Compensation of Over and Under Exposure Image Using Multiple Light Switching

Jonghoon Im, Hiromitsu Fujii, Atsushi Yamashita and Hajime Asama, *The University of Tokyo*

***Abstract*—In this paper, we propose a method to compensate the over and under exposure regions in the image. The image processing consists of four steps. Firstly, two images are acquired by alternately turning on and off illuminations which set in two different positions. Then the image obtained first is defined as base image and the image obtained second is defined as sub image. Secondly, over and under exposure regions are extracted from the base image. Thirdly, luminance of the base image and the sub image is corrected. Finally, the over and under exposure regions in the base image are compensated by the sub image. The experiment results show that the over and under exposure regions in the base image are recovered by our proposed method.**

I. INTRODUCTION

When people investigate dangerous place where they cannot enter, it is necessary to use remote control robots. Especially, in order to obtain the information of environment in dark area without external lighting as shown in Fig. 1, it is necessary to use some lightings which are attached to the robot. However, when the lightings which are attached to the robot were used, it is difficult to illuminate targets equally like lightings which are attached to the ceiling. In this case, a serious problem occurs, that a portion of the image is unclear because of over and under exposure. And operator has difficulty in controlling the robot in this case.

In order to solve this problem, Multi-Exposure Fusion (MEF) techniques [1], [2] and High Dynamic Range (HDR) imaging [3], [4], [5] techniques have been proposed. These techniques are obtaining one image by combining a plurality of images with different exposure level. For example, the bright areas is extracted in the image whose exposure value is decreased and the dark areas is extracted in the image whose exposure value is increased. Then the image is clarified by combining extracted areas. If the more images are used, dynamic range of the combined image becomes large and it made the over and under exposed areas are removed effectively [5]. As a method of acquiring a plurality of images having different exposure value, method of adjusting the shutter speed [6], [7], [8] and using a beam splitter [9], [10], [11] were proposed.

However, it is difficult to compensate the over exposed areas and the under exposed areas using previous methods in the environment that has large contrast such as Fig. 1. In the previous methods, when the lighting is so strong or the distant from the lighting to the object is so close, the over and under exposed areas in the image are not recovered correctly because the over and under exposed areas severely are damaged.

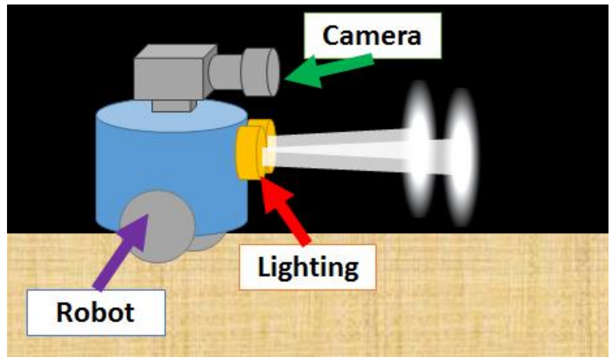


Fig. 1. Investigation using remote controlled robot with attached lightings

To solve this problem, it is necessary to acquire multiple images which the location of the over and under exposure areas is different. In order to acquire multiple images, we use multiple lightings which can be controlled freely in this research.

In this paper, we propose a method to compensate the over and under exposure region in the image using multiple light switching. We assume the situation that operator investigates in a dark environment using a remote control robot like Fig. 1. Two lightings, such as the headlights of the car are attached to the left and right of the front of the robot, and each lighting can be turned on and off by the operator.

The rest of the paper is organized as follows. Section 2 describes proposed method, and Section 3 depicts experiment and the result. Finally, Section 4 concludes the paper.

II. PROPOSED METHOD

We propose the method that the over and under exposure areas in the image can be compensated by alternately tuning on and off multiple lightings which set are in different position. In this study, we use two lightings. The schematic view of our proposed method is shown in Fig. 2. The image processing consists of four steps. Firstly, two images are acquired by alternately turning on and off two illuminations which set in two different positions. Then the image obtained first is defined as base image and the image obtained second is defined as sub image. Secondly, over and under exposure regions in the image are extracted from the base image.

