International Journal of Computational Engineering Science
Vol. 0, No. 0 (2002) 000–000

CHARACTERIZATION OF MICROFLUIDIC DEVICES USING MICRO PARTICLE IMAGE VELOCIMETRY

ZHIGANG WU, THAI-QUANG TRUONG, NAM-TRUNG NGUYEN, and XIAO-YANG HUANG

School of Mechanical and Production Engineering
Nanyang Technological University, Singapore, 639798
Email: zgwu@pmail.ntu.edu.sg

Received (received date)
Revised (revised date)

Along with the rapid growth of research of microfluidics, monitoring and understanding micro flow behavior is a challenge for researchers. Particle Image Velocimetry (PIV), a powerful tool that makes flow visible, was extended to microscale by Santiago et al. 1998. In this paper, we presented the micro Particle Image Velocimetry (μPIV) system at Nanyang Technological University (NTU), its calibration and characterizations of microfluidic devices using μPIV. Since the fully developed microchannel flow has been well investigated, it is suitable to calibrate the measurements of μPIV. In our experiment, an in-channel microdispenser fabricated on printed circuit board is used to form a microchannel. A syringe pump forces water that contains fluorescent particles. The flow field is obtained by μPIV. At the same time, a three-dimensional model with ANSYS/FLOTRAN was used. The comparison between the two results demonstrates that our μPIV system works well. Furthermore we use this system to characterize a Tesla valve - a non-moving part valve. The valve consists of a fluid channel structure that has rectification property, which favors forward flow while hampers reverse flow. The velocity fields are also validated by ANSYS/FLOTRAN.

Keywords: Microfluidic; Characterization; μPIV; Microchannel; Tesla Valve.

1. Introduction

With the development of science and technology, microfluidics grows very quickly recently. Many microfluidic devices such as flow sensors, chemical reactors, separation capillaries, pumps, and valves were developed and investigated,. They are applied in the wide fields of chemical analysis, drug delivery, biological sensing and analysis. It has a high potential value and high capacity of commercial market in the coming future. Therefore, monitoring and understanding the flow in micro scale is urgent at present.

However, due to micorscale effects, monitoring micro flow become one of the key challenges in microfluidics[1]. Particle Image Velocimetry (PIV) based on optical measurement, a powerful tool that make flow visible, was extended to micorscale by Santiago et al.[2]. The most significant benefit is that it cannot affect the flow field. Furthermore, it can get the information in the whole field. In this paper, we presented the μPIV system at NTU, its calibration and characterization of microfluidic devices using μPIV.

2. μPIV and the setup

The major concept of μPIV is to visualize the micro flow with the tracer particles that faithful move with the fluid movement. It captures images of flow, and then uses corresponding correlation algorithms to get velocity further[3]. At present, cross-correlation is preferred for its good performance. It requires two images in different frames in the interval time Δt. Then in the divided interrogation window, using cross-correlation algorithm, the averaged displacement of the particles in the window is:

$$\Phi(m,n)=\sum_{j=1}^{q}\sum_{i=1}^{p} f(i,j)\cdot g(i+m,j+n) \tag{1}$$

where $f(i, j)$ and $g(i, j)$ are the gray-value array of the two windows, i, j, m, n are indices for pixel positions. Then divided by Δt, the corresponding velocity can be calculated for the interrogation window.

Our setup of μPIV consists of three main components: an illumination system, an optical system, and a control system. The illumination system, consisting of a double head Nd:YAG laser (QUANTEL) with Q-switches (quality switches), is used to illuminate the seeded flow. The working wavelength is 532 nm with a maximum energy of 160 mJ. The optical system is used to guide the light and collect the images. It includes two parts: an inverted microscope (Nikon ECLIPSE TE2000) with epi-fluorescent attachments and a high-resolution digital camera (Sony ICX 84). Among them, the microscope is used to guide light and the camera is used to capture high quality images. In our setup, we used fluorescent particles (Duke Scientific Co., the maximum excitation and emission wavelength are 540 nm and 610 nm respectively) to seed the flow. Therefore, a filter cube is installed in the microscope. The characteristic parameters are 540/25 nm EX (excitation), 565 nm DM (dichroic mirror), and 605/55 nm BA (barrier access). The control system is a programmed timing unit (PTU) to synchronize the laser pulses and the camera. It is designed as a peripheral component interface (PCI) card and plugged in the controlled computer with its software (LAVISION DaVis 6.2). The setup can be seen in Fig. 1.

