PHOTOREFRACTIVE PARTICLE IMAGE VELOCIMETRY

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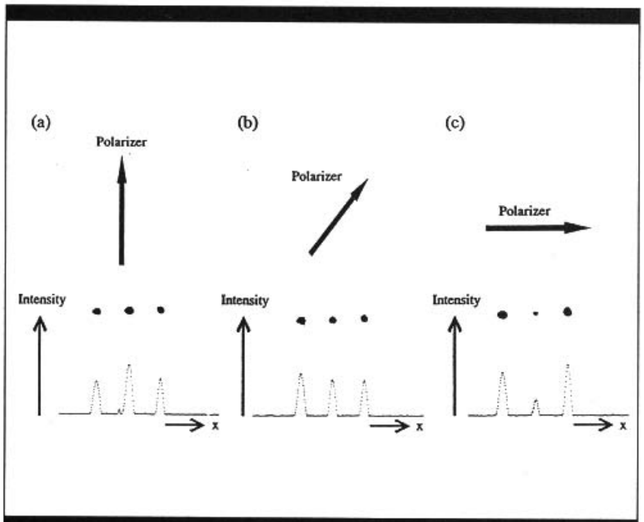
Optical signal processing techniques are attractive when the input is a two-dimensional transparency. With the help of the photorefractive effect, this processing is achieved quite easily in real-time using holographic schemes. We have recently demonstrated particle image velocimetry (or PIV) over a large area of a transparency in parallel using a photorefractive correlator.[1] In such an optical system, the input is a double exposure photograph of a particle flow. The autocorrelation function of this flow is carried out in a two-step procedure. First, the Fourier transform of an area of the transparency and a plane reference wave induce a phase grating in a photorefractive BSO crystal. The reference wave is then switched off and the hologram is read out with the Fourier transformed object beam itself to yield autocorrelation on the output screen. The result consists of two side-peaks and a central spot in the case of a uniform particle velocity. The distance between the peaks and their relative orientation determine the velocity and direction of the flow.

This holographic particle image velocimeter has been suggested by J. Coupland and N. Halliwell.[2] In their analysis, however, they assumed that the recording medium was isotropic. In our work, we include the effect of birefringence and optical cavity of the BSO crystal. Our analysis shows that the polarization and the intensity of the autocorrelation peaks are sensitive to parameters such as applied voltage, particle displacement, and the polarization of the incident beams. The behavior of the polarization states can qualitatively be explained by a theoretical model that includes the birefringence and optical activity of the crystal.



INTENSITY PROFILE OF THE PEAKS FOR THREE ORIENTATIONS OF THE ANALYZER.

We have analyzed the performance of the photorefractive PIV with a simple model. In such an approach, the transparency in the object arm contains only two point scatterers (or point sources). These are, in fact, the two locations of the same particle captured during the double exposure. The two-spherical waves that are generated after illumination of this transparency are transformed into two plane waves by a lens. These and the reference beam form phase gratings in the photorefractive BSO crystal. There are two gratings (G_1 and G_2) caused by the interference of the reference wave with each of the two scattered waves, and one grating (G_3) caused by the interference of the two scattered waves. The diffraction of the object beam (which consists of the scattered waves) gives the three peaks. Assuming a linear combination of the three gratings, the center spot consists of two contributions that correspond to Bragg diffraction from G_1 and G_2. The two autocorrelation peaks correspond to off-Bragg diffraction when each of the scattered waves diffracts from the grating created by the other scattered wave and the reference beam.

In our characterization of the PIV, we have replaced the transparency with two plane waves, as suggested in the simple model. The figure shows the intensity profile of the diffracted peaks for three different orientations of a polarizer placed just behind the BSO crystal. The incident recording beams, derived from an Ar-ion laser operated at a wavelength of 514 nm, are linearly polarized perpendicular to the plane of incidence. Even though all three peaks correspond to a first order diffraction in the BSO crystal, their polarization states are different. This is evidenced by the fact that the intensity of the center spot decreases while that of the autocorrelation peaks increases as the direction of the linear polarizer at the output is changed from vertical to horizontal position. Since the information for the velocity distribution is in the two side peaks, we can use these different states to increase the signal-to-noise ratio of the optical correlator.

