3-D Shape Measurement Method with Modulated Slit Light Robust for Interreflection and Subsurface Scattering

Tatsuhiko FURUSE Shinsaku HIURA Kosuke SATO
Graduate School of Engineering Science, Osaka University
1-3 Machikaneyama-cho, Toyonaka, Osaka 560-8531 Japan
`{furuse,shinsaku,sato}@sens.sys.es.osaka-u.ac.jp`

Abstract

We propose a method to accurately measure the shape of objects by suppressing the effect of indirect reflection caused by the interreflection and subsurface scattering. We use a M-sequence pattern shifted along the line of the slit light, and the sequence of captured images is analyzed using synchronous demodulator. This method utilizes two properties of indirect reflection; one is the transfer characteristics of higher spatial frequency components, and the other is geometric constraint between the projector and the camera. Prior to the measurement, epipolar constraint is obtained through calibration, and then the phase consistency is evaluated to suppress the interreflection. The cross-correlation value is also used to suppress the dilation of the slit light caused by the subsurface scattering.

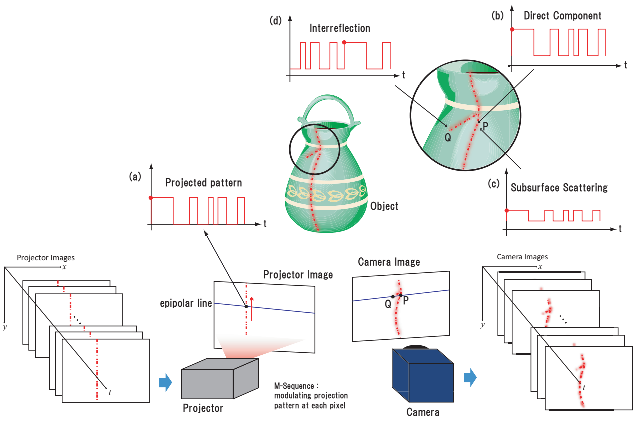


Figure 1. Principle of our method. For the subsurface scattering (c), the ratio of amplitude to the mean value is relatively smaller than the center of the slit. Interreflection causes the false image of the slit (Q), but the phase of the M-sequence (d) is different from the phase calculated by the epipolar constraint (a).

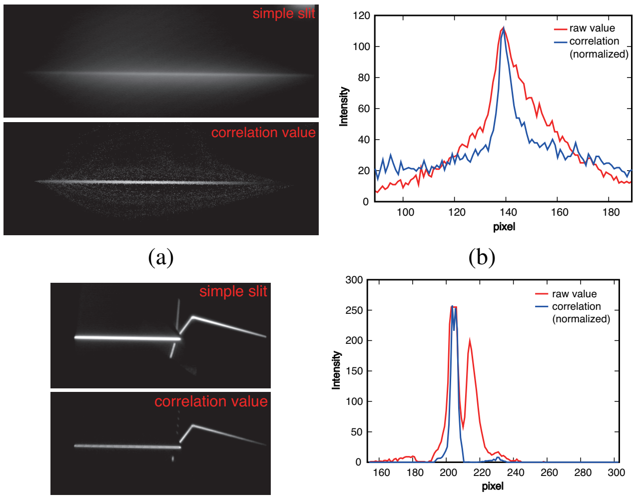
1. Introduction

In this paper, we propose a method to accurately measure the shape of objects by suppressing the effect of subsurface scattering and interreflection. Generally, reflected light in the scene can be classified into direct and indirect components, and most 3-D shape measurement methods with structured light projection assume that the former is dominant in the captured image. However, indirect component often produces spurious or dilated distribution of projected light, and it makes the accuracy of measured shape worse. Especially, details of plastic object are much affected by the subsurface scattering because most colored plastics consist of pigments mixed in the translucent base materials. Moreover, matte finish of plastic or metallic material is actually a collection of cluttered shiny facets, so the smaller details we want to measure, the heavier influence by indirect component we will have.

It is known that the polarization is useful to suppress the subsurface scattering. Chen et al. [1] showed the effect of polarization by comparing the polarization-difference imaging with simple parallel polarization. However, since the polarization ratio of specular reflection is larger than the diffuse reflection, interreflection caused by two shiny surfaces will be ineptly emphasized by polarization in some cases. They also mentioned about the effect of high spatial frequency pattern that is proposed by Nayar et al. [2], but it does not suppress the interreflection by mirror reflection. The novelty of our method is the use of M-sequence pattern with the epipolar constraint between projector and camera to distinguish the false image of slit light from the true one, and the subsurface scattering is simultaneously suppressed by the similar principle of Nayar's method.

