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Specular Highlight Removal for High Reflection Surface with Linear Diffuser

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Abstract

In structured light 3D measurement field, when the object has smooth surface, it can form a highlight area due to the specular reflection, and the distortion of the object will make a large measurement error. In order to solve this problem, this paper use seven steps sine-phase shift combined with linear diffuser to remove highlight. Firstly, the principle of removing specular with diffuser is analyzed, then the overall design of the system is introduced, which includes 3D reconstruction and system calibration method. Finally the reconstructed experiments are carried out with ceramic plate. Experimental results show that the proposed method can significantly reduce the highlights area of reconstructed image compared with the highlights area without diffuser. The diffuser can obviously inhibited by highlights, although it can not completely remove the highlights, it plays a very important role in reconstructing specular object with more accurate and better quality.

Keywords: *Structured light; 3D measurement; Specular highlight; linear diffuser*

1. Introduction

Structured light vision measurement is the most effective way for obtaining objects three-dimensions (3D) information [1-2], It can realize 3D measurement on the human body in the industry of medicine, clothing, sculpture and archaeological *etc.*, [3-4]. In the 3D vision measurement technology, coded structure light can greatly improve measurement speed by projection patterns, and have more widely applications [5]. However, in industrial inspection area, there are large numbers of specular objects need to be measured, and highlights which exist on the specular objects will not only make the camera saturation, lost stripes gray level information, but also will change the stripe gray distribution, and influence the accuracy of stripe center extraction. The problem of highlight removal has become a difficult and common problem in 3D vision measurement area.

Shafer proposed double colour reflection model to separate reflection components [6]. Klinker *et. al.*, used T-shaped colour distribution features of diffuse and highlight pixels in the RGB colour space to remove highlights, but this T-shaped colour distribution is sensitive to noise [7]. S.P.Mallick reconstructed specular surfaces using colour, which can avoid image segmentation [8]. K. J.Yoon used voting mechanism to estimate the diffuse and specular reflection pixels, whereas it was not suitable for the complex textured surface [9]. R.Kokku *et. al.*, improve 3D surface measurement accuracy on metallic surfaces based on template feature extraction, however, it cannot get good results for

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objects with no or complex features [10]. Tan Ping used complementary method with surrounding region information of highlights to fill highlight areas [11]. Chai Yuting [12] put forward a highlight removal method based on frequency domain filtering, but this method was only applicable to the situation that surface curvature change is not significant. Wolff and Boult *et. al.,* [13] used the polarization method to separate the reflect components, the disadvantage of method is that it needs more images with different polarization direction, polarization quantities are determined by incident and exit angles. Toshihide Tsuru [14] used the elliptical polarization method to measure specular objects. however, the polarization method needs more polaroids, which increases the complexity of the experimental measurement. In terms of hardware processing, Rogerio [15] used the method of multi-light sources to reduce the influence of specularities, but multi-light source method can only reduce specular reflection, overlapping highlight part is still not be completely eliminated. In 2007, Guo Hongwei of the Shanghai University used a moving diffuse light source to measure the surface of a strong reflective object [16]; in 2012,the diffuser was applied to the strong reflection measurement field by S.K. Nayar, and achieved good results [17]. In 2014, Ken Sills [18] used the high power light emitting diode with programmable array to irradiate strong reflection surface, it can obtain a series of images reflecting the change of different angle of incident light, then can use these images to build reflection model, but there is still a problem of complex image mosaic.

Through the above analysis, double colour reflection model does apply to nonconductive material, not be applicable for ceramics and metal surfaces, and polarization method is easy to cause the camera's saturation when incident angle is close to 90 degrees. Multi-light sources and Multi- exposure method still has overlapping parts of highlight regions. S.K. Nayar used diffuser to avoid strong highlights and achieved good results. The paper was prompted by S. K. Nayar, in this paper, we take diffuser to establish the 3D measurement system based on coded structure light and carry out an experiment to

The paper is inspired by S. K. Nayar, analyzes the principle that the diffuser reduces specularities, and uses the projection phase shift coding and decoding method to achieve three-dimensional reconstruction for high reflective ceramic objects of different shapes, the experimental results show that the diffuser has the characteristics of reduction of specularities, which can reduce the specularity information of strong reflection surface.

2. The Principal of Removing Highlights with Diffuser

For conventional diffuser, as shown in Figure 1, chemical particles are often added in the substrate as diffused particles, which can cause lights refraction, reflection and scattering in multi-angles, when lights pass through the scattering layer with two different refractive indexs. As described in the paper [17], microstructure diffusion plate has high light transmittance, it can adjust the diffused angle, the space and energy distribution of light field and realize the different uniformity and transmittance. So in this paper, we use linear micro structured diffuser (NT43-029) to carry out 3D reconstruction experiments.

