filter" case(1/16000s to 1/30s). In the same manner, exposure time of a image was twice as the one. Figure <#####> shows the sample images taken with ND1 image. Similar to the no filter case, saturation is still find in every case though the image is much more dimmer

Figure4.2: Sample image whom ND1 filter is applied.

(3) ND2 filter. The exposure range and time of each image are similar to no filter case. Even though the result(Fig4.3) is much dimmer, saturation is still found in every image.

Figure4.3: Sample image whom no filter is applied

(4) ND3 filter. The exposure range and time of each image are similar to no filter case. The result(Fig.4.4) are very dim. Saturation is found only when the exposure time is set more than 1/2000s. For the exposure time of the range 1/16000-1/4000s, the images are black and no saturation is found.

Figure4.4: Sample image whom ND3 filter is applied

(5) ND4 filter. The exposure range and time of each image are similar to no filter case. Saturation is found only when the exposure time is set more than 1/125s. For the exposure time of the range 1/16000-1/250s, the images are black and no saturation is found.

Figure4.5: Sample image whom ND4 filter is applied

		Filter				
		No Filter	ND1	ND2	ND3	ND4
shutter speed	1/30[s]	1/30	1/300	1/3000	1/30000	1/300000
	1/60[s]	1/60	1/600	1/6000	1/60000	1/600000
	1/125[s]	1/125	1/1250	1/12500	1/125000	1/1250000
	1/250[s]	1/250	1/2500	1/25000	1/250000	1/2500000
	1/500[s]	1/500	1/5000	1/50000	1/500000	1/5000000
	1/1000[s]	1/1000	1/10000	1/100000	1/1000000	1/10000000
	1/2000[s]	1/2000	1/20000	1/200000	1/2000000	1/20000000
	1/4000[s]	1/4000	1/40000	1/400000	1/4000000	1/40000000
	1/8000[s]	1/8000	1/80000	1/800000	1/8000000	1/80000000
	1/16000[s]	1/16000	1/160000	1/1600000	1/16000000	1/160000000

Table4.1 Exposure of the image in the experiment

The exposure as calculated from the irradiance and exposure time for the above experiments is shown in Table 4.1.

From the result, it indicated the vanishing point of the saturation lies between the exposure of 1/2000000 and 1/2500000.

4. 1.2 Contour line construction for the sun

We first convert the color image to gray-scale image. Then, the image is binarized. The pixel with the intensity less than 128 is considered 0(black); otherwise it is 1(white). The edge is then extracted from the binary image by edge extraction algorithm. The process is repeated in every available data. Then the picture of each exposure is merged up and form the contour line of the sun radiance.

Figures 4.6-4.9 showed the progress of the edge extraction. The original image in Figure 4.6 is converted to gray-scale image(Figure 4.7). The gray-scale image is then transformed into the binary image(Figure 4.8). At this stage, the noise as shown in the fuzzy area in Figure 4.7 is removed. The sharp edge can then be extracted as shown in Figure 4.9.

Figure 4.10 showed the merging of the edge at the different exposure. The contour line of the light source can then be estimated.

