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Optical identification system of three-dimensional random phase object by use of speckle patterns in propagation distances

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Abstract. An optical identification system of a three-dimensional (3D) random phase object by use of speckle patterns in different propagation distances is proposed and evaluated experimentally. The 3D random phase object is used as a 3D key. It can be secure when the scattering is strong enough because the interferometric measurement is not applied. The identification is implemented by evaluating crosscorrelation value between the measured and stored speckle patterns. To achieve a higher level of identification, two speckle patterns obtained at different propagation distances are used. The tolerance of 3D position of 3D random phase object are evaluated. We also investigate the influence of occlusion and binarization of speckle patterns on identification capability.

1. Introduction
In a highly developed information society, security technology for personal identification is one of important issues. Optics can provide a high level of security as show in hologram, biometrics, or random phase modulation [1]-[7]. Biometrics is a very powerful method for personal identification, but it becomes a serious problem when unchangeable personal information is stolen. A method using simple and cheap optical elements is expected for personal identification.

Double random phase encryption using random phase mask is the most powerful method in the optical encryption technique [1]. In the encryption process, original real-valued data is encrypted by two random phase masks located at the input and the Fourier planes. In the decryption process, encrypted data is decrypted by multiplying conjugate of the random phase mask in the Fourier plane. When the random phase mask is a two-dimensional distribution or is made by surface modulation such as embossed method, the random phase mask can be duplicated. Therefore, a three-dimensional (3D) random phase object in a volume medium is a promising way to protect the measurement of the random phase distribution. The 3D phase object without surface modulation can be secure when the scattering is strong enough because it prevents from the interferometric measurement of the 3D random phase object. In this paper, we present a secure identification system using a 3D random phase object for personal identification. The identification can be implemented by evaluating the crosscorrelations between measured speckle patterns and stored speckle patterns in a database. A speckle pattern from a 3D random phase object has only two-dimensional information. To achieve a high level of identification
capability, more than two speckle patterns are evaluated. We have already proposed the use of different wavelength illumination to obtain two different speckle patterns in an image sensor[6, 7].

In this paper, we use two speckle patterns obtained at different propagation distances by two image sensors. We present two systems. One system uses the evaluation of identification capability of 3D random phase object. The influence of position error of 3D random phase object on recognition capability is evaluated. The other system is a simultaneous detection system of two speckle patterns by using two image sensors. We investigate the identification capability when a part of 3D random phase object is occluded. Finally, we investigate the binarization of speckle pattern for the improvement of recognition capability.

2. Optical Identification System based on Speckle Patterns Obtained at Different Propagation Distances

Figure 1 shows a proposed optical identification system. A 3D random phase object is put on a card. By illuminating a laser beam, a speckle pattern is obtained at an image sensor. Crosscorrelations between measured speckle patterns and stored speckle patterns in a database are calculated and then the identification is done by finding maximum correlation value. To achieve a high level of identification, more information is required because the speckle pattern from the 3D phase object has only two-dimensional information. We use two speckle patterns obtained at different propagation distances. Two different wavelength illumination can be used [6, 7].

![Figure 1. Schematic of the proposed identification system of speckle patterns from a 3D random phase object obtained at different propagation distances.](image)

We describe the identification process by use of two correlations of speckle patterns at different propagation distances. Let a speckle pattern at a propagation distance, $z$, between the 3D phase object and the image sensor be denoted by $f_z(x, y)$. Let the stored speckle pattern in database be $g_z(x, y)$ obtained at propagation distance $z$. The two crosscorrelations, $C(z_1)$ and $C(z_2)$ between the measured patterns and the stored patterns at propagation distances $z_1$ and $z_2$, respectively, are given by

$$C(z_1) = f_{z_1} \otimes g_{z_1},$$

(1)
and

\[ C(z_2) = f_{z_2} \otimes g_{z_2}. \]  

When the 3D phase object is identical to the object when the stored speckle patterns are recorded, Eqs. (1) and (2) become autocorrelation. The peak value of the autocorrelation is high. By evaluating two correlation values, the identification can be implemented. Evaluation of two crosscorrelation makes the system more secure even when one speckle pattern is close to the stored speckle pattern at different propagation distance.

3. Experiments

Figure 2 shows an experimental setup to demonstrate the identification. A He-Ne laser at a wavelength of 632.8 nm is used as a coherent light source. The laser beam passes through a beam expander and then incidents normal to the surface of the 3D random phase object. The size of surface of the 3D random phase object is 5 × 5 mm. A 3D phase object is fabricated by attaching two diffusers with diffusion angle of 5°. The speckle patterns at a distance of \( d \) from a CCD image sensor are obtained. A CCD image sensor is 3072 × 2048 pixels with 10 bit intensity distribution. Each pixel size is 9 \( \mu \text{m} \) × 9 \( \mu \text{m} \).

![Experimental setup](image)

**Figure 2.** Experimental setup; BE, beam expander; AP, aperture; RP, random phase object; MS, movable stage.

We investigate the position selectivity of a 3D phase object along the optical axis as shown in Fig. 3(a). Propagation distances are changed from 500 mm to 1000 mm with an interval of 100 mm. We evaluate the position selectivity by changing the position of the random phase mask at each propagation distance. Figure 3(b) shows the crosscorrelation peak as a function of position error. When the crosscorrelation peak rapidly decreases by changing the position, the position selectivity is high. In propagation distance of 500 mm, the crosscorrelation width at 0.8 of maximum is about 4 mm. We found that strong position selectivity is obtained in small propagation distance. This is because the speckle size is small and the speckle pattern is dramatically changed by small position difference.