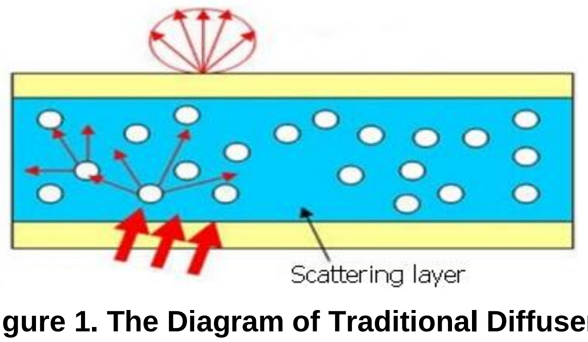

Figure 1. The Diagram of Traditional Diffuser

As shown in Figure 2 (a), point P lies on a specular highlight, its reflection light is beyond the scope of camera, so the point P will be a hole after the 3D reconstruction. As shown in Figure 2 (b), the diffuser is placed between the light source and object, which makes the strong incident illumination of point P from a single direction diffuse to the uniform illumination for several directions. Therefore, the reflected lights of point P are received by the camera, and the effective informations of point P can be reconstructed accordingly.

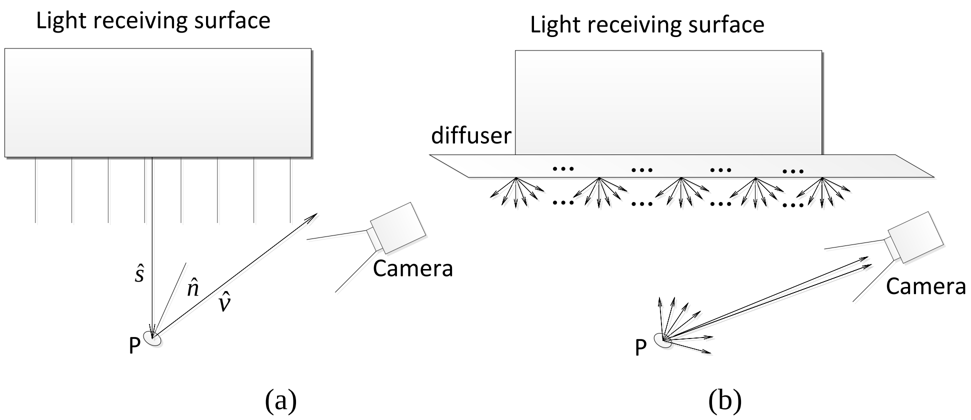

Figure 2. The Surface of Object Reflects the Strong Lights are Not Captured by the Camera

3. System Introduction

3.1. System Design

In actual measurement, the equipments used in our structured light 3D measurement system are an infoucus 82 Projector with XGA (1024*768) resolution and a DH-HV315UC industrial Camera with 2048*1536 pixels resolution, the diffuser is a lenticular array(Edmund Optics part number NT43-029). The scattering angle of diffuser is approximately ±50°degrees along the diffusion axis, and is negligible perpendicular to the axis. Figure 3 shows the structure of 3D measurement system.

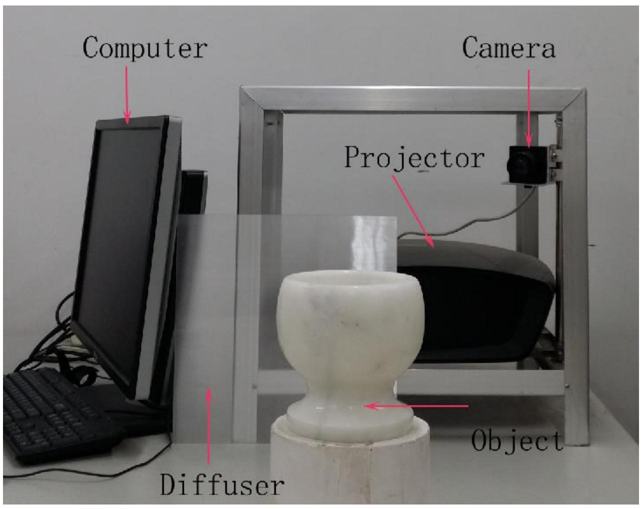

Figure 3. Three-Dimensional Measurement System

3.2. Camera Calibration

Camera calibration is important to 3D accuracy, for meeting the experiment requirement, as shown in Figure 4, a 450×600mm black dot matrix template with white background was designed. In order to ensure the accuracy, as shown in Figure 5, optical precision guide was used, and template moved along in the vertical direction of optical precision guide. Calibration errors are mainly from position errors of space standard point and image sampling point. In this paper, the accuracy of calibration template and optical precision guide is 0.1mm. The black dot center position in template can be extracted with gray center method.