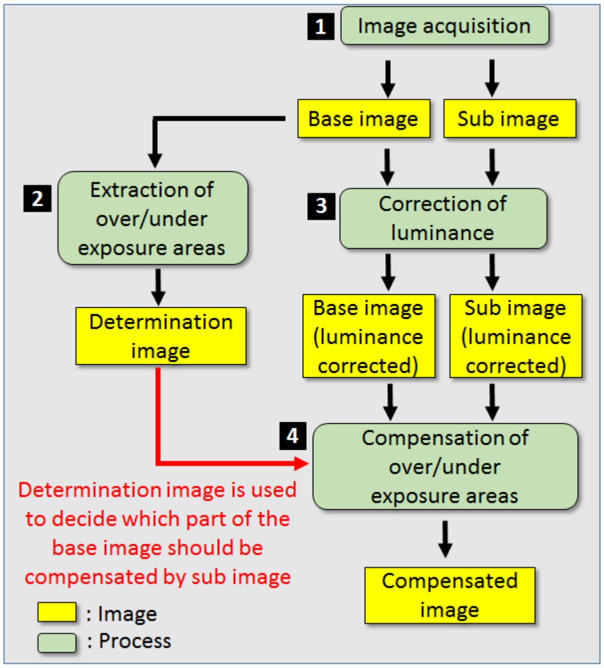


Fig. 2. The schematic view of our proposed method for compensation of over/under exposure using two images obtained in multiple lighting system.

Thirdly, luminance of the base image and the sub image is corrected. Finally, the over and under exposure regions in the base image are compensated by the sub image. Each step is described in detail and two prepared sample images are used for explaining the process of our proposed method.

A. Image Acquisition

In this process, multiple photographs that over and under exposure appeared in different location are captured by changing lighting condition at the same background (Fig. 3(a)). In this research, two images are acquired by alternately turning on and off each illumination which set in two different positions. The first acquired image set to base image $\boldsymbol{I}_0^{\text{base}}$ (Fig. 3(b)) and the other image set to $\boldsymbol{I}_0^{\text{sub}}$ (Fig. 3(c)). For example, the over exposure is appeared in the lower left of Fig. 3(b) and the under exposure is appeared in the upper right of the Fig. 3(b). On the other hand, the over exposure is appeared in the lower right of Fig. 3(c) and the under exposure is appeared in the left of the Fig. 3(c).

B. Extraction of Over and Under Exposure Areas

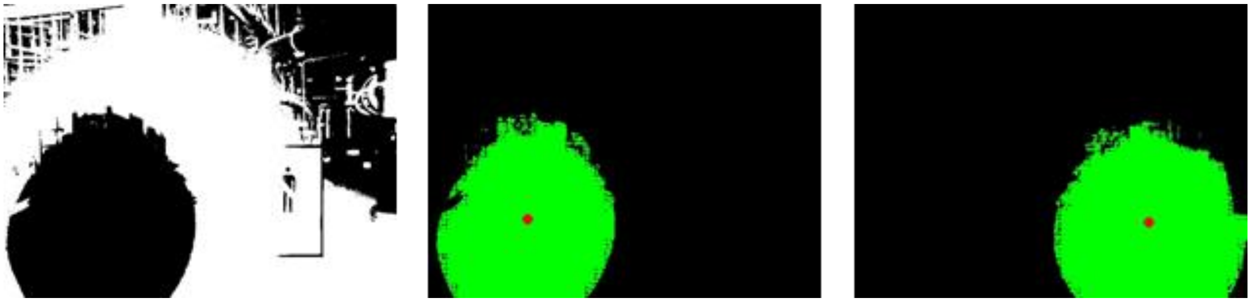
This process extracts the over and under exposure areas in the base image in order to get rid of these areas. Two threshold values τ_H and τ_L which are set in advance are used for the extraction as shown (1).

$$\boldsymbol{D}(i,j) = \begin{cases} 1 & \text{if } \tau_H > \boldsymbol{I}_0^{\text{base}}(i,j) > \tau_L \\ 0 & \text{otherwise} \end{cases}, \quad (1)$$

where $\boldsymbol{I}_0^{\text{base}}(i,j)$ is a pixel value of the base image coordinates (i, j). The pixel value describes how bright that pixel is. $\boldsymbol{D}$ is the reference matrix for determining over and under exposure areas, which is obtained as a result of the extraction process of over and under exposure. This reference matrix is defined as a determination image. If the pixel value of the base image coordinates (i, j) is over τ_H which is set in advance, it is determined over exposure areas and the pixel value is converted to 0. If the pixel value of the base image coordinates (i, j) is under τ_L which is set in advance, it is determined under exposure areas and the pixel values is converted to 0. Otherwise if the pixel value of the base image coordinates (i, j) is included between τ_H and τ_L, it is determined non-over or under exposure areas and the pixel value is converted to 1. This assumption has been widely used in many related publications [12], [13], [14] to extract over and under exposure pixel. As a result, the determination image $\boldsymbol{D}$ is acquired (Fig. 4(a)). The over and under exposure areas are

(a) (b) (c)

Fig. 3. Images obtained in image acquisition step : (a)The background image, (b)The base image $\boldsymbol{I}_0^{\text{base}}$ which can be obtained by turning on the left lighting, (c)The sub image $\boldsymbol{I}_0^{\text{sub}}$ which can be obtained by turning on the right lighting.



