Composite filters based on digital holograms for distortion-tolerant three-dimensional object recognition

Yann Frauel[a], Enrique Tajahuerce[b], Maria-Albertina Castro[a], Bahram Javidi[*a]

[a]University of Connecticut, ECE Dept., U-157, 260 Glenbrook Road,
Storrs, CT 06269, USA, Tel. 860-486-1800, Fax 860-486-2447, Bahram@engr.uconn.edu

[b]Dept. de Ciencies Experimentals, Universitat Jaume I, Campus Riu Sec, s/n
P.O. Box 224, 12080-Castelló, SPAIN, Tel. 964-728053, Fax 964-728066

We make distortion-tolerant nonlinear composite filters using views of a 3D reference object reconstructed from digital holograms. As an example, we demonstrate tolerance to out-of-plane rotation and longitudinal shift.

Composite filters based on digital holograms for distortion-tolerant three-dimensional object recognition

Yann Frauel[a], Enrique Tajahuerce[b], Maria-Albertina Castro[a], Bahram Javidi[*a]

[a]University of Connecticut, ECE Dept., U-157, 260 Glenbrook Road,
Storrs, CT 06269, USA, Tel. 860-486-1800, Fax 860-486-2447
[b]Dept. de Ciencies Experimentals, Universitat Jaume I, Campus Riu Sec, s/n
P.O. Box 224, 12080-Castelló, SPAIN, Tel. 964-728053, Fax 964-728066

1. Introduction

The use of optoelectronic systems for information processing has been widely explored.[1-6] In particular, a lot of work has been done on 2D pattern recognition using optical correlation techniques.[4-6] Recently, these techniques have been extended to be used in conjunction with digital holography in order to recognize 3D objects.[7-9] In this presentation, we show how it is possible to create nonlinear composite filters with various views of a 3D reference object reconstructed from digital holograms. These composite filters allow us to achieve distortion-tolerant recognition. As an example, we demonstrate tolerance against out-of-plane rotation and longitudinal shift along the *z*-axis.

2. Description of the technique

The experimental setup used to record digital holograms is shown in Fig. 1. It is based on a Mach-Zehnder interferometer architecture. The object beam illuminates the 3D object which scatters light in the direction of the camera. This light is superimposed to the reference beam and an interference pattern is recorded on the camera. The phase of the reference beam can be modified thanks to a quarter- and a half-wave plates. We record four different interferograms in order to be able to reconstruct the complex amplitude of the object beam in the plane of the camera.[10] By using the Fresnel-Kirchhoff integral to simulate the propagation of the light,[11] we can then reconstruct the amplitude of the object beam in any plane, including the plane of the object. Moreover, we can use a partial window in the hologram for this reconstruction. Depending on the lateral position of this window, we can reconstruct different perspectives of the 3D object.[9] We can use these properties to reconstruct several views of the object to be recognized and use them to make a nonlinear composite filter.[9] This filter is compared to reconstructed views of the tested 3D objects which are also obtained from digital holograms.

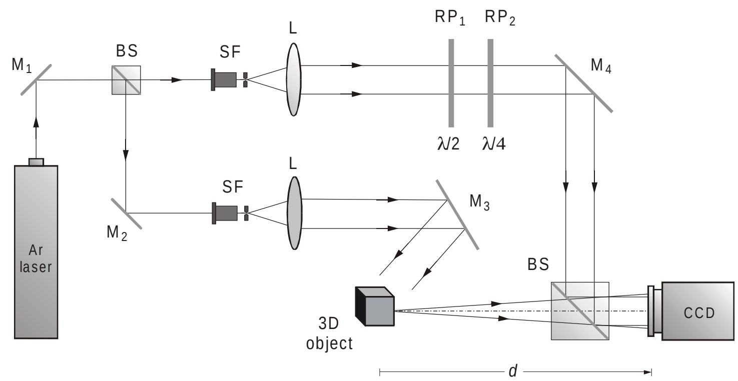

Figure 1. Experimental setup -M mirror, BS beamsplitter, SF spatial filter, L lens, RP retardation plate.

3. Experimental results

We record a digital hologram of a die, which will be our 3D reference object. We use three partial windows to reconstruct views of the die. The locations of these windows allow to reconstruct perspectives of the object with a separation angle of twice 0.6°. Moreover, for each window, we reconstruct views in five different planes longitudinally located at -20 mm, -10 mm, 0 mm, 10 mm and 20 mm from the plane of the object. We thus obtain 3 x 5 = 15 views of the die with which we construct a composite filter.[9] In order to test this filter, we record 19 holograms of the die with several out-of plane rotations within a 9° range (Images #1-19). We also record holograms of the die with a very different illumination (Image #20) and in a different 3D position (Image #21). For this latter case, we will present the correlation in the best focus plane. Finally, we record holograms of seven various 3D objects (Images #22-28) which are different from the die.

