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Controlled Illumination for the Object Recognition with Projector Camera Feedback

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Abstract

In this paper a novel image capturing method for a solution of shading problem in computer vision is proposed. In the experiments, we performed the evaluation about the conditions of environment lighting and additional lighting and proposed controlled lighting method. Image-processing of self quotient image algorithm, histogram equalization, and luminance equalization were used for pre-processing to remove shading from a captured image for the comparative evaluation. Through the evaluation of robustness assumed appearance based method, the proposed method showed most stable results. In addition to this, the capability of the high dynamic range image reconstruction with approximation by using of projector camera system has been shown.

1 Introduction

The shadow produced on the object's surface strongly depend on the lighting direction. The object recognition under the various illumination is one of the important problems in computer vision, and many methods have been proposed. For this solution, there are two main strategies of invariant features extraction and learning strategy for various illumination.

In the invariant features extraction, the histogram equalization (HE) [1, 2] is one of the effective pre-processing methods for the illumination change. For the facial image recognition, the Self Quotient Image (SQI) is popular and it is a promising pre-processing to improve robustness against attached shadow. Other popular feature extraction techniques are based on histogram equalization, Gamma correction, and logarithmic transforms [4, 5, 6]. For the learning strategy, the parametric eigenspace method [7] (PEM) is a major solution for shading problem. In the PEM, the direction of illumination can be used for one of parameter and environmental lighting can be estimate simultaneously. The property of illumination cone is also useful for the analysis of illumination. Okabe et. al. [8] proposed an object recognition method under varying illumination that used properties of illumination cone and support vector machine for the learning.

The invariant features extraction strategies are not successful for the environment which has the strong shadow since the color or edge information in the shaded parts is varying image noise. On the contrary, the learning strategy is stable for this problem because its shade can be used for the recognition as a one of important feature. However, all of possible combination of illumination variation should be learned in the learning term and it is computation consuming. Besides these approach, we can contrive in image capturing process.

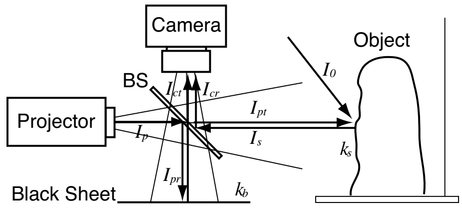


Figure 1. Co-linear projector camera system

In the machine vision research, lighting modules of diffused-on-axis and rings are used for shadow-free inspection. These lighting mechanism can reduce a cast shadow, but it only raises scene brightness uniquely, and the unevenness of brightness caused by environmental light still remains. Recently, the projector camera systems were proposed for the irradiance compensation and for the appearance control [9, 10, 11, 12, 13]. We believe these techniques are useful not only for the human visual perception assists but also for pattern recognition as well. In this paper, we propose a novel imaging technique which employed a projector camera system for the scene illumination control.

2 Shade Removal by Pro-Cam Feedback

2.1 Co-Axial Projector Projection System

In this research, we consider a co-linear projector system

to remove shade from the dynamic scene that illustrated in figure 1. We denote the illumination decreasing for the spherical distribution is included in screen reflectance coefficients in the following equations for the approximation. The projection light ray I_p is divided to

$$I_p = I_{pt} + I_{pr}, \tag{1}$$

where I_{pt} is transmitted light ray, and $I_{pr}$is reflected light ray. These light rays can be express by $I_{pt} = tI_p$, $I_{pr} = rI_p$ by the beam splitter of transmission factor t (reflection factor $r = 1 - t$), and I_{pt} and I_{pr} are projected on the scene and black sheet. The reflection light ray from the scene I_s can be expressed as

$$I_s = k_s(I_{pt} + I_0), \tag{2}$$

where k_s is reflection factor on the object, I_0 is the environment light ray. Thus, the incident light ray