(a) (b) (c)

Fig. 4. Image obtained in extraction of over and under exposure areas step and images obtained in finding center of irradiated area step : (a)The determination image $\boldsymbol{D}$, (b)The center of the irradiated area $\boldsymbol{C}^{\text{base}}$ in Fig. 3 (b), (c)The center of the irradiated area $\boldsymbol{C}^{\text{sub}}$ in Fig. 3 (c).

displayed in black and non-over and under exposure areas are displayed in white in the Fig. 4(a).

C. Luminance Correction

The brightness distribution of the base image $\boldsymbol{I}_0^{\text{base}}$ and the sub image $\boldsymbol{I}_0^{\text{sub}}$ is changed by the illumination. It can be confirmed by comparing Fig. 3 (b), (c) that is acquired by changing light condition. In order to obtain an image, it is necessary to correct the brightness distribution of the acquired images. In this step, firstly we find the center of irradiated area, secondly correct the brightness of each pixel by considering distance from the center of the irradiated area.

In order to find the center of irradiated area, firstly the over exposure areas that are caused by lightings are extracted. One threshold value τ_C which is set in advance is used for the extraction as shown (2).

$$\boldsymbol{C}(i,j) = \begin{cases} 1 & \text{if} \quad \boldsymbol{I}_0^{\text{base}}(i,j) > \tau_C \\ 0 & \text{otherwise} \end{cases}, \tag{2}$$

where $\boldsymbol{I}_0^{\text{base}}(i, j)$ is the pixel value of the base image coordinates (i, j), $\boldsymbol{C}$ is the obtained image as a result of luminance correction process. And the image is defined as an image of the center of the irradiated area $\boldsymbol{C}$. If the pixel value of the base image coordinates (i, j) is over τ_C which is set in advance, it is determined over exposure area and the pixel

(a) (b)

Fig. 5. Images obtained in luminance correction step : (a)The luminance corrected image $\boldsymbol{I}_p^{\text{base}}$, (b)The luminance corrected image $\boldsymbol{I}_p^{\text{sub}}$.

(a) (b) (c)

Fig. 6. Images obtained in compensation of over and under exposure areas step : (a)The output areas from the base image, (b)The output areas from the sub image, (c)The compensated image $\boldsymbol{I}_f$.

value is converted to 1. Otherwise it is determined non-over exposure area and the pixel value is converted to 0. As a result, the center of the irradiated area ***C*** is acquired (Fig. 4(b)). The over exposure areas are displayed in green and non-over exposure areas are displayed in black in the Fig. 4(b). Next, the center of the irradiated area in the over exposure areas is searched. Acquired position of the center of the irradiated area set to (Xc, Yc). The position is displayed in red circle in the Fig. 4(b). The same procedure is performed to the sub image (Fig. 4(c)).

Then, we correct the luminance of the images using distance between the center of the irradiated area and each pixel. In the Fig. 3(b) and Fig. 3(c), around the center of the irradiated area is the brightest. And the luminance become gradually darker when the distance between the center of the irradiated area and each pixel become longer.

$$\boldsymbol{L}'(i, j) = \alpha \cdot \boldsymbol{L}(i, j) \cdot r^2 , \tag{3}$$

$$r = \sqrt{(i - Xc)^2 + (j - Yc)^2} , \tag{4}$$

where α is correction factor which is set in advance, $\boldsymbol{L}(i, j)$ is luminance value at the coordinates (i, j) before luminance correction, r is the distance between the center of the irradiated area and each pixel, $\boldsymbol{L}'(i, j)$ is luminance value at the coordinates (i, j) after luminance correction and Xc and Yc are the position of the center of the irradiated area. The luminance correction value in the equation (3) is determined depending on the distance from the center of the over exposure area, regardless of the shape of the object. As a result of the luminance correction, the obtained image is set to $\boldsymbol{I}_p$ (Fig. 5(a), (b)).

