http://ansinet.com/itj

ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 12 (19): 4901-4905, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.4901.4905

Image Based Micro Flow Measurement Technology

[1]Lu Jian-Gang, [1]Liu Yu-Cong, [2]Ye Xin-Xin, [3]Shi Ying-zi, [4]Gao Hua and [1]Yang Jiang
[1]State Key Laboratory of Industrial Control Technology, Department of Control Science and Engineering, Zhejiang University, Hangzhou, 310027, China
[2]Bank of China Head Office, Fuxingmennei Street 1, Beijing, 100818, China
[3]College of Education, Hangzhou Normal University, Hangzhou, 311121, China
[4]Institute of Information Technology, Zhejiang Institute of Communications, Hangzhou, 311112, China

Abstract: Based on the image processing of the liquid droplets at the outlet of a single micro pipe, a novel low cost micro flow measurement technology for micro-chemical process is introduced. The connected component labeling algorithm is implemented firstly to extract a rough contour of the droplet from binary image. The droplet contour is refined by Laplace-Young equation based fitting which is to use Newton-Raphson method to optimize the shape parameters. Then the droplet volume is obtained by integration method. Finally, the flow rate can be calculated periodically through the real-time calculation of the droplet volume. The experimental results illustrate that the total average absolute deviation (AAD%) of the measurements is 2.09% over the micro liquid flow rate range of 5-60ml/h. This novel method can be readily extended to measure multi-pipe micro flows simultaneously which is of great significance for micro chemical plants where a large number of pipes may be used.

Key words: Micro flow measurement, contour extraction, laplace-young equation, contour fitting, newton-raphson method

INTRODUCTION

Micro-chemical technology can enhance the product selectivity, reaction speed, cost efficiency and risk aversion of chemical process. However, the mini-size and hermetic micro-chemical equipment raise the difficulties of measurement and controlling micro-chemical process which consequently limits the popularization of micro-chemical technology. Though there are some flow measurement devices at present, they are more or less bothered with problems of the high price which violates the low cost intention of micro-chemical technology, or low accuracy. For instance, Jaw *et al*. (2012) used Micro-PIV for micro-flow measurement, while the accuracy largely depends on the quality of the tracer particle which is quite expensive. Yoon *et al*. (2000) introduced a micro electromagnetic flow sensor which is difficult to be implemented in micro-chemical process, especially the installation part. Therefore, this paper aims at developing a low cost flow rate measurement technology for micro-chemical process.

In most scenarios of micro-chemical process, the liquid flow rate is so slow that droplets will appear at the pipe outlet. So it can be expected that the real-time changes of the droplet volume can illustrate the flow rate of micro liquid flow.

However, the real-time calculation of the droplet volume is difficult. Rotenberg *et al*. (1983) proposed the sessile drop method to calculate the drop volume by differential equations. The math foundation of the sessile drop method is the Laplace-Young equation and the derived partial differential equation groups of the drop contour. The two-dimension Newton-Raphson method is used for parameter optimization. Nevertheless, solving of the partial differential equations needs intensive computation and may not converge to a desired result. Yuan *et al*. (2002) simplified the sessile drop method by reducing the optimizing parameters to two.

Due to the need of real-time processing the droplet contour, further enhancement should be focused on the processing efficiency.

The rest of the paper is organized as follows. Section 2 gives the general procedures of the image based technology for micro-liquid flow measurement. Section 3 describes the image processing algorithm. Section 4 discusses the numerical method of getting the corresponding flow rate by fitting the drop contour. Section 5 provides the experiment results. Section 6 offers the conclusions.

Corresponding Author: Yang Jiang, State Key Laboratory of Industrial Control Technology, Department of Control Science and Engineering, Zhejiang University, Hangzhou, 310027, China

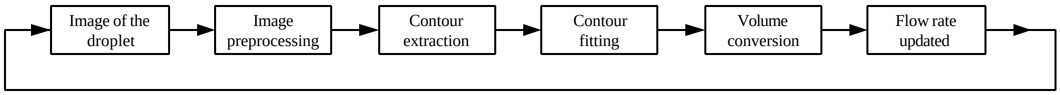

Fig. 1: Process flow chart

OVERALL STRUCTURE

The method consists of four steps:Image preprocessing, contour extraction, contour fitting and the volume conversion algorithm, as shown in Fig. 1.