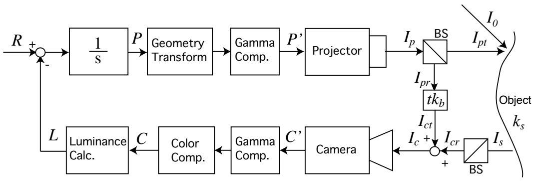


Figure 2. System diagram

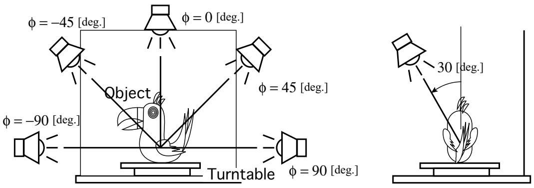
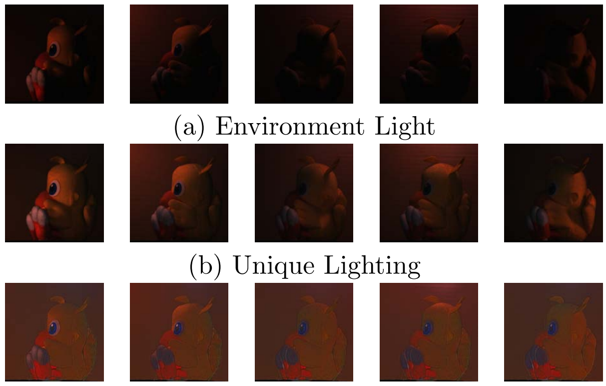


Figure 3. Environment Light Setup



(a) Environment Light

(b) Unique Lighting

(c) Proposed Method

Figure 4. Images with Various Light Directions

from the scene I_{cr} can be expressed as

$$I_{cr} = rI_s = trk_sI_p + rk_sI_0. \quad (3)$$

In addition to received light ray I_c includes I_{cr} and light ray from black sheet

$$I_{ct} = tk_bI_{pr} = trk_bI_p, \quad (4)$$

where k_b is reflection factor of black sheet. Since the light ray I_{ct} make artifacts, we should make it $I_{cr} \gg I_{ct}$ for the clear scene imaging. However, the power ratio of I_{cr} and I_{ct} is depending reflection factors k_s and k_b since $I_0 \approx 0$. Therefore we use low reflection blackout material and keep it as far away from camera as possible to make small k_b.

2.2 Irradiation Uniformalization

To remove shadow in the captured image, we composed feedback system shown in fig. 2 and make scene irradiance unique. The compensated image C is calculated from the captured image C' via gamma compensation and color correction. The projection image P is generated by the integration of the error between reference brightness R and luminance L of the image C. Then, the P is projected from the projector after the geometry transformation and gamma compensation. When $k_b \ll k_s$, we can describe received light source I_c as

$$I_c = I_{cr} + I_{ct} \approx rI_s. \quad (5)$$

Thus, $C \propto I_s$ by gamma correction of camera response. Therefore, we can suppose this feedback system linear system by the response linearization of projector, and the brightness of image C is controllable with projector camera feedback.

3 Experimental Results

3.1 Scene Irradiance Control

The XGA resolution commercially manufactured projector and IEEE1394 camera are used for projector camera system and those equipments has been placed coaxially with the beam splitter. We chose beam splitter of reflection factor $r = 0.3$ on an experimental basis to project bright I_p, and to get enough intensity of I_c compared with image noise. The compact fluorescent lamps (Equivalent to 100W lamp) were arranged as shown in fig. 3 . It is used as the lighting environment.

The object is placed on the turn table and images are captured from several orientations with variable directions of environment light. The figure 4(a) shows the captured images with environment light of $\phi = -90, -45, 0, 45, 90[deg.]$. Since a single light source is used for environment light, the high contrast is observed in captured image for strong attached shadow. With the uniform assistant luminaire, which is the white image projection, we got brighter images under this environmental light shown in figure 4(b). The attached shadows seen in the figure 4(a) were reduced, but these images still have brightness unevenness which is caused by attached shadow, and it leads recognition error by appearance based image recognition such as eigenspace method. However, if we use the irradiation uniformalization by the projector camera feedback, the attached shadow was completely removed from the scene as in the figure 4(c). Unevenness in these images was derived from strong reflection of environment because the brightness of Chas exceeded R without assistant luminaire. For example, at the head of the puppet.