D. Compensation of Over and Under Exposure Areas

In this step, the over and under exposure areas of the base image are compensated by sub image. The determination image D (Fig. 4(a)) which is obtained in Section II-*B* is used. The rule of the synthesis is shown in (5).

$$\boldsymbol{I}_f(i, j) = \begin{cases} \boldsymbol{I}_p^{\text{base}}(i, j) & D = 1 \\ \boldsymbol{I}_p^{\text{sub}}(i, j) & D = 0 \end{cases} , \tag{5}$$

The areas where $\boldsymbol{D}(i, j)$=1 in the determination image D, which are shown as white in Fig. 4(a), are compensated by the base image after luminance correction (Fig. 5(a)). The output areas from the base image are shown as Fig. 6(a). The areas where $\boldsymbol{D}(i, j)$=0 in the determination image D, which are shown as black in Fig. 4(a), are compensated by the sub image after luminance correction (Fig. 5(b)). The output areas from the sub image are shown as Fig. 6(b). As a result of this process, compensated image is obtained and the image is defined as $\boldsymbol{I}_f$ (Fig. 6(c)).

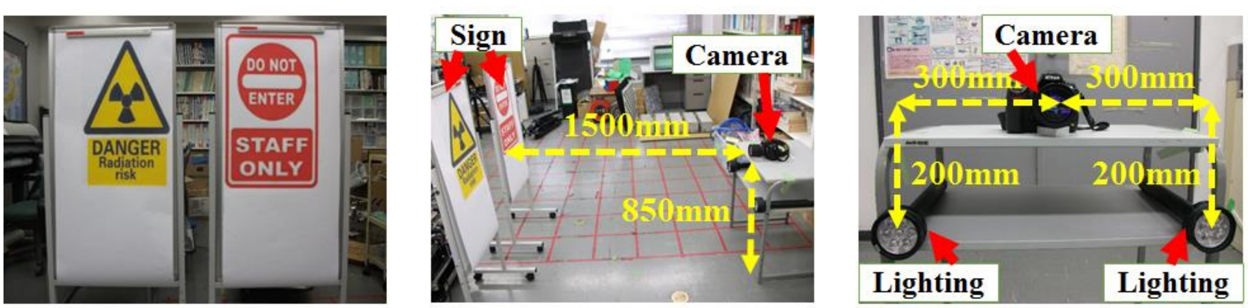
III. EXPERIMENT

A. Experiment environment

Two lightings are placed on the left and right sides of the camera in order to acquire two images that over and under exposure appeared in different location. For the experiment,

Table 1 Photographing conditions

Camera	NIKON D200
Definition	640 ×480
ISO	1,000
F-number	*f*/5
Shutter speed	1/20sec
Focal length	18mm
Luminance of lighting	1,000lm



(a) (b) (c)

Fig. 7. Experiment environment : (a)Two signs which were used in the experiment, (b)The distance between the signs and the camera, (c)The distance between the camera and the lightings.

(a) (b) (c)

Fig. 8. Experiment result : (a)The base image $\boldsymbol{I}_0^{base}$ which is used in the experiment, (b)The sub image $\boldsymbol{I}_0^{sub}$ which is used in the experiment, (c)The compensated image $\boldsymbol{I}_f$. which is obtained by the proposed method.

we prepared two signs in advance (Fig. 7(a)). 'DANGER Radiation risk' letters were written on the left side sign, and 'DO NOT ENTER, STAFF ONLY' letters were written on the right side sign. Fig. 7(b) showed the distance between the signs and the camera, and Fig. 7(c) showed the distance between the camera and the lightings. The height of the camera was 800mm from the floor, and the distance between the signs and camera was 1500mm as shown in Fig. 7(b). The left side lighting was located in 200mm under 300mm left side of the camera, and the right side lighting was located in 200mm under 300mm right side of the camera as shown in Fig. 7(c). All of the photographing conditions were fixed except the distance between the camera and the lightings during the image acquisition process. The photographing conditions are depicted in Table 1. Finally, two images are acquired by alternately turning on and off each lighting which set in two different positions.

B. *Experiment result*

All experiments are simulated on a CPU 2.5 GHz PC with 8 GB RAM. The computing time of the proposed method is about 0.14 seconds in C++. The image $\boldsymbol{I}_0^{base}$ that was used as the base image in this experiment was shown in Fig. 8(a), and the image $\boldsymbol{I}_0^{sub}$ that was used as the sub image in this experiment was shown in Fig. 8(b). Fig. 8(c) described the result image which was combined by our proposed method. In the base image, the over exposure appeared on the left side sign and the under exposure appeared on the right side of the image. In consequence, the letters which were written on the left sign lost the color information and it cannot be read. Also the right side of the image cannot identify because of the under exposure. On the other hand, in the sub image, the over exposure appeared on the right side sign and the under exposure appeared on the left side of the image. As a result, the letters which were written on the right sign lost the color information and it cannot be read. The left side of the image cannot identify because of the under exposure. As the result of applying the proposed compensation algorithm to the base image, the over exposed areas in the base image became clear, and 'DANGER Radiation risk' letters became visible. Also, the under exposed areas in the base image were compensated and the areas became clear.