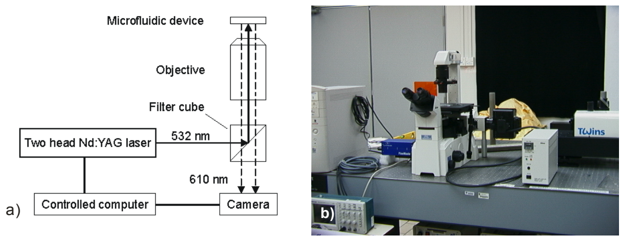

Fig. 1. The μPIV system: a) schematics, b) actual setup.

3. Calibration

Since the fully developed microchannel flow has been well investigated, it is suitable to calibrate the measurements of μPIV. In our experiment, an in-channel micro dispenser on printed circuit board (PCB) is used to form a microchannel[4]. The channel widths of the two capillaries are 1700 μm and 700 μm, respectively. The channel depth is equal to the thickness of the copper layer (40 μm). The channel structure is covered by a glass slide, which allows optical access for the μPIV measurement. Fig. 2a) depicts the fabricated channel structures with the image windows. Among the widows, the bottom window is used to calibrate the system; the top window is used to characterize the flow in the dispenser (see section 4).

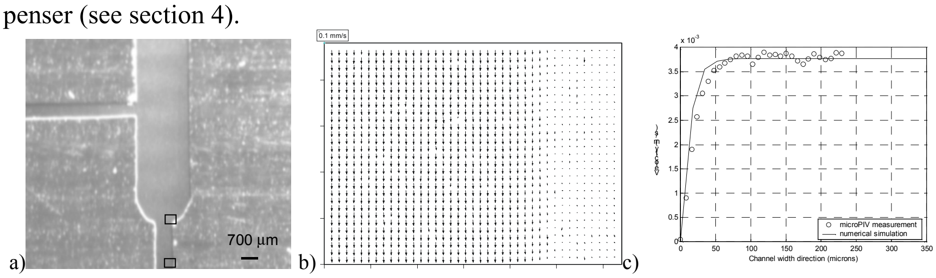

Fig. 2. Calibration: a) channel structure; b) velocity vectors plot; c) comparison of flow velocity.

In our experiment, the water was driven by a syringe pump and 1 µm red fluorescent particle was used to seed the flow. With a 20× objectives, the images were captured by camera. The corresponding image size is 240 µm × 320 µm. Thus, the whole channel width (700 µm) could not be observed. The two 24 mJ lasers were short in the interval of 450 µs to excite the particles. The evaluation was carried out by PIVview (PivTec GmbH, Germany) and then EDPIV from Purdue University[5]. A 32 pixels×32 pixels with an overlap ratio of 50% interrogation window, which satisfies the Nyquist sampling criterion[6], is used in the evaluation. The result can be seen in the Fig. 2b).

Then using ANSYS/FLOTRAN, a three-dimensional numerical model was set up to validate the measurement results. The velocity profile of section was extracted and compared with the measurement results. In Fig. 2c), the line denotes numerical solution and circles denote the measurement results. They agree well with each other. This comparison indicates our system works well can be used to characterize other microfluidic devices further.

4. Experimental Results and Discussions

After the calibration, we investigated another flow fields: the transition area in the dispenser and a Tesla valve fabricated in polymethyl methacrylate (PMMA).

4.1. *Transition Area*

This experiment follows the above calibration under same conditions. That is the top window in Fig. 2a). The channel width changes from 1700 µm to 700 µm here. Using the same methods, the results are put in Fig. 3a) the particle image and Fig. 3b) the velocity field with contour image. In the velocity field, it is easy to see the change of velocity from high to low. Recurring to the ANSYS model set up in section 3, the contour velocity image is given in Fig. 3c). The two results agree well, too.

