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Interactive Computation of Holograms Using a Look-up Table

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ABSTRACT

Several methods of increasing the speed and simplicity of the computation of off-axis transmission holograms are presented, with applications to the real-time display of holographic images. The bipolar intensity approach allows for the real-valued linear summation of interference fringes, a factor of 2 speed increase, and the elimination of image noise caused by object self-interference. An order of magnitude speed increase is obtained through the use of a precomputed look-up table containing a large array of elemental interference patterns corresponding to point source contributions from each of the possible locations in image space. Results achieved using a data-parallel supercomputer to compute horizontal-parallax-only holographic patterns containing 6 megasamples indicate that an image comprised of 10,000 points with arbitrary brightness (gray scale) can be computed in under 1 second. Implemented on a common workstation, the look-up table approach increases computation speed by a factor of 43.

INTRODUCTION

The real-time display of holographic images has recently become a reality. The Spatial Imaging Group at the MIT Media Laboratory has reported the successful generation of small three-dimensional (3-D) computer-generated holographic images reconstructed in real time using a display system based on acousto-optic modulation of light[1, 2, 3]. In any holographic display, a computer-generated hologram (CGH) must be computed as quickly as possible to provide for dynamic and interactive images. However, the numerical synthesis of a holographic interference pattern requires an enormous amount of computation, making rapid ($\sim$1 s) generation of holograms of even limited size impossible with conventional computers.

A holographic fringe pattern is computed by numerically simulating the physical phenomena of light diffraction and interference[4]. Computation of holographic interference patterns often utilizes the fast Fourier transform (FFT) algorithm. Though relatively fast for images composed of discrete depth surfaces[5, 6], this approach becomes slow when applied to images that extend throughout an image volume. A more general ray-tracing approach computes the contribution at the hologram plane from each object point source. This method can produce arbitrary 3-D images, including image-plane holograms (i.e., images that lie in the vicinity of the hologram), a case that is more suitable for various display geometries. However, this method is slow, since it requires one calculation per image point per hologram sample. As presented in this paper, the application of several methods of reducing computation complexity leads to computation times as short as 1 s on a data-parallel-processing supercomputer. First, a *bipolar intensity* representation of the holographic interference pattern is applied and shown to eliminate unwanted image artifacts and simplify calculations without loss of image quality or generality. Second, a look-up table approach is described and shown to provide a further speed increase and to reduce computation to a minimum. Finally, exemplary computation times are presented.

HOLOGRAPHIC IMAGING

This paper focuses on the computation of off-axis transmission holograms possessing horizontal parallax only (HPO). It is possible to represent an HPO hologram with a vertically stacked array of one-dimensional (1-D) holographic lines[6, 7]. The goal of this paper is to compute these 1-D *holo-lines* as quickly as possible. Consider an HPO hologram made optically using a reference beam with a horizontal angle of incidence. Spatial frequencies are large in the horizontal direction ($\sim$1000 lp/mm) and increase with the reference beam angle. Since an HPO CGH contains only a single vertical perspective (i.e., the viewing zone is vertically limited to a single location), spatial frequencies are low ($\sim$10 lp/mm) in the vertical dimension. The number of holo-lines is, therefore, matched to the vertical image resolution. In the horizontal dimension, the sampling rate (or *pitch*) must be high to accurately represent the holographic information. During reconstruction of this hologram, diffraction occurs predominantly in the horizontal direction. A holo-line diffracts light to a single horizontal plane (*scan plane*) to form image points describing a horizontal slice of the image. Therefore, one holo-line should contain contributions only from points that lie on a single horizontal slice of the object. Essentially, the 2-D holographic pattern representing an HPO 3-D