IMAGE PROCESSING ALGORITHM

The image processing algorithm consists of image preprocessing, contour extraction and contour fitting.

Image preprocessing includes gray processing and image binaryzation, whose result is the foundation of following steps.

Contour extraction is based on the labeling of connected components in a binary image. According to the algorithm in Suzuki *et al.* (2003), the rough contour of the drop is obtained, as shown in Fig. 2. The contour extracting result is quite satisfied at a high resolution.

It is noteworthy that the droplet contour is rough at low resolution, as shown in Fig. 3. Due to the lack of efficient contour points, high error will occur if the contour is used for integration directly. On the purpose of reducing the cost, common camera with low resolution is often used, thus, a further contour fitting is necessary for the low cost cases.

Contour fitting is based on Laplace-Young equation of the droplet.

$$\gamma(\frac{1}{R_1}+\frac{1}{R_2})=\Delta P \quad (1)$$

where, γ is the surface tension, R_1 and R_2 are the curvature radiuses, ΔP is the pressure difference between the liquid surfaces.

Taking the vertex of the droplet as the origin of the coordinate, the tangent orientation of the vertex as the X-axis, coordinate of the droplet is established, as shown in Fig. 4.

According to Rotenberg *et al.* (1983) and Yuan *et al.* (2002), the contour fitting can be expressed as an optimization problem:

$$\min E(R_0,\beta)=\sum_{i=1}^{?}[(R_0x_i-X_i)^2+(R_0z_i-Z_i)^2] \quad (2)$$

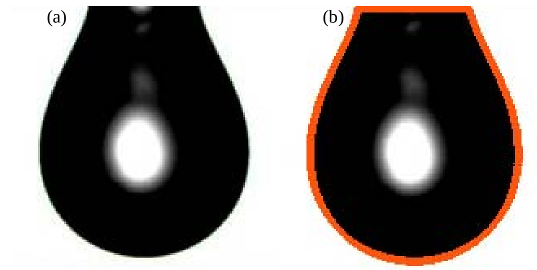

Fig. 2(a-b): Contour extraction at high resolution, (a) The original droplet image and (b) Contour extraction result

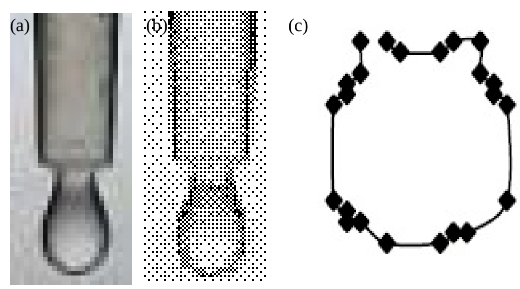

Fig. 3(a-c): Contour extraction at low resolution, (a) The original droplet image, (b) Contour extracting result and (c) The rough contour

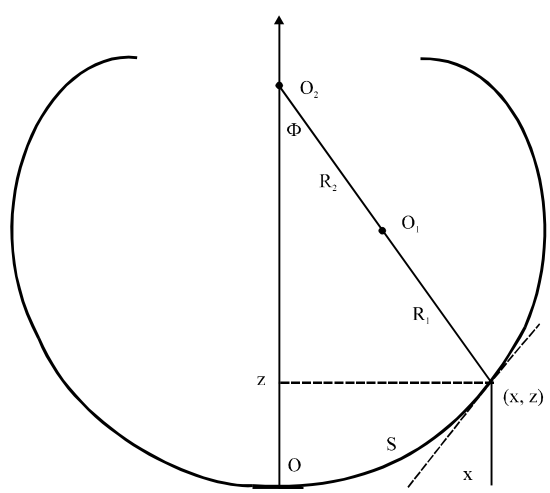

Fig. 4: Coordinate of the droplet

$$\begin{cases} \dfrac{dx}{dS} = \cos\phi \\ \dfrac{dz}{ds} = \sin\phi \\ \dfrac{d\phi}{ds} = 2 + \dfrac{\Delta\rho g R_0^2}{\gamma} z_1 - \dfrac{\sin\phi}{x} = 2 + \beta z_1 - \dfrac{\sin\phi}{x} \\ x(0) = z(0) = \phi(0) = 0 \end{cases} \tag{3}$$

where, R_0 is the curvature radius of the O-point, $\beta = \Delta\rho g R_0^2/\gamma$ and ΔP is the density difference between the liquid surface.

