Three-dimensional optical correlator using sub-image array

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Three-dimensional (3D) information processing has been an active field of research in the point that it provides a direct way to capture, recognize, and display 3D object in real world. As a direct method to recognize and locate the reference object in the 3D space, 3D optical correlator has attracted growing attention recently. Several schemes using multiple cameras(1), hologram(2), or lens array(3),(4) were proposed to realize the 3D correlator. Among them, a scheme which uses a lens array has some advantages over other techniques since many perspectives, or also called elemental images in the literature regarding integral imaging, of the 3D object can be captured by the lens array at one time, and there is relatively small load for digital image processing. Conventional 3D correlation schemes using the lens array utilize the collection of the elemental images. In this paper, we propose a 3D correlation method using the sub-images that are synthesized from the elemental images captured by the lens array.

The sub-image is a collection of the pixels at the same location in every elemental images. For example, the [*i*, *j*]th sub-image is a collection of the [*i*, *j*]th pixels in all elemental images. The number of pixels constituting one sub-image is the same as the number of the elemental images or elemental lenses of the lens array. Thus the 3D object is sampled with the period of the elemental lens pitch of the lens array in each sub-image. Figure 1 shows the geometry of the sub-image. Since the sampling period of the sub-image is constant regardless of the object depth as shown in Fig. 1, the sub-image has two useful features; size-invariance and observing-direction-invariance. Size-invariance means that the size of the object in each sub-image is constant regardless of the object depth and observing-direction-invariance means that each sub-image represents a specific observing direction regardless of the depth and transverse position of the object. Due to these two features, we can compare the images that observe the reference and signal objects at the same direction without considering object depths or transverse positions using the conventional two-dimensional (2D) correlator. In the proposed method, not only the 3D shift but also the out-of-plane rotation can be detected by comparing the sub-images of reference and signal objects. Suppose that the reference object is located at (y_r, z_r) and the signal object is located at (y_s, z_s) with θ_s rotation as shown in Fig. 1. Also, suppose that i-th sub-image observes the object with an angle of θ_i. Firstly, we can detect the rotation angle by correlating one sub-image for reference object with every sub-image for signal object Through this correlation process, we can find the sub-image pair that satisfies $\theta_1-\theta_2=\theta_s$ where θ_1 is the observing angle of the sub-image of the reference object and θ_2 is that of the signal object. Since the θ_1 and θ_2 are known values, θ_s can be detected. After θ_s is detected, 3D position of the signal object can be detected by correlating two sub-image pairs. The peak position of correlation between the sub-image of the reference object corresponding to θ_i and that of the signal object corresponding to $\theta_i+\theta_s$ is given by

$$u = (1/\phi) \times \{ y_s - y_r + z_s \tan(\theta_s + \theta_i) - z_r \tan\theta_i \} \tag{1}$$

where ϕ is the elemental lens pitch. Since only the y_s and z_s are unknown, they can be found through the correlation of two sub-image pairs. We implemented a 3D correlator using sub-images and joint transform correlator. Figure 2 shows a schematic diagram of the implemented 3D correlator. We verified our idea experimentally using the lens array consisting of 70×70 elemental lenses of 1 mm pitch and 3.3 mm focal length. Figure 3 shows an example of the peak intensity profile of the correlations between one sub-image of the reference object and every sub-image of the signal object according to the rotation angle. Figure 4 shows some example of the correlations between sub-image pairs of the reference and signal objects for 3D position detection. More in-detail description and full experimental results will be provided in the presentation.

References

1. J. Rosen, "Three-dimensional optical Fourier transform and correlation," Opt. Lett. 22, 964-966 (1997).
2. B. Javidi and E. Tajahuerce, "Three-dimensional object recognition by use of digital holography," Opt. Lett. 25, 610-612 (2000).
3. O. Matoba, E. Tajahuerce, and B. Javidi, "Real-time three-dimensional object recognition with multiple perspectives imaging," Appl. Opt. 40, 3318-3325 (2001).
4. B. Lee, J.-H. Park, and H. Choi, "Three-dimensional image capture and correlation using the integral imaging technique," Proc. SPIE, 5642, paper 5642-23, (2004).

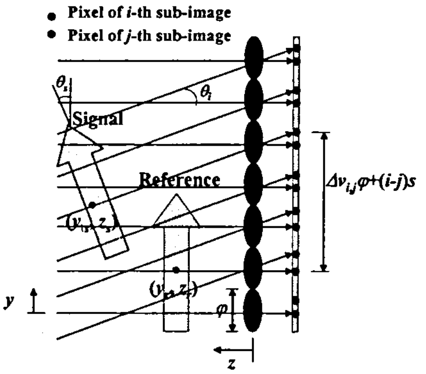

Fig. 1. Geometry of the sub-image

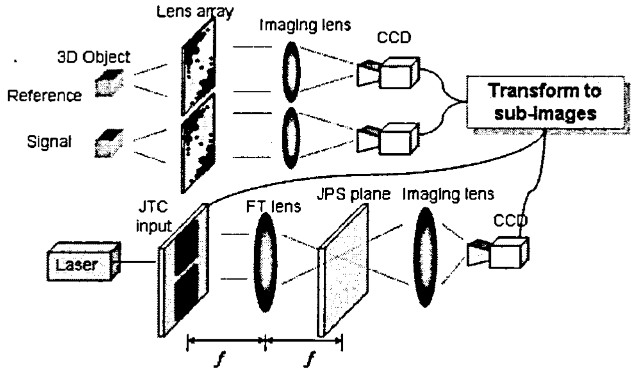

Fig. 2. Schematic diagram of the proposed method

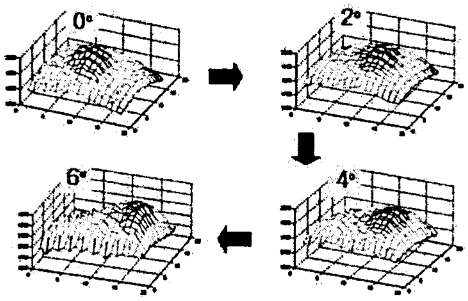

Fig. 3. Peak intensity profile of the correlations between one sub-image of the reference and every sub-images of signal

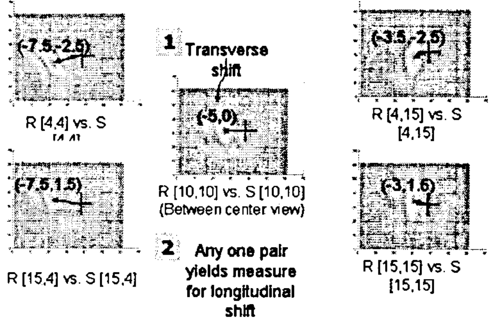

Fig. 4. Some examples of the correlations between the corresponding sub-image pairs