Fig. 2(a) shows the values of the correlation peaks for a filter made with only one view of the die which is close to Image #10. It can be seen that - except for the one that is very close to the training image - the true targets are barely distinguished from the false targets. In Fig. 2(b) are shown the correlation results for the previously described composite filter. It can be seen that it is easy to discriminate true targets from false targets by using a threshold. When comparing Figs. 2(a) and 2(b), it is clear that using a composite filter enhances the recognition of the out-of-plane rotated 3D object. Moreover, since the composite filter includes defocused views of the reference object, it is able to recognize the die even when the reconstruction plane is longitudinally shifted along the *z*-axis.[9] We thus achieve a longitudinal shift tolerance.

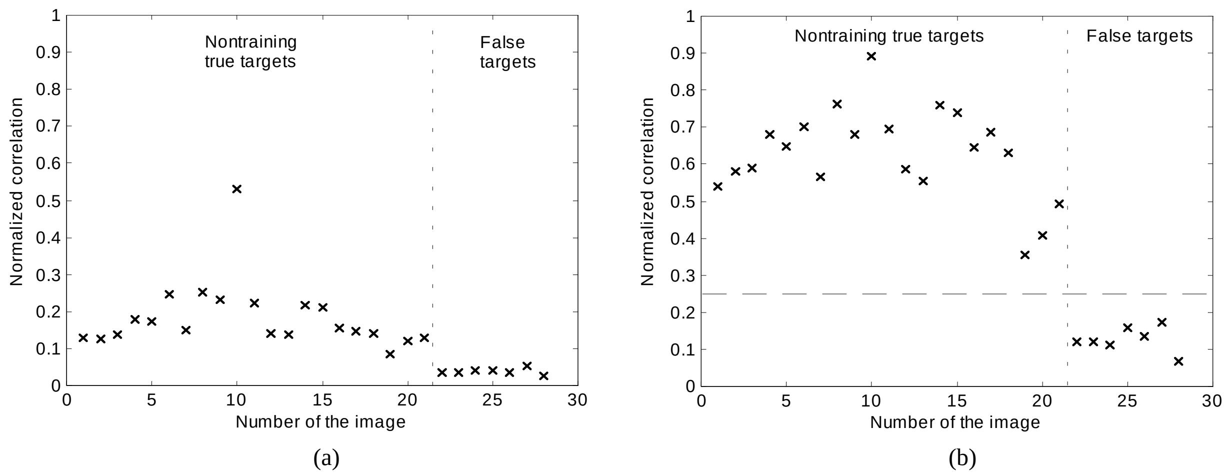

Figure 2. Correlation results with various 3D test objects. (a) Filter made from one single view. (b) Filter made from 15 focused and defocused views based on one single hologram.

4. Conclusion

We have described a method to perform distortion-tolerant pattern recognition of 3D objects. The 3D information is obtained through digital holography; distortion tolerance is achieved by using nonlinear composite filters. As an example, we have demonstrated some tolerance to out-of-plane rotation and to longitudinal shift along the *z*-axis. This technique can be applied to other kinds of distortions.

References

1. A. B. VanderLugt, *Optical Signal Processing*, John-Wiley (1992).
2. A. D. McAulay, *Optical computers architectures*, John Wiley and sons, New York (1991).
3. B. Javidi ed., *Smart Imaging Systems*, SPIE Press, Bellingham, Washington (2001).
4. J. W. Goodman, *Introduction to Fourier optics*, McGraw-Hill, New-York (1968).
5. D. Casasent, "Unified synthetic discriminant function computational formulation," *Appl. Opt.* **23**, 1620-1627 (1984).
6. B. Javidi and D. Painchaud, "Distortion-invariant pattern recognition with Fourier-plane nonlinear filters," *Appl. Opt.* **35**, 318-331 (1999).
7. B. Javidi and E. Tajahuerce, "Three dimensional object recognition using digital holography," *Opt. Lett.* **25**, 610-612 (2000).
8. E. Tajahuerce, O. Matoba, B. Javidi, "Shift-invariant three-dimensional object recognition by means of digital holography," *Appl. Opt.* (accepted March 2001).
9. Y. Frauel, E. Tajahuerce, M. A. Castro, B. Javidi, "Distortion-tolerant 3D object recognition using digital holography," *Appl. Opt.* (accepted May 2001).
10. J. H. Bruning, D. R. Herriott, J. E. Gallagher, D. P. Rosenfeld, A. D. White, D. J. Brangaccio, "Digital wavefront measuring interferometer for testing optical surfaces and lenses," *Appl. Opt.* **13**, 2693-2703 (1974).
11. I. Yamaguchi, T. Zhang, "Phase-shifting digital holography," *Opt. Lett.* **22**, 1268-1270 (1997).