Three-dimensional Speckle Correlation Imaging

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1. Introduction

Imaging through scattering media is a longstanding issue in the field of optics and various methods for this task have been proposed [1-3]. Speckle correlation imaging is a non-invasive method for imaging through scattering media [4, 5]. This method uses a shift-invariance of scattered impulse responses, which is called the memory effect [6]. Speckle correlation imaging has been mainly studied for two-dimensional image acquisition based on the lateral memory effect. Recently, an axial memory effect has been reported [7]. In this study, we present three-dimensional speckle correlation imaging based on the axial memory effect.

2. Principle and demonstration

The optical setup for three-dimensional speckle correlation imaging is shown in Fig. 1. A three-dimensional object is located between two diffusers. The object is illuminated with a spatially incoherent light source (M565L3 manufactured by Thorlabs, nominal wavelength: 565 nm) through the first diffuser and the scattered light from the object is captured with an image sensor (hr29050MFLGEA manufactured by SVS-Vistek, pixel count: 4384 × 6576, pixel pitch: 5.5 × 5.5 μm) through the second diffuser. No imaging optics is employed. We have demonstrated a multi-shot approach, where the image sensor is axially scanned to obtain a three-dimensional speckle, and a single-shot approach [8, 9]. The single-shot approach is applicable for imaging of dynamical scenes, but its field-of-view is limited compared to the multi-shot one.

By supposing the axial memory effect, the scattered impulse response is scaled depending on the object distance. In the multi-shot case, we take the three-dimensional autocorrelation for the captured three-dimensional speckle to remove the scattering effect. In the single-shot case, we computationally scale a single speckle image to determine the scales of the impulse responses on the speckle and take the three-dimensional autocorrelation for the computationally scaled speckle images. Then, the three-dimensional phase retrieval is applied to the autocorrelation results [10].

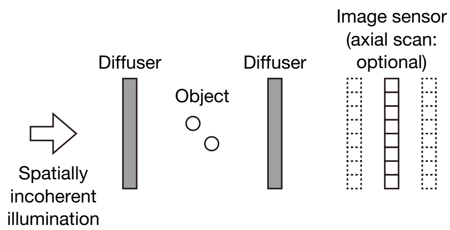
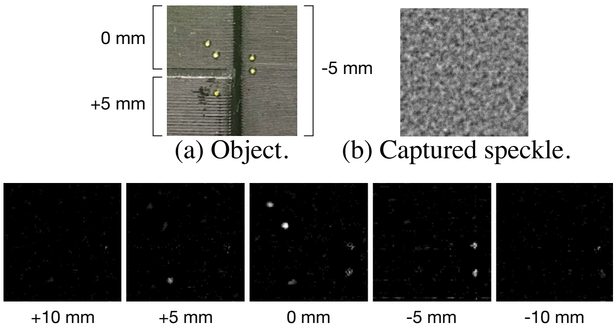


Fig. 1. Optical setup of three-dimensional speckle correlation imaging.



(a) Object. (b) Captured speckle.

(c) Reconstruction result.

Fig. 2. Experimental results of single-shot three-dimensional speckle correlation imaging.

The experimental results in the case of the single-shot approach are shown in Fig. 2. We used an object with three layers with differently aligned halls for the demonstration as shown in Fig. 2(a). The object point sources were three-dimensionally reconstructed from the captured speckle image in Fig. 2(b), as shown in Fig. 2(c).

3. Conclusions

We presented and demonstrated three-dimensional speckle correlation imaging. This approach is noninvasive, and it is implementable with a simple lensless setup. Therefore, our method is applicable to various fields, such as medicine, industry, and security.

References

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