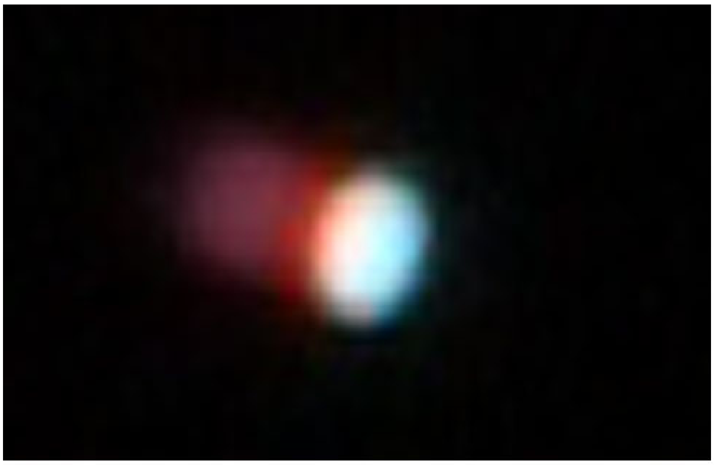


Figure 4.6: Original image

Figure4.7 : gray scale image

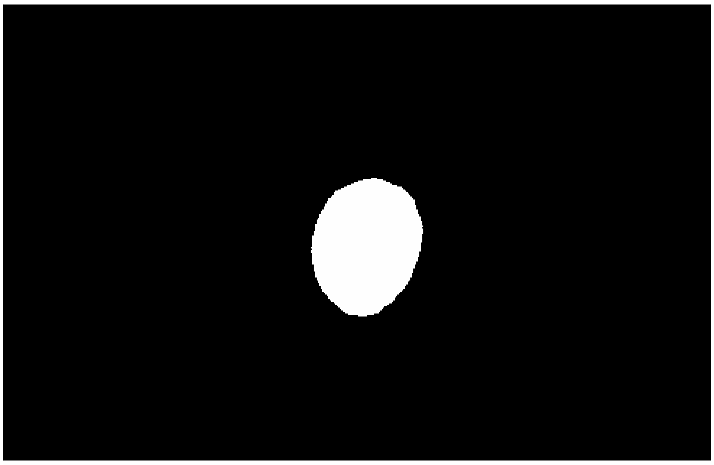


Figure4.8: binary image

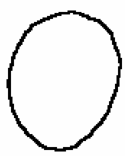


Figure4.9: Extracted edge

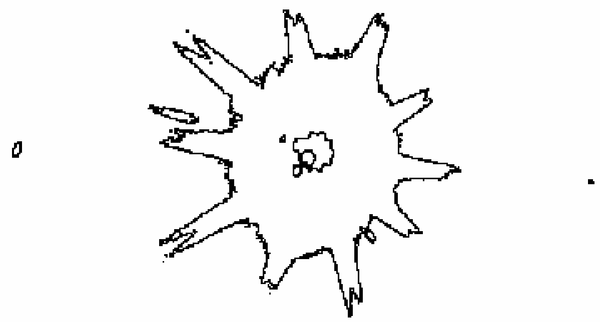


Figure4.10: Contour line of the radiance whom are exposured by 1/2000000, 1/200000, 1/20000, 1/2000, and 1/250

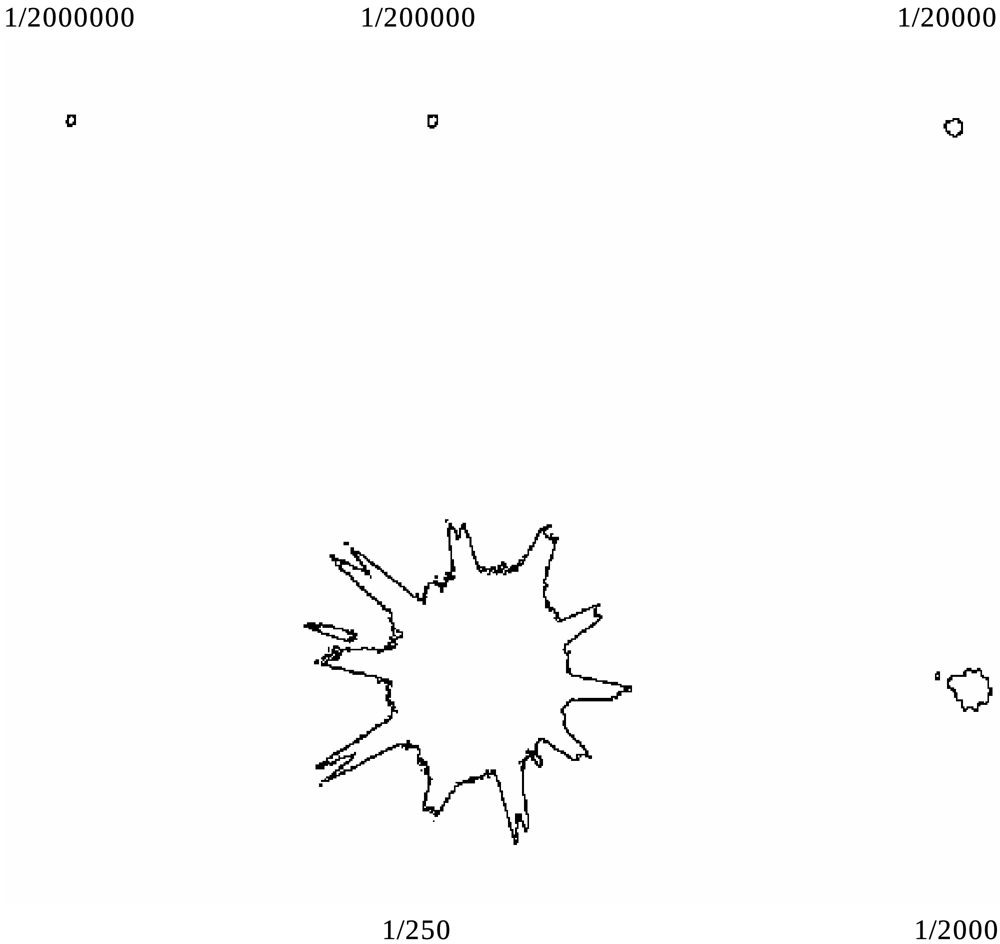


Figure4.11:comparison of the size

4. 2 Construction for high dynamic range

In the previous section, contour line of the light source is acquired. From the contour information, the intensity without saturation can then be estimated. It is then possible to create the image without saturation. That is the dynamic range of the image is increased. Fig 4.13 and Fig.4.14 show the constructed image with different dynamic range.

