Compression of digital holograms for 3D imaging

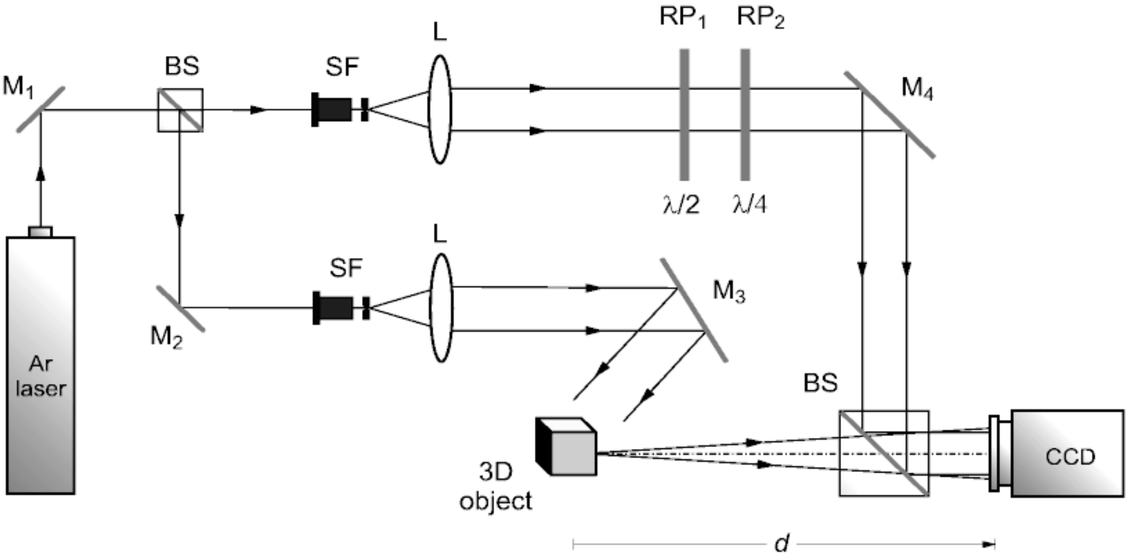

Figure 1. Experimental setup for digital holography: M, mirror; BS, beam splitter; SF, spatial filter; L, lens; RP, retardation plate.

Many existing three-dimensional (3D) imaging and processing techniques are based on the explicit combination of several 2D perspectives (or light stripes, etc.) through digital image processing. With holography, multiple 2D perspectives are optically combined in parallel. When either of the two stages in holography, recording or reconstruction, are performed digitally the process has been referred to as computer, or digital, holography. This subject that has seen renewed interest[1,2] with the recent development of megapixel digital sensors with sufficient spatial resolution and dynamic range. Synthesis of holograms by computer[3] and digital reconstruction of optically-recorded objects[4] have been demonstrated. We record digital holograms using a technique called phase-shift interferometry[5] and introduce a third step, that of digital compression and decompression.

We record digital holograms with an optical system based on a Mach-Zehnder interferometer (see Figure 1). The object beam from the linearly-polarized Argon-ion (514.5nm) laser illuminates a 3D object placed at a distance d=350mm from a 10-bit 2028×2044-pixel Kodak Megaplus CCD camera. The reference beam passes through half-wave plate RP_1 and quarter-wave plate RP_2, and can be phase-modulated by rotating the two retardation plates. Through permutation of the fast and slow axes of the plates, we can achieve phase shifts of 0, $\pi/2$, π, and $3\pi/2$. The reference beam combines with the light diffracted from the object and forms an interference pattern in the plane of the camera. At each of the four phase shifts we record interferograms, then we use these to compute the camera-plane complex-valued field by phase-shift interferometry. We call this computed field a digital hologram. Each hologram encodes multiple views of the object from a small range of angles. A particular view of the object can be reconstructed by extracting the appropriate window of pixels from the hologram and applying a numerical propagation technique.[3,4]

In advance of knowing which of the 4Mpixels are required for particular views, each hologram requires 65Mbytes of storage in its native double precision format (5s of transmission time over a 100Mbit/s network connection). This is too slow for realtime object reconstruction or recognition. We would like to compress these holograms for more efficient storage and transmission. Our digital holograms are composed of complex-valued pixels, which means they cannot be processed directly with standard image compression tools. Furthermore, digital holograms contain speckle, which gives them a white-noise appearance. It is not a straightforward procedure to remove the holographic speckle because it actually carries 3D information. The noisy appearance of digital holograms causes lossless data compression techniques such as Lempel-Ziv, Lempel-Ziv-Welch, Huffman, and Burrows-Wheeler to perform poorly.[6]

The use of lossy compression techniques seems essential. This introduces a third reason why compression of digital holograms and that of digital images differ: a change locally in a digital hologram will, in theory, affect the whole reconstructed object. Furthermore, compression losses introduced into the hologram itself might not be significant. We are interested instead in how compression losses affect subsequent object reconstruction, range of viewing angles, and so on. The lossy techniques employed here were based on subsampling, quantization, and blockwise discrete Fourier transformation. Median filtering was employed to lessen the effects of speckle in the reconstruction plane. We found that as many as 92% of the cosine and Fourier coefficients can be removed from the hologram plane, depending on the level of median filtering applied, and each complex-valued holographic pixel quantized to 8 bits of resolution, without significant reconstruction error.[6] Further work will involve combining DCT/DFT transformation, quantization, and Huffman encoding into a JPEG-style compressor for digital holograms and complex-valued inputs in general.

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