3.2 Evaluation of the Stability

In order to demonstrate the effectiveness, we compared with condition of environmental light (EL) and several pre-processing methods of image capturing using uniform assistant luminaire in addition to EL (WL), WL with histogram equalization (WL-HE), WL with self quotient image algorithm (WL-SQI), and image capturing using irradiation uniformalization under the environmental lighting by the projector camera feedback (FB). It should be noted that in case of WL, we used assistance luminaire of comparable power to EL, and we decided R so that average power of P became equal to WL power in FB. In addition to these, we performed evaluation by WL with luminance equalization (WL-LE). This WL-LE achieves similar appearance with FB without projector camera feedback. However, the difference will be seen from the aspect of dynamic range, since white-out and black-out effects are seen in specular and

Figure 5. Shade Removal with various methods

dark region in WL condition. The sample images were captured from 36 steps object orientation $\theta = 0, 10, \ldots, 350[deg.]$ and 5 different environment light directions $\phi = -90, -45, 0, +45, +90[deg.]$ as shown in fig. 3. In this experiment, we suppose the appearance base method as an object recognition method and we calculated the eigenspace for the sample set of $\phi = 0[deg.]$. The each column in the figure 5 shows 3 objects used for the experiment, and from the top to bottom, processing results by EL, WL, WL-HE, WL-SQI, FB and WL-LE are shown in each row.

In this figure, we can see strong attached shadow for the uneven environmental light in EL. The uniform assistant luminaire is effective to get better quality of image, but affection for attached shadow is remaining in WL and WL-HE. In the WL-SQI, the use of self quotient image algorithm for WL contributes to get much better result. The faint unevenness remains by the strong reflection in FB, but the attached shadow was completely removed from the scene. In the last row, WL-LE produced similar images with FB. However, pseudo colors are seen in the black-out region caused by attached shadow.

Figure 6 shows parametric eigenspace curves of object 2 about 5 directions of environmental lighting in each method. The samples were plotted by using first and second principal components and each locus is corresponding to environment light direction

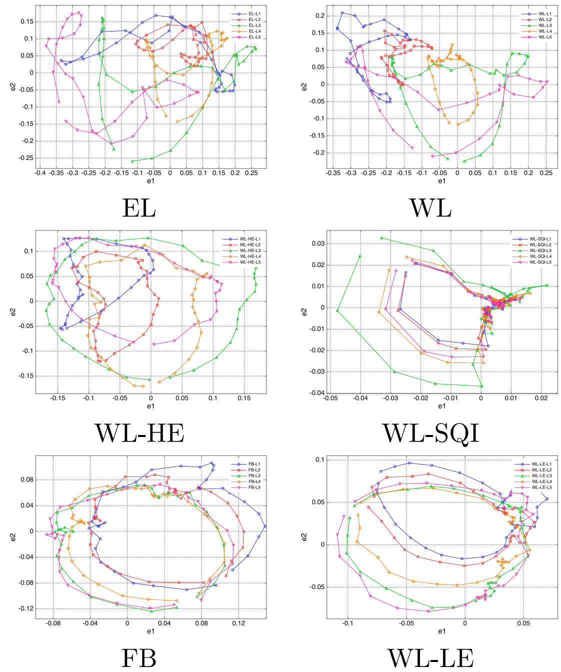


Figure 6. Parametric Eigenspace Cuves

$\phi = -90, -45, \ldots, 90[deg.]$. From these results, we can see the stability of FB for the various environment light directions.