The optimal parameters are obtained with the Newton-Raphson method (Xu, 2005), the iteration scheme of R_0 and β is:

$$\begin{cases} R_0^{k+1} = R_0^{k} - \delta R_0^{k} \\ \beta^{k+1} = \beta^{k} - \delta\beta^{k} \end{cases} \tag{4}$$

The parameter increments (δR_0,$\delta\beta$) can by obtained by:

$$\begin{bmatrix} \delta R_0 \\ \delta\beta \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^{N} \dfrac{\partial^2 e_i}{\partial R_0^2} & \sum_{i=1}^{N} \dfrac{\partial^2 e_i}{\partial R_0 \partial\beta} \\ \sum_{i=1}^{N} \dfrac{\partial^2 e_i}{\partial R_0 \partial\beta} & \sum_{i=1}^{N} \dfrac{\partial^2 e_i}{\partial\beta^2} \end{bmatrix}^{-1} \begin{bmatrix} \sum_{i=1}^{N} \dfrac{\partial e_i}{\partial R_0} \\ \sum_{i=1}^{N} \dfrac{\partial e_i}{\partial\beta} \end{bmatrix} \tag{5}$$

Where:

$$\begin{cases} \dfrac{\partial e_i}{\partial R_0} = (R_0 x_i - X_i)x_i + (R_0 z_i - Z_i)z_i \\ \dfrac{\partial e_i}{\partial\beta} = (R_0 x_i - X_i)R_0 x_i' + (R_0 z_i - Z_i)R_0 z_i' \\ \dfrac{\partial^2 e_i}{\partial R_0^2} = x_i^2 + z_i^2 \\ \dfrac{\partial^2 e_i}{\partial R_0 \partial\beta} = (R_0 x_i - X_i)R_0 x_i' + (R_0 z_i - Z_i)R_0 z_i' + R_0(x_i x_i' + z_i z_i') \\ \dfrac{\partial^2 e_i}{\partial\beta^2} = (R_0 x_i - X_i)R_0 x_i'' + (R_0 z_i - Z_i)R_0 z_i'' + R_0^2(x_i^2 + z_i^2) \end{cases} \tag{6}$$

and (x_i, z_i) is the ith point of the real contour, (X_i, Z_i) is the point best fitted by calculation.

The derivatives in Eq. 6 can be calculated as follow:

$$\begin{cases} \dfrac{dx'}{ds} = -\phi' \sin\phi \\ \dfrac{dz'}{ds} = \phi' \cos\phi \\ \dfrac{d\phi'}{ds} = z + \beta z' - \dfrac{\cos\phi}{x}\phi' + \dfrac{\sin\phi}{x^2} x' \end{cases}$$

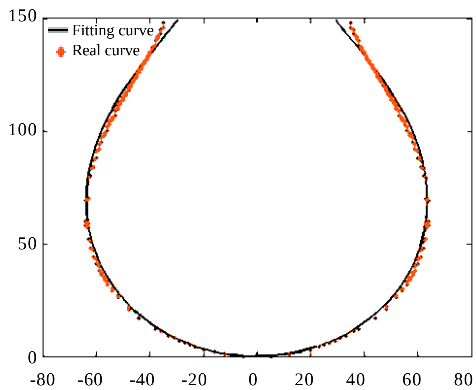

Fig. 5: Contour fitting result by Newton-Raphson method

For illustration purpose, we set the initial value of parameters: $R_0 = 10$, $\beta = -0.1$. The optimized parameters are: $R_0 = 60.384$, $\beta = -0.275$. And the contour fitting result is shown in Fig. 5.

THE NUMERICAL METHOD

During the experiment, we noticed that chattering occurred when the droplet began to form or fall which would result in great error. Currently, we cannot find a way to deal with this problem appropriately, so the sampling data is simply discarded when the droplet volume is lower than 0.1 V_{max} or greater than 0.85 V_{max}, where V_{max} is the volume of the former droplet.

