**Micro Particle Shadow Velocimetry (μPSV)**

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**Motivation**

The increasing demand for microfluidic systems has made the fundamental understanding of fluid dynamics at such small length scales an inevitable challenge in many fields of science.

Due to the relatively high sensitivity of the sensors required to measure the small physical quantities encountered in micro-fluidics and the limited space available for installing instrumentation on micro-devices development of non-intrusive optical techniques with high spatio-temporal resolutions is of crucial importance for microfluidic applications.

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**Optical Concept**

Forward scattering of the non-fluorescent particles within the acceptance angle ‘numerical aperture’ of the objective is captured by the imaging array and the large difference in between the captured forward scattering and the back illumination intensity produces dark particles ‘shadows’ on a bright background.

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**Experimental Setup and Processing Technique**

A transparent test section was used to allow back-lit LED illumination of the centre plane of a circular micro channel.

This test section comprised a straight horizontal fluorinated ethylene propylene (FEP) circular tube with a measured internal diameter of 280 μm which was submerged inside a water bath held within a transparent plexiglass container (see Fig. 3).

Demineralised water was pumped through the test section by a Mitos P- pump which provided a steady non-oscillating flow. Water flow rate was measured with a Mitos flow rate sensor. The average temperature was used to determine water physical properties at the region of interest (ROI).

The refractive index matching used in this configuration ensured no distortion in the images due to refraction at the curved walls.

The illuminated ROI was observed through a long working distance Nikon Plan Fluor 40X infinity corrected dry objective with a numerical aperture of 0.6.

The recorded particle shadow images were interrogated via the cross-correlation technique to infer the fluid velocity field while the accuracy of the interrogated velocity vectors was increased by applying the cross-correlation averaging technique.

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**Results**

The velocity field across the centre plane of the 280 μm diameter micro channel was measured (see Fig. 7).

Velocity values are normalised by the maximum velocity at each flow rate and compared with the analytical solution for steady-state laminar flow in a circular channel (see Fig. 8).

Assuming the flow to be axisymmetric, the experimental axial velocity profiles were integrated across the cross section of the tube to calculate the volumetric flow rate.

The good agreement with the expected theoretical parabolic Poiseuille velocity profile indicates the high accuracy provided by μPSV over a large range of flow velocities and even close to the walls.

The high accuracy and sensitivity obtained by using μPSV suggests that it can be used to non-intrusively measure even very low instantaneous flow rates in the multiple feed lines of microfluidic devices (see Fig. 9).

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**Concluding Remarks**

- As a relatively cheap and easy-to-setup technique, μPSV can be considered as an effective method for non-intrusive measurement of flow dynamics and even flow rates especially with the fast development of transparent polymeric micro-fluidic devices.

- The optical concept of this technique makes it appropriate for bio-fluidic analysis where the working fluid already contains some particles (e.g. blood cells) and seeding the fluid with extra particles is problematic.