Table 1 shows recognition ratio with each pre processing method. The the learning samples included all objects samples of $\phi = 0$ lighting condition at each method and the eigen vectors were calculated for feature space. We employed the Nearest Neighbor discernment rule for the recognition process. The sufficient interclass distribution was seen in the global eigenspace for all methods. Hence, we can see comparable result in WL-SQI, FB and WL-LE, but, slightly advantage of FB has been shown in higher dimension.

4 Discussion

4.1 Performance Evaluation

The variance of the sample set $\phi = 0[deg.]$ is larger than other sample sets, and it shows a large locus in the eigenspace. It is that the eigen vectors are calculated with only sample set $\phi = 0[deg.]$ and it give maximum correlation to its samples. In the result of EL, since the attached shadow is dominant, the shape of loci are varying greatly according to lighting conditions. We can consider it caused by the lack of information at the dark pixels, and it makes drastic change of direction in the image vector space. For the assistant luminaire, WL makes image brighter and it improves uniformity but the trend of loci is still different. In the WL-HE, the histogram equalization reduces attached shadow effect and same trend has been obtained in loci. In the results of WL-SQI, we can see the similar figure of loci. However, those sizes are changing with different direction of environment light. On the contrary, stable and same size of similar loci can be seen in the result of FB. The slight differences arose by unevenness of image brightness caused by the strong reflection of environ-

Table 1. Comparison with Several Pre-processing

Dim	EL	WL	WL-HE	WL-SQI	FB	WL-LE
2	73.4	75.0	91.7	**99.7**	93.8	85.4
3	72.5	75.0	92.1	**99.8**	99.5	97.0
4	71.8	75.0	92.2	**99.8**	99.0	96.0
5	72.0	75.0	92.2	**99.8**	99.3	98.1
6	72.5	75.0	92.4	99.8	**100**	98.6
7	72.5	75.0	94.7	**99.8**	99.7	99.0
8	72.0	75.0	94.4	99.8	**100**	99.5
9	71.8	75.0	94.7	99.6	**100**	99.7
10	72.6	75.0	95.6	99.6	**100**	**100**

(a) Captured (b) Projection (c) Estimated

Figure 7. True Appearance Estimation

ment light. The WL-LE obtained similar loci with the results by FB, but, the size of locus is changed along with lighting direction. It can be thought the artifact color made these differences.

4.2 HDR imaging with Procam Feedback

The potential of proposed method that can acquire a stable image compared with other conventional methods for the various illumination is shown through the experimental results. It can be thought this robustness is caused by its dynamic range of each method. In case of EL, to get accurate color and to remove shadow by the histogram equalization and self quotient image algorithm makes image-noise at darker part because of low exposure. Utilizing of uniform assistant luminaire makes an image bright and reduces image noise. However, true color and texture information has been lost by the saturation because of strong reflection of assistance luminarie. Hence, we can say the high dynamic range imaging is necessary to remove strong attached shadow. The appearance of FB is not good for human perception since it has been changed scene illumination equally. However, brightness of every part is being controlled to the perceivable brightness of camera and we can estimate not saturated true reflectance from projection image P and captured-image C those are captured during the feedback process as shown in figure 7. With these images, we can get a high dynamic range image approximately by

$$C_{est} = C./(P + offset) \tag{6}$$

as shown in figure 7(c). We denote the operator ./ means the division at each element. The $offset$ is given by environmental lighting. The strong reflections by the environmental lighting on the fabric and texture at darker part are seen together in C_{est} since it has the high dynamical range. Additionally, the proposed method can capture this high dynamical range image continuously. It is another benefit of proposed method.

5 Summary and Conclusions

We have proposed projector camera feedback for the novel imaging technique to remove shadow by the irradiance equalization for the scene. For the dynamical adaptation, we composed a coaxial projector camera system by using beam splitter. Through the evaluation of robustness that assumed eigenspace method, the stable results are shown by the proposed method. Additionally, we have shown the high dynamic range image is generable by using of projection pattern for the lighting control.

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