According to the contour obtained by fitting, the volume of the droplet can be calculated as follow:

$$V = A \cdot V' = A \cdot \sum_i V_i = A \cdot \sum_i \left[\pi \cdot h_i \cdot (R_i^2 + R_i \cdot r_i + r_i^2)/3\right]$$

where, V is the volume of the droplet; V' is the volume of the droplet image; A is the conversion coefficient getting by experiment; h_i, r_i and R_i are the height, the radii of the top and bottom of the ith truncated cone, as shown in Fig. 6, respectively.

After getting V_k (the droplet volume at time k), the droplet volume change in the time interval (T) gives out the volume change rate F_k:

$$F_k = \frac{V_k - V_{k-1}}{T} \tag{10}$$

The flow rate at time k can be updated by the volume change rate F_k and the following strategy is taken to update the flow rate at time k:

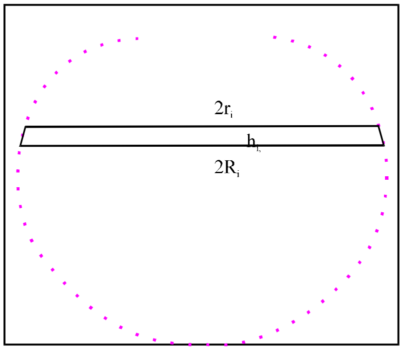

Fig. 6: Volume calculation

Table 1: Flow measurement error (5-60 mL h^{-1})

Setting flow rate (mL h^{-1})	Measurement value (mL h^{-1})	Deviation (%)
5.00	5.08	+1.60
10.00	10.17	+1.70
20.00	20.53	+2.65
30.00	29.35	-2.17
40.00	39.28	-1.80
50.00	47.88	-4.24
60.00	60.28	+0.47
AAD (%)		2.09

$$\begin{cases} \text{no update, when } V_k < 0.1V_{max}, \text{the drop began to form} \\ F_k, \quad \text{when } 0.1V_{min} \le V_k \le 0.85V_{max} \\ \text{no update, when } V_k > 0.85V_{max}, \text{the drop began to fall} \end{cases}$$

EXPERIMENTAL RESULTS

Test scenario

Test condition: BASLER camera for industrial applications, MATROX image grabber, frame rate (40fps), image resolution (1000×1000), sampling frequency (10 Hz), image size (100×100), the precision of injection pump (±2%), minimal flow rate (0.1 mL h^{-1}).

Test method: As this method is mainly applied to the measurement of low-speed and micro-liquid flow, our testing flow rate is at the range of 0-60 mL h^{-1} with step of 0.1 mL h^{-1}.

Test result: The droplet is photographed in real time, as shown in Fig. 7, whose image quality can satisfy our needs for contour calculation.

In Fig. 8, we can see that the volume measurement is comparatively ideal except some burrs and the smaller the flow rate, the bigger the error. By calibration, the conversion coefficient A is 150.3.

When the real flow rate varies from 5 to 60 mL h^{-1}, the flow rate measured is shown in Table 1. The total average absolute deviation (AAD%) of the measurements is 2.09%. Taking the precision of the injection pump (±2%)

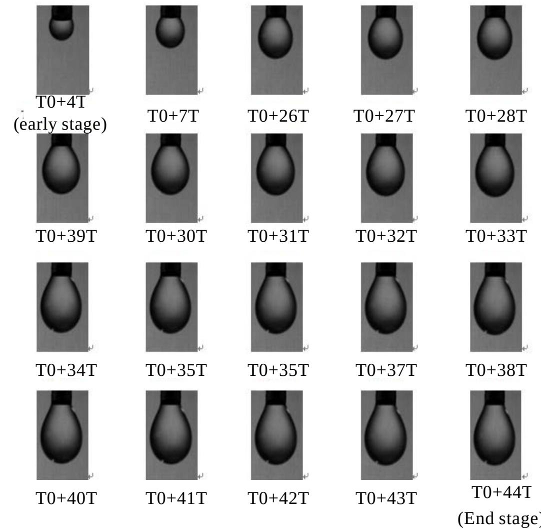

Fig. 7: Images of the droplet (Flow rate = 30 mL h^{-1}, T = 100 ms)