In our compensation method, one image sets to base image and the other image sets to sub image. And the over and under exposure areas in the base image were compensated by same areas from the sub image. As a result, in the case of the over or under exposure areas in the base image belong to over or under exposure area in the sub image, it was not successfully corrected. In order to solve this problem, it is necessary to acquire images that the over and under exposure areas in the base image and the over and under exposure areas in the sub image do not locate the same position. For example, it is possible to obtain a plurality of images that the over and under exposure locate in different position by increasing the number of lightings.

IV. CONCLUSION

In this paper, we proposed the method of compensation the over and under exposure images using multiple light switching. We assume the situation that operator investigates in a dark environment using a remote control robot, and in this time, two lightings, such as the headlights of the car are attached to the left and right of the front of the robot, and each lighting can be turned on and off by the operator. And we build experimental environment that we assumed. Next, two images were acquired using two light switching. Finally, the over and under exposure areas were compensated by the proposed method. The experimental results showed the effectiveness of our proposed method.

For future work, we plan to apply our method to real situation such as Fukushima nuclear power plant. And it is necessary to control brightness of the light or adjust the angle of the light not only ON/OFF of the light in order to acquire more images which the over and under exposure areas appeared in different location.

ACKNOWLEDGMENT

This research was supported by the Agency for Natural Resources and Energy and International Research Institute for Nuclear Decommissioning, Japan, Fiscal Year 2013.

REFERENCES

[1] T. Mertens, J. Kautz and F. Van Reeth, "Exposure Fusion: A Simple and Practical Alternative to High Dynamic Range Photography," *Computer Graph. Forum*, Vol. 28, No. 1, pp. 161–171, 2009.

[2] R. Shen, I. Cheng and A. Basu, "QoE-Based Multi-Exposure Fusion in Hierarchical Multivariate Gaussian CRF," *IEEE Transactions on Image Processing*, Vol. 22, No. 6, pp. 2469-2478, 2013.

[3] S. Mann and R. W. Picard, "On being 'Undigital' with Digital Cameras : Extending Dynamic Range by Combining Differently Exposed Pictures," *Proceedings of the 48th Annual Conference of the Imaging Science and Technology*, pp. 442-448, 1995.

[4] K. Agusanto, L. Li, C. Zhu and S. W. Ng, "Photo Realistic Rendering for Augmented Reality Using Environment Illumination," *Proceedings of the Second IEEE and ACM International Symposium on Mixed and Augmented Reality*, pp. 208-216, 2003.

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

[6] D. C. H. Schleicher and B. G. Zagar, "High Dynamic Range Imaging by Varying Exposure Time, Gain and Aperture of a Video Camera," *2010 IEEE Instrumentation and Measurement Technology Conference*, pp. 486-491, 2010.

[7] Y. Piao and W. Xu, "Method of Auto Multi-Exposure for High Dynamic Range Imaging," *2010 International Conference on Computer, Mechatronics, Control and Electronic Engineering*, Vol. 6, pp. 93-97, 2010.

[8] N. Barakat and T. E. Darcie, "Minimal Capture Sets for Multi-Exposure Enhanced-Dynamic-Range Image," *2006 IEEE International Symposium on Signal Processing and Information Technology*, pp. 524-529, 2006.

[9] M. D. Tocci, C. Kiser, N. Tocci and P. sen, "A Versatile HDR Video Production System," *ACM Transactions on Graphics*, Vol. 30, No. 4, pp. 41, 2011.

[10] M. Aggarwal and N. Ahuja "Split Aperture Imaging for High Dynamic Range," In *Proceedings of IEEE International Conference on Computer Vision 2001*, pp. 10 – 17, 2001.

[11] M. Aggarwal and N. Ahuja "Split Aperture Imaging for High Dynamic Range," *International Journal of Computer Vision 58*, pp. 7–17, 2004.

[12] W. Zhang and W. K. Cham, "Gradient-Directed Multi-Exposure Composition," *IEEE Transactions on Image Process*, vol. 21, no. 4, pp. 2318–2323, 2012.

[13] T. Jinno and M. Okuda, "Multiple Exposure Fusion for High Dynamic Range Image Acquisition," *IEEE Transactions on Image Process*, vol. 21, no. 1, pp. 358–365, 2012.

[14] O. Gallo, N. Gelfand, W. Chen, M. Tico, and Kari Pulli, "Artifact-Free High Dynamic Range Imaging," *Proceedings of IEEE International Conference on Computational Photography*, pp. 1–7, 2009.