HPIV USING POLARIZATION MULTIPLEXING HOLOGRAPHY IN BACTERIORHODOPSIN (bR)

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Summary Using an off-axis reference beam and forward-scattered holographic geometry, dual-exposure particle images in a fluid flow has been recorded successfully onto the bR film. This was achieved by photo-induced anisotropy in bR to multiplex two polarization holograms at the same location of the holographic film. Using a sequential holographic read-out method, the two recorded holograms can be retrieved independently during the read-out process. This system allows directional ambiguity to be removed in the HPIV flow data.

INTRODUCTION

Barnhart *et al* (2002) realized the potential of applying bR for holographic particle image velocimetry (HPIV), and subsequently pointed out that a centimeter-square area of bR film has the same information capacity for several hundred state-of-the-art CCD cameras [2]. They have also discussed the advantages and limitations of using bR as a recording medium for HPIV. As has been discussed in Chan *et al* (2004), various multiplexing methods can be used to record multiple holograms onto a same bR film. Polarization multiplexing by photo-induced anisotropies in bR offers the possibility in removing directional ambiguity in the HPIV data [4].

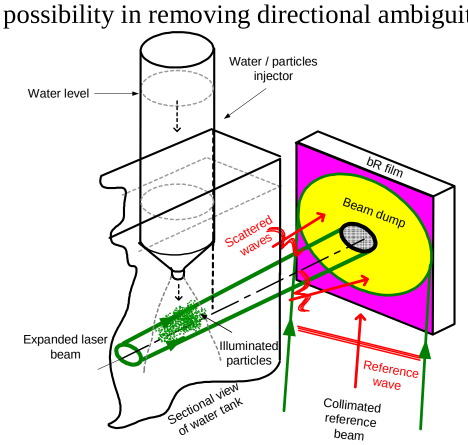

Figure 1: *Schematic of recording a hologram on bR using forward scattering on off axis geometry.*

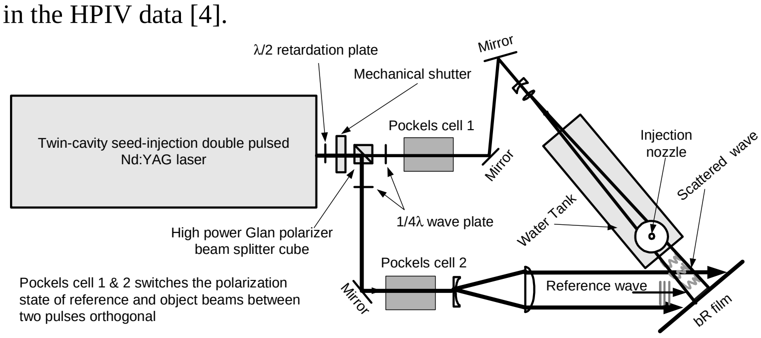

Figure 2: *Schematic of the recording set up for the HPIV experiment.*

EXPERIMENTAL SET UP FOR HOLOGRAPHIC RECORDING

As a proof of principle, an experiment was performed on a water jet seeded with 100µm solid glass sphere. This jet was injected into a clear tank of water through a syringe nozzle. The nozzle has an exit diameter of 2mm. The central position of the measurement control volume was located at six diameters down from the nozzle exit (i.e. X/D=12), which led to a measurement window that was ranging from X/D=8 to X/D=16 along the streamwise direction. In order to maximize the signal to noise ratio of the hologram, we have adopted a forward scattering geometry at a high numerical aperture (NA) configuration. This led to the recording of diffraction-limited particle images [3]. In the current set up as shown in figures 1 and 2, a small expanded laser beam from a dual-cavity seed-injection pulsed Nd:YAG (532nm) with output energy of 300mJ per pulse with pulse duration of 7ns, was used to illuminate the flow volume twice with a pulse separation time of 230µs. The object and reference beam fluences were adjusted to be equal to 80mJ/cm^2 (expanded beam diameter = 9mm) and 5mJ/cm^2 (expanded beam diameter = 80mm) respectively, where it is noted that only a small fraction of the object light scatters onto the bR film. When considering polarization holography in bR for HPIV, the recording of a hologram involves a two-step procedure [3]. During the first exposure both Pockels cells were switched off, such that the object and the reference wavefront would have left hand circular polarization and right hand circular polarization, respectively, at the plane of the hologram. For the second exposures the Pockels cells were supplied with the half wave voltage, resulting in an interchange of the object and reference polarization. With this set up, we have multiplexed two time separated holograms inside a single film.