The polarization properties of diffraction from gratings recorded in a birefringent and optically active medium have been analyzed previously with numerical methods.[3] Under simplifying assumptions such as weak coupling, it is possible to solve analytically the diffraction problem in BSO crystals. An expression for the diffraction efficiency was recently given by Vachss and Hesselink.[4] When applied to our photorefractive PIV system, this analytical model qualitatively explains the polarization sensitivity to applied voltage and flow velocity. It also predicts the asymmetry in the polarization states of the diffracted spots. However, only qualitative agreement has been achieved so far. It is believed that less restrictive numerical analysis, such as described by Marrakchi *et al.*,[3] could lead to a more accurate description.

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COMPACT AND ROBUST PATTERN RECOGNIZER USING A MICRO-LASER ARRAY

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Although the classical coherent optical processor[1,2] has been widely used in many different fields of analog optical computing, pattern recognition, neural networks, and optical interconnects, its bulky volume and critical alignment requirements make its integration difficult. Furthermore, for an optical computing/processing system to be practical, it is important to be integrable with semiconductor technology to facilitate the interfacing with other devices. The recent invention of surface-emitting laser diode arrays (SELDAs)[3] opened many possibilities in the field of optical computing. In particular, the compact two-dimensional nature of SELDA makes possible compact optical signal processing systems.

We have recently developed a pattern recognition system[4] that uses the unique coherence properties–high temporal coherence and spatial incoherence–of a SELDA to implement a compact and robust incoherent correlator.[5] As shown in the figure, the light from each of the SELs reconstructs holographic images on the output plane, with the position of each image shifted according to the position of the SEL. The reconstructed images generated by the light from different SELs add up incoherently because each laser operates independently, averaging out the phase-sensitive interference terms. The eventual summation of all the reconstructed images generated by all the SELs in the input plane gives the correlation between the input and the reference image stored on the hologram.

Since the summation is done incoherently, the system is not affected by delicate phase changes as in conventional coherent systems. This gives the system a large amount of robustness and flexibility in terms of filter positioning tolerances and the choice of recording materials, compared with the conventional systems. Furthermore, the system does not involve any moving parts, bulky optical components, or critical alignments. By replacing the lenses with holographic optical elements or zone plates, the whole system can be miniaturized and integrated.

The correlator demonstrated here can be combined with a SELDA-based holographic memory system[6] that is capable of random retrieval of a page of information within 1 nsec using the SELDA. The combined system would be able to perform more sophisticated functions like content addressable memory of learning. Due to the compactness and integrability of the system, it can be cascaded to implement even more intelligent multilayer networks.

In the future, SELDAs operating at a visible wavelength region together with new holographic recording materials, which permit on-line recording and erasure of holographic memories, may make this system suitable for a wide range of applications.

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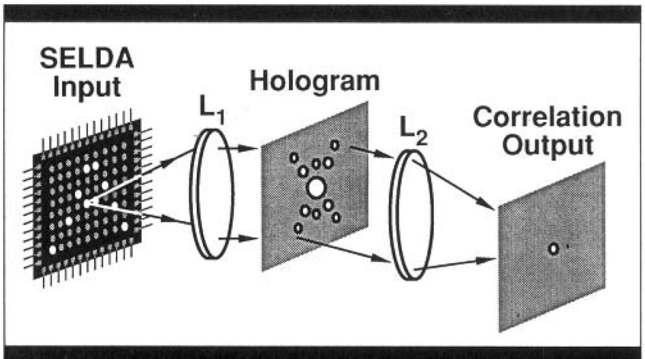

SCHEMATIC OF THE COMPACT AND ROBUST SELDA CORRELATOR.