Fig 4.12 shows the saturation point. The center of the sun is black. This means that the pixel of the center of the sun cannot be calculate.

Fig 4.13 and Fig.4.14 are not saturated. These can use to be a light environment in Chapter3. It makes better image than the conventional method.

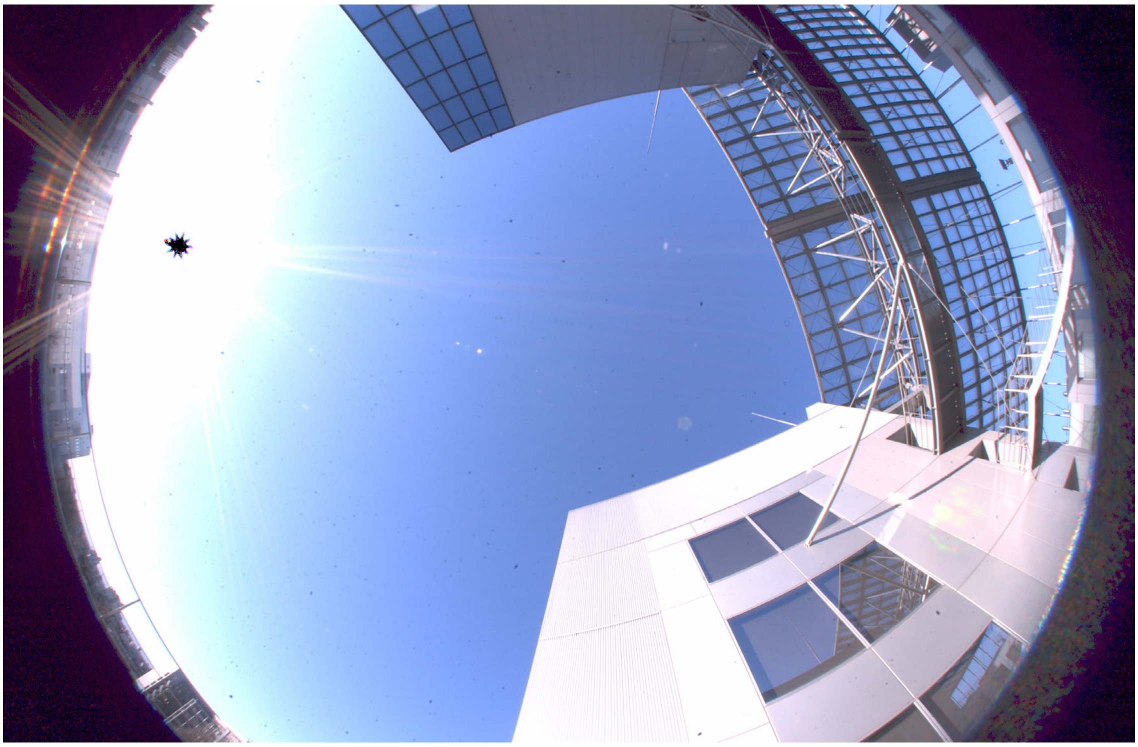


Figure4.12: image made from all saturation images.

Figure4.13: image with no saturation

Figure4.14: Downing exposure of Figure4.13

Chapter5

Conclusion

This paper introduced a method for measuring a radiance map on the sunshine, and creating a high dynamic range of the sunshine. In conventional method, we cannot create too high density object. The high dynamic image of the sunshine in this paper can use as the light source image for the image processing like Chapter 3. As a result , our method can superimpose virtual objects with convincing shading and shadows onto real scene.

Reference

[1] Paul E. Debvec, Jitendra Malik “Recovering High Dynamic Range Radiacne Maps from Photographs” Proceeding of SIGGRAPH 97, Computer Graphics Proceedings, Annual Conference Series, pp.369-378

[2] http://www.debvec.org/

[3] Tsai,R.Y. “A Versatile Camera Calibration Technique for High Accuracy 3D Machine Vision Metrology Using Off-the Shelf TV Cameras and Lenses.” IEEE Journal of Robotics and Automation 3(4):pp323-344, August 1987

[4] T. Mitunaga and S. K. Nayar “High Dynamic Range Imaging: Spatially Varying Pixel Exposures” proceedings of IEEE conference on Computer Vision and Pattern Recognition

[5] http://radsite.lbl.gov/radiance

[6] Imari Sato, Yoichi Sato, Katsushi Ikeuchi “Acquiring a Radiance Distribution to Superimpose Virtual Objects onto a Real Scene” IEEE Transactions on Visualization and Computer Graphics, Vol.5, No.1, pp.1-12, January-March 1999

[7] Paul E. Debvec, Jitendra Malic “Rendering synthetic objects into real scenes: Bridging traditional and image-based graphics with global illumination and high dynamic range photography”, Proceeding of SIGGRAPH 98, Computer Graphics Proceedings, Annual Conference Series, pp.189-198