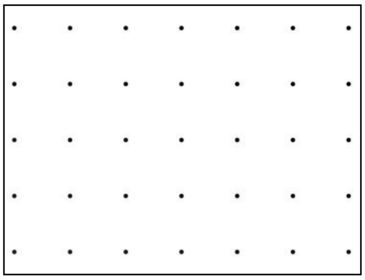

Figure 4. Calibration Template

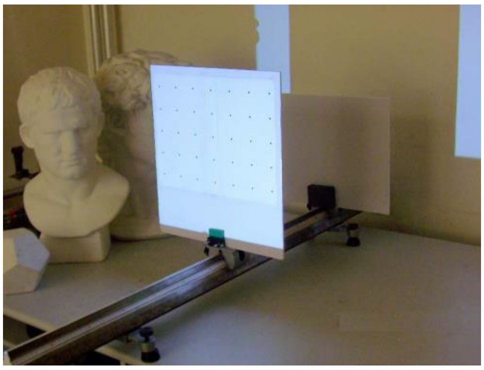

Figure 5. Calibration Device

The projection distance of the projector we used is from 1.5 to 10m, we set the projector in the shortest projected distance, the projection plane is used as the zero point in the process of camera calibration, and then take negative 4 position near the projector and take 4 position away from the projector.

Camera calibration can be divided into the following steps:

1. Use projector to project the white picture as light source and then capture dot matrix image in three different positions; Dot matrix image were taken respectively in the 0, +4, -4 three positions, where the projection plane is used as the zero point.

2. Binary images to dot matrix calibration template white background

3.Calculate the subpixel location of each image, and set up the corresponding relationship between the CCD image coordinates and the spatial standard point coordinates.

3.3. Projector Calibration

Now, the existed projector calibration methods are still have some problems, such as poor anti-interference ability, low calibration accuracy. In this paper, we use projector calibration method with orthogonal gray code. The projectd orthogonal gray code is shown in Figure 6, and the principal is shown in Figure 7. This calibration system consists of calibration template, optical precision guide and camera. As shown in Figure 7, the template can moved along in the vertical direction of optical precision guide, the calibrated projector project horizontal and vertical gray code patterns to template.

