ECE 299 Holography and Coherent Imaging

Lecture 8. Light in flight holography

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Holographic recordings have been made using lasers of short coherence and pulse length. Continuous frameless moving pictures show the wave front (pulse front) of light reflected by a mirror and focused by a lens. Light passing through interferometers has also been studied using this new method of dynamic observation. Cross sections between a thin sheet of light and a 3-D object have been recorded to demonstrate the possibilities of contouring. Finally a number of future experiments are proposed ranging from the measurements of industrial products to the study of relativistic effects.

II. Basic Idea

In a hologram only those parts of an object will be recorded for which the path length from the laser to the holographic plate via the object does not differ from the path length of the reference beam by more than the temporal coherence length of the laser light used for the recording. If the coherence length is short, a large object will be seen during reconstruction intersected by one bright fringe of near-zero path length difference. This fringe represents the object intersected by an imaginary interference surface in the form of an ellipsoid, one of its two foci being the point from which the spherical wave fronts of illumination are emitted (spatial filter \(A\) in Fig. 1) and the other focus being the point on the holographic plate used for the observation \(B\). Thus, to each point on the plate a corresponding ellipsoid exists in the image space representing zero path length difference between object and reference beams.
finite coherence signal
Fig. 1. L, laser; A, spatial filter; O, object; C, observed point; H, hologram plate; B, point of observation; and D and E, two mirrors. $e_0$, $e_1$ and $e_2$ are portions of ellipsoids perpendicular to the bisector of ACB, while $h_0$, $h_1$ and $h_2$ are portions of hyperboloids parallel to the bisector of CBD. From the intersection of H by $h_0$, only those parts on O are seen that represent its intersection by $e_0$, because the pathlength ACB is equal to AEDB.
Fig. 2. L, laser; A, spatial filter; O, object surface; M, mirror; \( W_m \), main wavefront; and \( W_r \), reflected wavefront.
Fig. 3. (a) A spherical wavefront from an argon laser enters at the left, illuminating a white-painted flat object surface at an oblique angle. The lower left end of a tilted mirror is just reached. (b) The wavefront has reached the middle of the mirror, the normal of which is inclined 40° to the horizontal line. The light is being reflected by the mirror upward and to the left. (c) All the reflected light is separating from the main wavefront which has just passed the mirror. (d) The two components of the light have separated completely, the reflected light leaving a black hole in the spherical wavefront. (e) The main wavefront exits to the right shadowed by some optical components.
Fig. 4. The experimental set up that produced the photos of Fig. 3. The white-painted object surface (O of Fig. 2) is an old door. It was chosen because it was large enough to reveal the curvature of the 30 mm thick spherical sheet of light. It was also mechanically rigid enough for the five seconds exposure and white-painted to give sufficient scattering of the light. To the door is fixed the mirror (M of Fig. 2). The large square black surface to the left is the reference mirror (E of Fig. 1) while the mirror (D of Fig. 1) and the hologram holder are seen far to the right.
Fig. 8. A composite of all the exposures shown in Fig. 7. An image of the lens is included to make the picture more clear.
Pulsed-image generation and detection

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We describe an experimental system that programs three-dimensional optical fields to 200-fs resolution over a
10-ps window by using photorefractive volume in
detected with an imaging interferometric cross.

Fig. 1. Experimental setup. The solid lines represent the write beams for recording holograms, and the dashed lines represent the probe, signal, and reference beams for reading pulsed images with mirror $M_1$ and the spatial mask removed.
Fig. 2. Surface plots of the pulsed image at 1-ps time intervals.

Fig. 3. Temporal cross correlations of two selected points in the pulsed image. Density plots of the image show the locations of the two points that are plotted.
Time-of-flight cross correlation on a detector array for ultrafast packet detection

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We describe and demonstrate an interferometric technique for measuring the first-order cross correlation of ultrafast optical pulses. This technique may permit single-shot pulse detection and is applicable to receivers for time-domain optical communications.

Fig. 1. Interferometric time-of-flight cross correlator. Signal (s) and reference (r) beams interfere on a detector array.
Fig. 2. Optical arrangement for the experimental time-of-flight interferometric cross correlator.

Fig. 3. Experimental cross-correlation data. The upper trace shows the raw data from the CCD detector. The lower trace shows the final data after filtering at the fringe frequency.
Spatial and temporal resolution of light in flight holography

\[ S(\tau) = \int \sigma(x) f\left(\tau - \frac{x}{v}\right) dx \]

\[ S(\tau) = \int \sigma(v \xi) f\left(\tau - \frac{\xi}{v}\right) d\xi \]

\[ g(\tau) = \int f(t) f(t + \tau) dt \]
Dynamic range and light in flight holography

\[ I = 1|R + S|^2 \]

\[ = |R|^2 + |S|^2 + RS^* + SR^* \]
Dynamic range and light in flight holography

For $p$ pixels, the average number of photoelectrons received per pixel is $M = 2\eta W_0/h\nu_0 p$, and the photoelectron shot noise is

$$\sqrt{M} = \left(\frac{2\eta W_0}{h\nu_0 p}\right)^{1/2}.$$  \hspace{1cm} (2)

The received signal consists of a maximum swing of $M/\sqrt{N}$ photoelectrons on a dc bias of $M$ photoelectrons. Thus the received voltage SNR is

$$\frac{V_{\text{sig}}}{V_{\text{noise}}} = \frac{M/\sqrt{N}}{\sqrt{M}} = \left(\frac{M}{N}\right)^{1/2} = \left(\frac{2\eta W_0}{Nph\nu_0}\right)^{1/2},$$  \hspace{1cm} (3)

and the detector output power SNR is

$$\text{SNR}_{\text{in}} = \frac{M}{N} = \frac{2\eta W_0}{Nph\nu_0}.$$  \hspace{1cm} (4)

After filtering, the detected power SNR is

$$\text{SNR}_{\text{out}} = \frac{2\eta W_0}{Nph\nu_0} \tau\nu_0 = \frac{2\eta W_0}{2N^2\nu_0\nu_{\text{max}}} \approx \frac{Q}{2N^2}.$$  \hspace{1cm} (5)

If the SNR $D$ is required for the desired BER, the number of photons required per bit received is then $Q/N \geq 2DN$. Thus the key difference between an interferometric cross correlator and a conventional serial receiver is that the number of photons required per bit in a pulse train grows linearly with $N$ in a cross correlator, whereas it is independent of $N$ in a serial receiver.
Solutions for better dynamic range?

- Nonlinear detection
- Spectral (non-multiplexed measurement).