DATA EXTRACTION RESULTS AND DISCUSSION

The two multiplexed holograms were reconstructed independently using phase conjugated playback geometry [3] as shown in figure 3. The collimated reconstruction beam for the read-out of a hologram has an intensity of 130μW cm^{-2}. Figure 4 shows the two multiplexed holograms that had been retrieved independently by sequentially switching the 1/2λ wave plate in and out (see figure 3). This rotates the incoming circularly polarized wave in the orthogonal orientation. We have reconstructed around 750 particles within a measurement volume of 7x8x9mm^3. The magnified view (top right corner) in figure 4 shows each string as a reconstructed particle. Three-dimensional image intensity analysis (local maxima along the string) was performed to determine all velocity components from the recorded flow hologram. Particle detection was performed by cross-correlating each slice with a particle "mask", a 5x5 Gaussian model particle. Subsequently, the local maxima in the resulting correlation plane were detected (which correspond to particle centers). To extract the velocity vectors, a nearest neighborhood search routine was performed on detected particle centers between the two stacks of images.

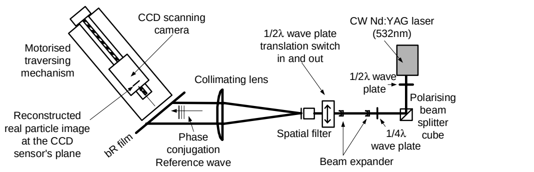

Figure 3: *Reconstruction of two sequentially multiplexed polarization holograms using circular polarization wave.*

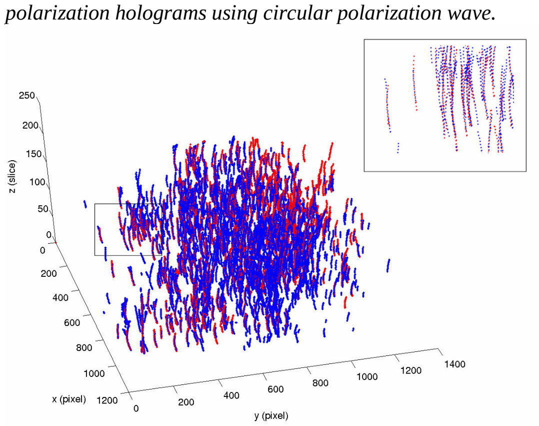

Figure 4: *Two independently reconstructed holographic particle fields superimposed on top of each other.*

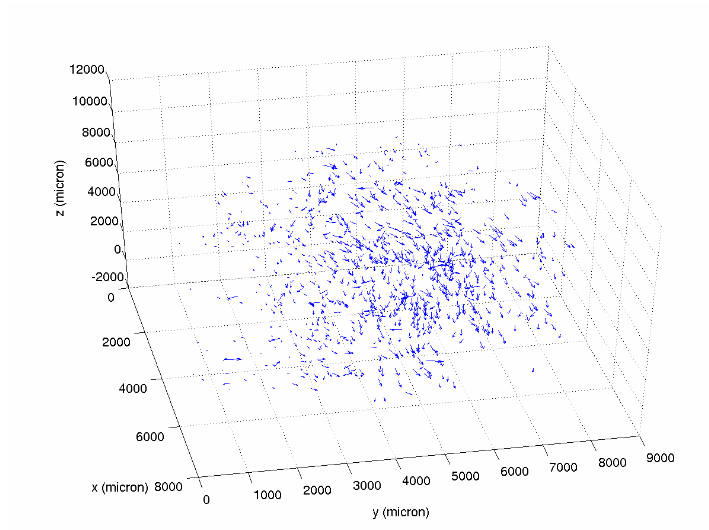

Figure 5: *Extracted HPIV vectors from figure 4, the jet is flowing from top to bottom.*

The directionally resolved data HPIV is presented in figure 5. The vector field exhibits a certain preferential orientation that indicates the jet flowing direction. The obtained maximum flow velocity in the streamwise direction is approximately = 0.5ms^{-1}. It shows a meandering flow profile which could be attributed to the fact that the heavier than water particle was used to seeded the jet.

CONCLUSIONS

As a proof of principal, an experiment was conducted on a particle laden water jet. A dual off-axis transmission hologram was recorded which maximizes the signal to noise ratio of particle images. Volumetric three-dimensional velocity information was extracted from the holograms by tracking the particle positions using the local maxima image intensity analysis with nearest neighborhood search. For the first time, we have demonstrated the feasibility in using bR for the recording of dual-exposure polarization multiplex particulate holograms to remove directional ambiguity in HPIV.

Acknowledgement

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References

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