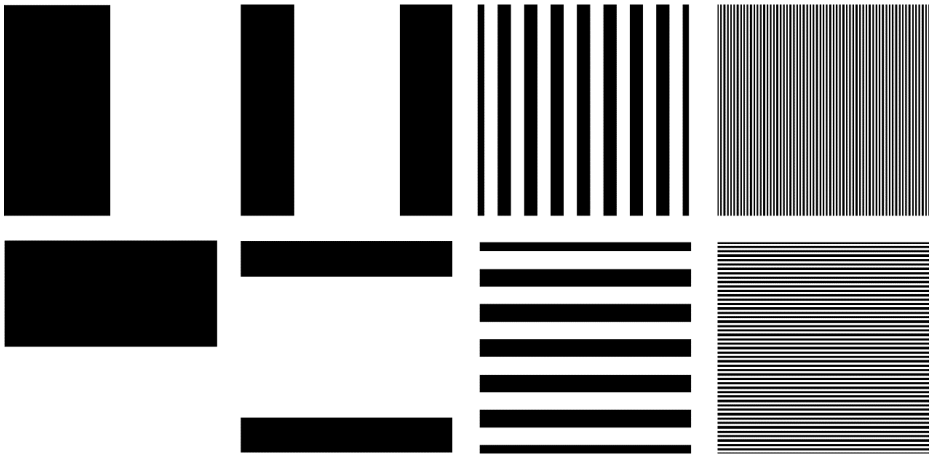

Figure 6. The Diagram of Orthogonal Gray Code

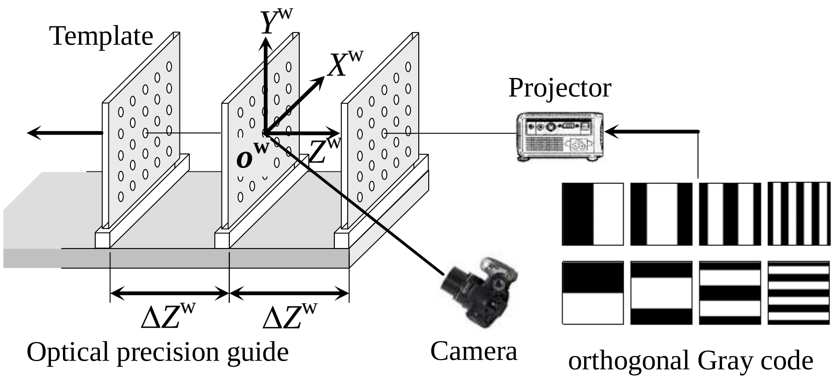

Figure 7. Projector Calibration Principle Based on Orthogonal Gray Code

Specific steps are as follows:

1. Use camera to capture three different positions of calibration template on the optical precision guide, the template is shown as Figure 4, and locate sub-pixel position of black dot with gray center method, then establish the relationship between coordinates of space standard point and coordinates of CCD sub-pixel point.

2. Use white template to replace standard template. At each position, horizontal and vertical gray code patterns were projected respectively. Each black dot in Step 1 all has a set of horizontal and vertical Gray code, so after capture these images, we use Formula 1 to calculate the DMD pixel position. then according to the DMD pixel position of each point, we can locate DMD sub-pixel of the point, finally we can get the corresponding relationship between the point’s coordinates of DMD pixel and the standard coordinates of the space.

$$n^{\mathrm{p}} = \frac{N^{\mathrm{p}}}{2} - \frac{N^{\mathrm{p}}}{2^{l}} \cdot (\Phi_{\mathrm{V}}(m^{\mathrm{c}}, n^{\mathrm{c}}) + 0.5)$$

$$m^{\mathrm{p}} = \frac{M^{\mathrm{p}}}{2^{l}} \cdot (\Phi_{\mathrm{H}}(m^{\mathrm{c}}, n^{\mathrm{c}}) + 0.5) - \frac{M^{\mathrm{p}}}{2} \quad (1)$$

3. From Step1 and Step2, the corresponding relationship between the point's coordinates of DMD pixel and the standard coordinates of the space can be got.

4. Experiment

Our experiment uses seven-step sinusoidal phase shift code as the encoding and decoding method. Figure 8, shows the diagram of projected sinusoidal phase shift code.

Figure 8. The Diagram of Projected Sinusoidal Phase Shift Code

Figure 9, is the result of the 3D reconstruction of ceramic plates. Figure 9b), and 9c) are the reconstruction results without diffuser and with diffuser respectively, Figure 9d), and 9e), are enlarged views respectively. From the result, we can see that the specularity is obviously reduced when the diffuser is used, and the texture of reconstructed image is more delicate.

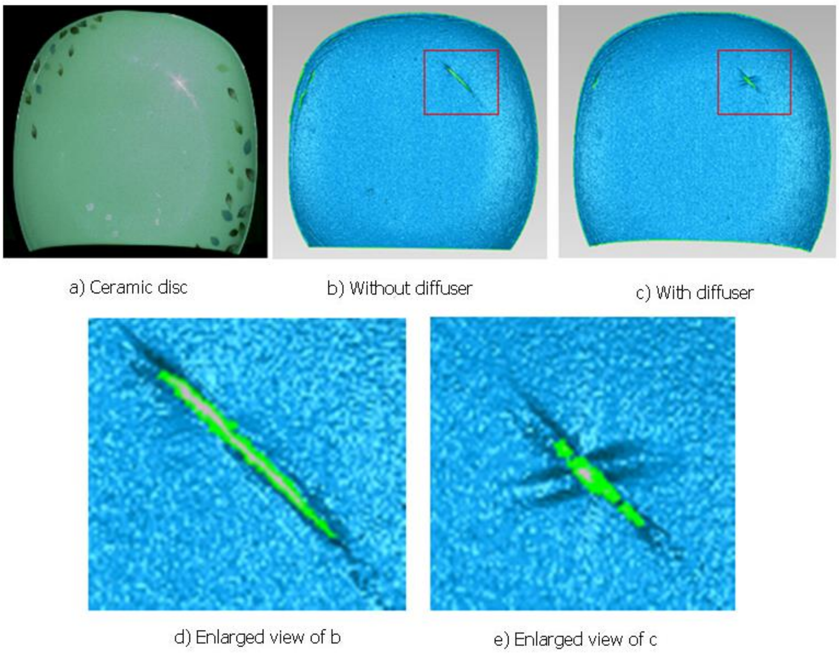

Figure 9. Reconstruction Result of a Ceramic Disc

In order to provide more intuitive result between diffuser and without diffuser, Table 1, shows the quantitative result of removing highlight. From Table 1, we can see that the diffuser can remove highlight from 1064 to 357, the reduced factor is 2.98. The diffuser can suppress highlight effectively.