2. Proposed Method

The principle of our method is illustlated in Figure 1. We modulate slit light with M-sequence(Maximum Length Sequences) along the line, and shifted as time t changes. Therefore, the intensity of the slit light is described as



(a) (b)

(c) (d)

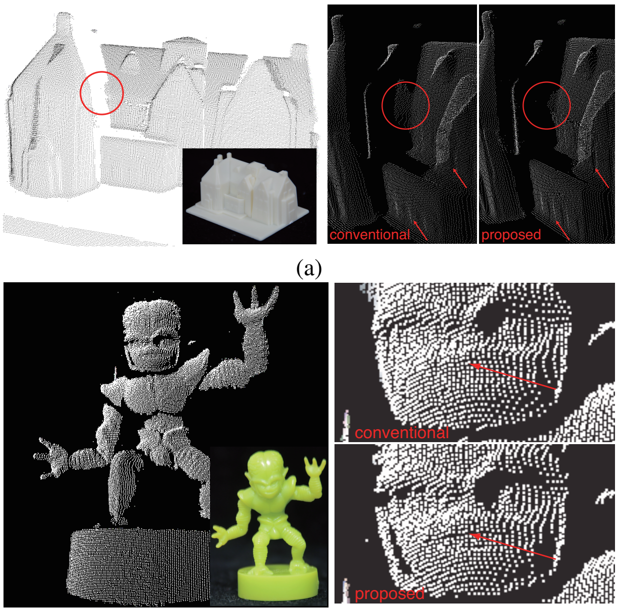
Figure 2. Evaluation of our method. (a) Images of subsurface scattering and (c) Case of interreflection. (b) and (d) are intensity of pixels on a vertical line. Correlation values are normalized for the peak.

$L(y,t) = M((t-y) \mod T)$ where T is the period of the M-sequence function $M(t)$. Since M-sequence consists of only two values $\{0,1\}$, it is easy to implement without photometric calibration of the projector. M-sequence has broad bandwidth which is utilized to suppress the subsurface scattering, and the false slit image caused by the interreflection can be eliminated by using the acute response of its autocorrelation.

In prior to the measurement, fundamental matrix which represents the epipolar constraint between the projector and the camera is obtained. Then, modulated slit light patterns are projected to the object, and captured sequentially. For each point on the captured image, we can calculate the corresponding epipolar line on the projector image as shown in Figure 1, and the phase of the M-sequence is determined by finding the vertical coordinate y of intersection of epipolar and slit line. We use zero-mean M-sequence $M((t-y) \mod T) - 0.5$ for calculating correlation value to eliminate the DC component.

3. Experimental Results

We used a LCD projector (EPSON EMP-1710, 1024×768 pixel) with additional close-up lens and 8 bit-monochrome camera (CV-340, 640×480 pixel) for experiments. The period of M-sequence we used is $T = 31$. As shown in Figure 2, both subsurface scattering and interreflection are clearly suppressed by our method. We also confirmed our method for resinous objects with complex shape as shown in Figure 3. In case (a), false shape caused by the interreflection is seen on the result with conventional slit light method. In addition, fine details on the resinous model is correctly measured by our proposed method. Similarly, fine details on the face of plastic model (b) is precisely measured by proposed method while the conventional method does not recover the edges around the mouth.



(a)

(b)

Figure 3. Measured shape of (a) resinous house(W:40mm) and (b) resinous figurine (H:38mm).

4. Conclusion and Future Work

We proposed the 3-D shape measurement method robust for both interreflection and subsurface scattering. M-sequence pattern is very useful to combine both geometric constraint and transfer characteristics in spatial frequency. Experimental results showed the practicality of our method for resinous object with fine details. Though the effect of our method depends on the size, shape, translucency and surface property of the measured object, one of the most important future work is quantitative evaluation. Since the false slit image caused by the interreflection sometimes has exactly same phase as the true one, multiple cameras or projectors will be useful to verify the true slit image using multiple epipolar lines. Extension to the pattern light projection method (e.g. Graycode) will be also worth to explore.

References

[1] T.Chen, Lensch.H.P.A, Fuchs.C, and Seidel.H.P. ”polarization and phase-shifting for 3d scannning of translucent objects”. *Computer Vision and Pattern Recognition, IEEE Conference on Volume pp1-8*, 2007.

[2] S.K.Nayar, G.Krishnan, Grossberg.M, and Rasker.R. Fast separation of direct and global components of a scene using high frequency illumination. *Transaction on Graphics,vol.25, no 3, pp.935-943*, 12(1):234–778, 2006.