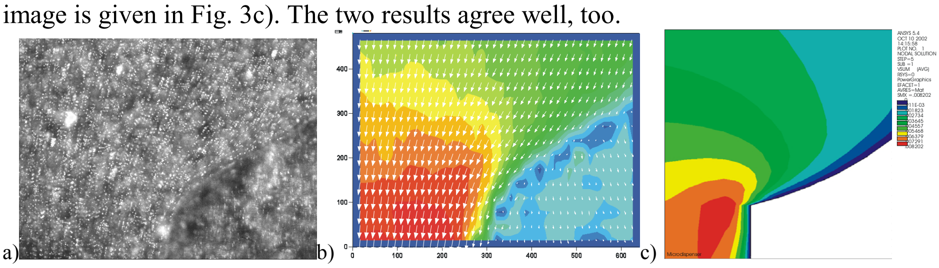

Fig. 3. Results of the transition area: a) particle image; b) velocity field; c) simulation.

4.2. *Tesla Valve*

Tesla valve[6], a non-moving part valve, was also investigated. The valve consisted of a channel structure that has rectification property, which favors forward flow while hampers reverse flow. The Tesla valve was fabricated in PMMA substrate (Fig. 4a)). The channel height was 90 µm, and the channel width was 100 µm. The whole channel was covered by a standard glass slip using SU-8 as glue, which allows optical access. The experiment was carried out under the same conditions while only the interval of laser pulse was adapted to 500 µs.

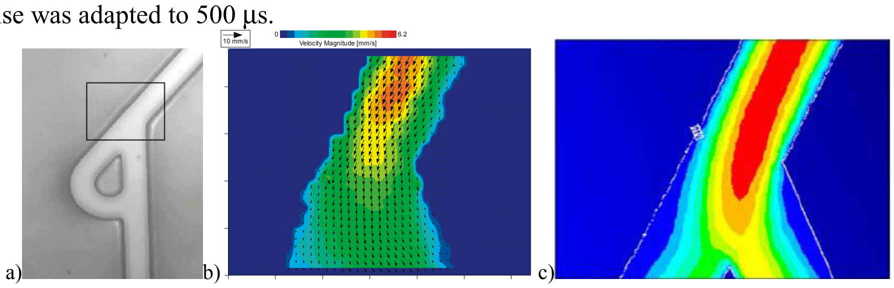

Fig. 4. Tesla valve and results: a) Tesla valve; b) velocity field; c) simulation.

The velocity of the window in Fig. 4a) was investigated. In Fig. 4 b), the velocity vectors field with contour image is given. Similar to the dispenser, a two-dimensional ANSYS model was developed. Fig. 4c) gives the velocity contour image in the interest window. Fig 4b) and Fig. 4c) show a high level of agreement between experiment and simulation.

5. Conclusions

In this paper, the µPIV system and at NTU and its calibration is presented. Furthermore, microfluidic devices are characterized successfully using this system. The results show that µPIV is a good and efficient tool in flow visualization and diagnosis in microfluidics. In the future, this system will be extended to a wider range of microfluidic measurement such as characterization of the mixing process and separation process in microchannel.

References

1. P. Mitchell, *Microfluidics – downsizing large-scale biology*, Nature Biotechnology volume 19 (2001) 717-721.
2. J. G. Santiago, S. T. Wereley, C. D. Meinhart and R. J. Adrian, *A particle image velocimetry system for microfluidics,* Experiments in Fluids 25 (1998) 316-319.
3. R. J. Adrian, *Particle-image techniques for experimental fluid mechanics*, Annual Review of Fluid Mechanics 23 (1991) 261-304.
4. S. Richter, N. T. Nguyen, A. Wego, L. Pagel, Chapter 7 *Microfluidic Devices on Printed Circuit Boards*, *Microfluidics and BioMEMS Applications*, edited by F. Tay, 1st Edition, Kluwer Academic Publishers, (2002), pp. 185-218.
5. N. T. Nguyen, S. T. Wereley, *Fundamentals and Applications of Microfludics*, 1st edition, Artech House, (2003).
6. R. D.Keane, and R. J. Adarin, *Theory of cross-correlation analysis of PIV images*, Applied Science Research, 49 (1992), pp. 191-215.
7. T. Q. Truong, Z. Wu, N. T. Nguyen, X. Huang, *Optimization and validation of rectification microvalves with micro particle image velocimetry*, the 7th Asian symposium on visualization, Singapore, 2003, accepted.