Table 1. Comparison of Highlight Points

Object	If there is diffuser	the number of highlight pixels	The proportion %	The reduced factor
Plate	no	1064	1.20	2.98
	yes	357	0.40	

5. Conclusions

This paper use seven step sine-phase shift combined with diffuser of 3D reconstruction method for the study on highlights inhibition, the experimental results show that the proposed method can significantly reduce the highlights area of reconstructed image compared with the highlights area without diffuser. The diffuser can obviously inhibited by highlights, although it can not completely remove the highlights, it plays a very important role in reconstructing image with more accurate and better quality.

Acknowledgments

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References

[1] S. Zhang, "3D Surface Data Acquisition", Department of Mechanical Engineering, SUNY at Stony Brook, **(2003)** October 16.
[2] S. Xinzhu, "A Method on 3-D Shape Measurement and its Trend in Development", Measurement Transaction, vol. 2, **(2001)**, pp. 36-37
[3] C. Tomasi, A. Rafii and I. Torunoglu, "Full-size projection keyboard for handheld device", in Commun. ACM, vol. 46, **(2003)**, pp. 70–75.
[4] J. Neumann, C. Fermuller, Y. Aloimonos and V. Brajovic, "Compound eye sensor for 3d ego motion estimation", in IEEE International Conference on Robotics and Automation, **(2004)** May.
[5] X. Yu, L.Shan, S.Cao and H. Wu, "The review of structured light time encoding technologies", Journal of Harbin University of Science and Technology, vol. 15, no. 1, **(2010)**, pp. 98-102.
[6] S. Shafer, "Using color to separate reflection components", Color Research and Applications, vol. 10, no. 4, **(1985)**, pp. 1.
[7] R. T. Tan, K. Nishino and K. Ikeuchi, "Separating reflection components based on chromaticity and noise analysis", PAMI, vol. 26, no. 10, **(2004)**, pp. 1.
[8] S. P. Mallick, T. E. Zickler, D. J. Kriegman and P. N. Belhumeur, "Beyond lambert: Reconstructing specular surfaces using color", CVPR, vol. 1, no. 2, **(2005)**, pp. 619-626.
[9] K. J. Yoon and I. S. Kweon "Voting-based separation of diffuse and specular pixels", Electonics Letters, vol. 40, **(2004)**, pp. 1260-1261.
[10] R. Kokku and G. Brooksby, "Improving 3D surface measurement accuracy on metallic surfaces", Proc.SPIE, vol. 5856, **(2005)**, pp. 618- 624.
[11] P. Tan, L. Stephen, Q. Long, S. H. Yeung, "Highlight removal by illumination-constrained inpainting", IEEE International Conference on Computer Vision, vol. 42, no. 2, **(2003)**, pp. 164-169.
[12] C. Yuting, "Highlight removal by frequency domain filtering", Laser & Optoelectronics Progress, vol. 50, no. 051205, **(2013)**.

[13] W. C. Ma, T. Hawkins, P. Peers, C. F. Chabert, M. Weiss and P. Debevec, "Rapid acquisition of specular and diffuse normal maps from polarized spherical gradient illumination", In EGSR, **(2007)** June.
[14] Toshihide, "Tilt-ellipsometry of object surface by specular reflection for three-dimensional shape Measurement", Optics Express, vol. 21, no. 5, **(2013)**, pp. 6625.
[15] R. Feris, R. Raskar, K. Tan and M. Turk, "Non-photorealistic camera: depth edge detection and stylized rendering using multi-flash imaging", ACM Special Interest Group on Computer Graphics and Interactive Techniques Conference(SIGGRAPH), **(2004)**.
[16] H. Guo and T. Tao, "Specular surface measurement by using a moving diffusive structured light source", Proc. SPIE, no. 6834, **(2007)**.
[17] S. K. Nayar and M. Gupta, "Diffuse Structured Light", IEEE International Conference on Computational Photography, **(2012)** April, pp. 1-8.
[18] K. Sills, G. M. Bone and D. Capson, "Defect identification on specular machined surfaces", Machine Vision and Applications, vol. 25, **(2014)**, pp. 377-388.