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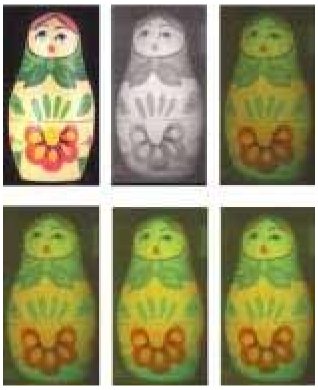
Multiwavelength digital holography fuses 3-D images

A team of researchers at the University of Connecticut (Storrs, CT), the Instituto di Cibernetica del Consiglio Nazionale delle Ricerche (Naples, Italy), and the Instituto Nazionale di Ottica Applicata (INOA; Pozzuoli, Italy) reports 3-D image fusion by use of digital holography (DH). In DH, which is an alternative to the use of a film or plate, a hologram is recorded directly on a solid-state sensor.[1]

For color DH display, it is possible to use multiwavelength digital holography (MWDH) and simultaneously reconstruct images recorded with different wavelengths. Typically, monochromatic images are reconstructed and combined into full-color images in a computer; however, this operation may not preserve the amplitude and phase information of the separate images. The formation of a composite image by combining images of the same scene obtained with different wavelengths is called image fusion.

To reconstruct better-quality color 3-D images than those obtained by direct red-green-blue (RGB) composition of reconstructed images (which are limited in resolution and contrast due to fluctuation of the speckle noise), the research team used multiresolution wavelet decomposition (MWD) image-fusion techniques in conjunction with MWDH for image processing. The selection of MWD as the image-fusion technique allows control of low-frequency and high-frequency components of the image. Furthermore, the technique is easily implemented.



From a matrioshka doll object (top left), red and green lasers are used to create separate holographic images that are then "fused" byu use of a multiresolution wavelet decomposition (MWD) algorithm (top center). In comparison to a reconstructed color image by simple summing of two sets of direct RGB images and subsequently producing a large amount of speckle noise (top right), the fused color holographic images of two sets of reconstructed images is much improved (bottom left). Further improvements are realized by applying a mean filter to the fused images (bottom center), as compared to mean-filtered images without the fusion process (bottom right)..

In MWD, the image is represented mathematically as a series of monochromatic images containing vertical, horizontal, and diagonal details with low- and high-frequency components. After obtaining the multiresolution wavelet coefficients of each image from different sensors, different image-fusion rules for the high- and low-frequency components are applied using various arithmetic manipulations. Registered multiwavelength images are transformed into multiresolution wavelets. The high- and low-frequency components of the multiresolution wavelet coefficients are fused according to the fusion rules selected. Then, these fused wavelet coefficients are inverse-wavelet-transformed into a final fused image.

Two wavelengths

The optical setup for recording MWDH holograms includes two lasers emitting at 632.8 nm and 532.0 nm. The optical configuration is arranged such that the two lasers propagate along the same path for either the object or the reference beams, with a reflecting prism in the path of the red laser beam permitting matching of the optical paths of the two interfering beams within the optical coherence length of the laser. The object beam is set at a distance of 850 mm in front of a 1024 ×1024-pixel array with square 6.7-µm pixels. Two holograms are recorded with the two wavelengths and are reconstructed separately using the Fresnel-transformation method. After first taking into account differences in the size of the images from the two lasers by known superposition techniques, red and green images of the same size were obtained.

The object used to create the images was a colorful matrioshka doll (see figure). The fused holographic images from the two wavelengths using MWD show some image content that could not be observed in the individual red or green images. By summing these two images, a reconstructed color holographic image is obtained, but with compromised contrast due to speckle noise, as predicted.

To reduce the speckle, the team used a second set of red and green images obtained by shifting the reconstructed red and green images horizontally and vertically by one pixel. The two sets of red images and green images were fused separately and then combined into one image. Using weighted average as a fusion rule, the low-frequency components were twice emphasized with respect to the high-frequency components to obtain reduced-speckle fused images.

To further reduce the speckle noise, the team applied mean filtering to the reconstructed red and green images before the fusion process. Despite slight blurring of this final image, it has better visual quality than the image obtained from summation of the mean-filtered images without the fusion process.

Full-color 3-D imaging by MWDH benefits from image-fusion algorithms and overcomes the limitations of poor resolution and contrast obtained by simple RGB composition of reconstructed images with multiple wavelengths. “There are broad applications in imaging, including improved multispectral 3-D visualization of a scene,” notes researcher Bahram Javidi.

REFERENCE

1. Bahram Javidi et al., *Optics Lett. 30*(2) 144 (Jan. 15, 2005).

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