We also investigate the position selectivity of 3D random phase object in the direction perpendicular to the optical axis as shown in Fig. 4(a). Propagation distances from 300 mm to 500 mm with an interval of 100 mm are evaluated. In this experiment, we use a CCD image sensor with 512 × 480 pixel. Each pixel is 6.35 \( \mu \text{m} \) × 7.4 \( \mu \text{m} \). A 3D random phase object is fabricated by attaching two diffusers with diffusion angle of 1°. Figure 4(b) shows the crosscorrelation peak.
Figure 3. Evaluation of shift selectivity of a 3D random phase object along the optical axis. (a) schematic and (b) the result of crosscorrelation peak profile as a function of position change, $z$.

Figure 4. Evaluation of shift selectivity of a 3D random phase object in the direction perpendicular to the optical axis. (a) schematic and (b) the result of crosscorrelation peak profile as a function of position change, $\Delta$.

as a function of position error in three different propagation distances. Spatial shift of speckle pattern causes the decrease of correlation peak, but it is not large. Crosscorrelation width at 0.8 of maximum is about 1.0 mm. This is because the speckle pattern is shifted in the CCD plane and then a part of speckle pattern is changed.

We fabricate a simultaneous detection system of speckle patterns at different location as shown in Fig. 5. We use a beamsplitter to divide the speckle light into two beams. Both light beams are detected by two image sensors. The two CCD image sensors are located at 500 mm and 530 mm from the random phase object. A 3D random phase object has $5 \text{ mm} \times 5 \text{ mm}$. Figure 6 shows speckle patterns obtained by the two CCD image sensors. Speckle size in CCD2 is slightly larger than that in CCD1. We calculate the crosscorrelation peaks in 10 trials. Figure 7 is a histogram of crosscorrelation peaks. We can see that the crosscorrelation peak is less than 0.07. This result indicates that these speckle patterns obtained at two image sensors are not correlated each other.

We investigate the tolerance of recognition capability when a part of the 3D random phase
object object is blocked. Here we block a part of the surface of the 3D random phase object by a mask. We show the result of 10% occlusion. A 3D random phase object is fabricated by two diffusers with scattering angle of 1°. The crosscorrelation between the speckle patterns obtained with and without a blocked mask is calculated. The two propagation distances of 300 mm and 500 mm are used for the evaluation. Figure 8 shows a histogram of peak crosscorrelation values. Most peaks of crosscorrelation are less than 0.8. This makes the system difficult for identification. The occlusion makes a serious problem in recognition. We have to make a system more robust by reducing a scattering angle of diffusing medium.

Figure 5. Simultaneous detection system of two speckle patterns; ND, neutral density filter; PM, phase mask; BS, beam splitter.

Figure 6. Examples of speckle patterns obtained at 500 mm and 530 mm.

Figure 7. Histogram of peak of crosscorrelations between two speckle patterns obtained in a system in Fig. 6.
4. Binarization of Speckle Pattern for Improvement of Recognition

We investigate the effect of binarization of speckle patterns for the recognition capability. The 3D position selectivity of random phase object and the influence of threshold value in binarization are evaluated. Figure 9 shows an example of histograms of speckle patterns obtained at a propagation distance of 300 mm. The average of the intensity is 0.36. We use this average value for binarization. Figure 10 shows the autocorrelation profile of speckle patterns with and without binarization. This result shows that the binarization can improve the shift selectivity in the direction perpendicular to the optical axis. We also evaluate the position selectivity along the optical axis as shown in Fig. 11. This result indicates that the position selectivity along the optical axis is improved by the binarization. The influence of threshold value on the correlation profile is evaluated. In Fig. 12, there is small influence of threshold value on position selectivity along the optical axis even when the threshold value changes from 0.06 to 0.66.

Figure 8. Histogram of peak of crosscorrelations between two speckle patterns with and without 10 % occlusion when propagation distances 300 mm and 500 mm.

Figure 9. Histogram of pixel values in measured speckle pattern.
**Figure 10.** Autocorrelation profiles of measured speckle patterns with and without binarization.

**Figure 11.** Crosscorrelation values as a function of position shift of 3D random phase object along the optical axis with and without binarization of speckle patterns.

**Figure 12.** Crosscorrelation values as a function of position shift of 3D random phase object along the optical axis when threshold values changes from 0.06 to 0.66.
5. Conclusion
We have proposed an optical personal identification system by use of speckle patterns of a 3D random phase object obtained at two different propagation distances. A 3D random phase object cannot be measured by interferometer when the scattering property is strong enough. The identification of the 3D phase object can be implemented by evaluating peak values of crosscorrelations between measured and stored speckle patterns. We evaluated experimentally the 3D position selectivity of a 3D random phase object. We also evaluated the tolerance of the identification ability when a part of 3D random phase object is occluded. The occlusion makes the system less recognition capability. Binarization of the speckle pattern can improve the position selectivity of 3D random phase object.

References