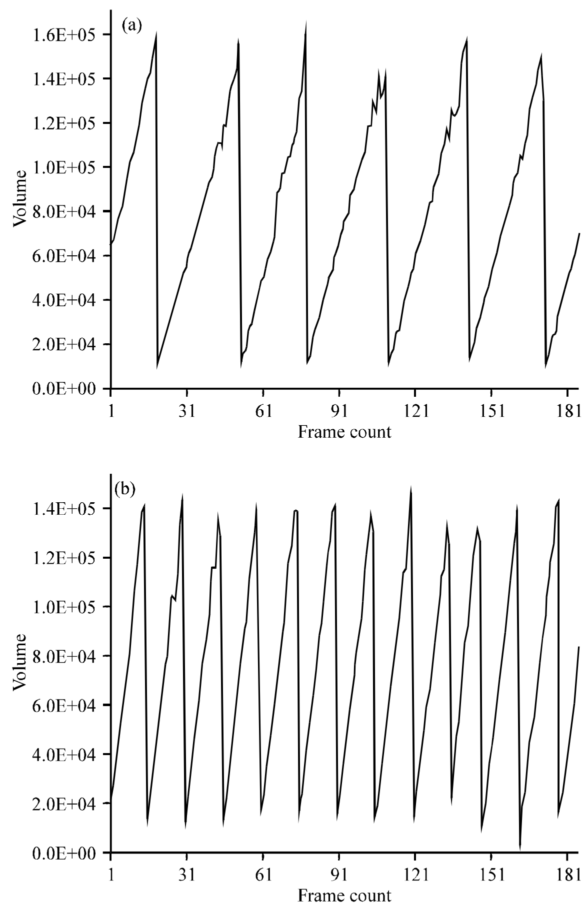

Fig. 8(a-b): Droplet volume curve at different flow rate, (a) 30 mL h^{-1} and (b) 60 mL h^{-1}

into account, the measurement result is quite precise as the setting flow rate is varied from 5 to 60 mL h^{-1}.

For the case of flow rate lower than 5 mL h^{-1}, the error is relatively large. Chattering is the main reason of the error even though some smoothing methods are taken.

CONCLUSIONS

A novel micro flow measurement technology based on the image processing was proposed to measure the micro liquid flow rate. The total average absolute deviation (AAD%) of the measurements is 2.09% over the micro liquid flow rate range of 5-60 mL h^{-1}. It can be expected to achieve better accuracy if we can find a way to handle with the droplet chattering phenomena. Although this novel method is discussed for single-pipe micro flow measurement, if combined with image segmentation technique, it can be readily extended to measure multi-pipe micro flows simultaneously which is of great significance for micro chemical plants where a large number of pipes may be used.

ACKNOWLEDGMENTS

This study was partially supported by the National Natural Science Foundation of China (NSFC) (No. 21076179) and the National Basic Research Program of China (973 Program: 2012CB720500).

REFERENCES

Jaw, S.Y., W.S. Chung, J.J. Sheen and C.C. Hu, 2012. Micro-flows measurement from a LED micro-PIV system. Proceedings of the 5th International Congress on Image and Signal Processing, October 16-18, 2012, Chongqing, Sichuan, China, pp: 731-734.

Rotenberg, Y., L. Boruvka and A.W. Neumann, 1983. Determination of surface tension and contact angle from the shapes of axisymmetric fluid interfaces. J. Colloid Interf. Sci., 93: 169-183.

Suzuki, K., H. Isao and S. Noboru, 2003. Linear-time connected-component labeling based on sequencial local operations. Comput. Vis. Image Understand., 89: 1-23.

Xu, S.L., 2005. Computer Algorithm in Common Use. Tsinghua University Press, Beijing, China.

Yoon, H.J., S.Y. Kim, S.W. Lee and S.S. Yang, 2000. Fabrication of a micro electromagnetic flow sensor for micro flow rate measurement. Proc. SPIE, 3990: 264-271.

Yuan, Z.F., K. Mukai, K. Takagi, M. Ohtaka, W.L. Huang and Q.S. Liu, 2002. Surface tension and its temperature coefficient of molten tin determined with the sessile drop method at different oxygen partial pressures. J. Colloid Interf. Sci., 254: 338-345.