Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 54(10) (2023) 451-454
DOI: 10.22060/mej.2022.20666.7290

Sliding Mode Control of Droplet Size in a Microchannel by Adjusting Syringe-Pump Flow: Experimental Study

A. A. Mahdizadeh, M. Nazari*, M. Nazari, H. Ahmadi

Department of Mechanical Engineering, Shahrood University of Technology, Shahrood, Iran

ABSTRACT: Microfluidics has many applications in modern sciences such as medicine and biomedical engineering. There are usually two ways of injecting fluids; using pressure regulations in fluid flow lines and using syringe pumps, which using syringe pumps is the most common way. Today, a lot of research has been done in this field, but a limited number of them have focused on active control of the droplet size. In this research, a microchannel was first fabricated using photolithography. To inject fluids into the channels, a syringe pump is designed and built using a DC motor with suitable speed and torque and the L298N module. The fluids used in this research are double distilled water as a discrete phase and oil as a continuous phase. An Arduino Mega 2560 board has also been used as the processor to automatically control this system. The droplet diameter is calculated using a digital microscope and its image processing with a high-speed algorithm. The sliding mode control algorithm has been used to control the droplet size due to the nonlinearity of the system behavior as well as the disturbances. The obtained results for three different diameters i.e. 82, 90, and 100 µm, show the accurate performance of the sliding mode controller.

Review History:

Received: Oct. 12, 2021
Revised: Aug. 26, 2022
Accepted: Aug. 28, 2022
Available Online: Oct. 24, 2022

Keywords:

Microfluidics
Micro-droplets
Syringe pump
Droplet size control
Sliding mode control

1- Introduction

T-shaped microchannels and concentrated flow-focusing microchannels [1] are two common types of microchannels for droplet generation, in which flow-focusing microchannels are the most common types. To flow fluid in a channel, a syringe pump can be used, which is easier and more economic. The fluids can be flown by applying pressure upstream.

Creating precise and uniform droplets in microfluidic systems is essential for most medical and microfluidic applications. On the other hand, these systems should be robust in dealing with disturbances and uncertainties.

To create precise droplets, many complicated solutions were considered, such as designing micro-pumps and micro-valves. Today, generating microdroplets in a closed-loop system is popular because these systems are robust and can generate microdroplets uniformly and precisely. To this aim, several control methods and closed-loop structures were designed. A robust controller was designed to adjust the flow rate by applying pressure upstream in Ref. [2]. Although pressure-driven microfluidic systems have less vibration, the control of flow in these systems is difficult, and they are sensitive to disturbances.

The droplet size in a microchannel was controlled using a PID controller in Ref. [3] where the sensor in this system was electrodes as a capacitor. A reinforcement learning-based controller was designed in Ref. [4]. The Iterative Learning Control (ILC) strategy was presented in Ref. [5]manipulation and application of microdroplets of a few micrometers size. It drastically enhances the advantages of microfluidics in terms of low consumption, automation and high throughput and is widely used in chemical, microelectronics, materials science, biology and biomedical engineering etc. In this paper, an iterative learning control (ILC to control the droplet size.

The flow of a syringe pump was controlled in Ref. [6] to control the droplet size using a robust controller. For measuring the droplet size, a high-speed camera was used. However, in this research, only the flow of the syringe pump was controlled and the sizes of the droplets were not used as feedback.

In the present paper, a T-junction microchannel is fabricated. To flow the fluids in their channels, two syringe pumps were used, and the droplet size was measured by a high-speed camera.

2- Experimental Setup

The closed-loop system is shown in Fig. 1. As shown in this figure, two syringe pumps are used to flow the fluids in their channels. To apply the controller, an Arduino board is considered.

A T-shaped flow-focusing microchannel is fabricated to

*Corresponding author’s email: nazari_mostafa@shahroodut.ac.ir

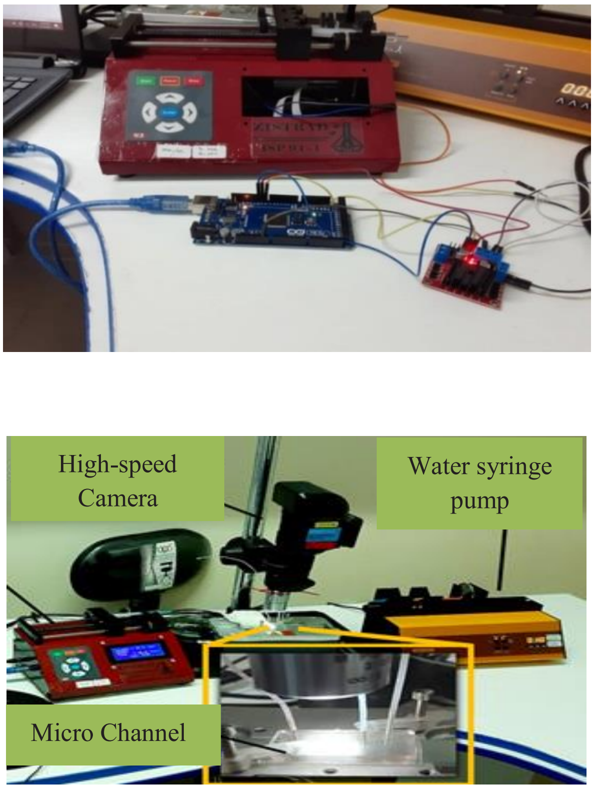

Fig. 1. a) View of fabricated syringe pump: b) Closed-loop system

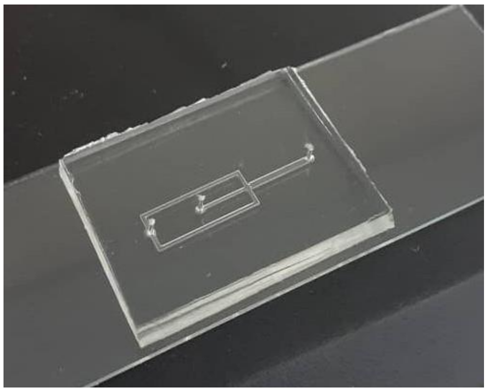

Fig. 2. The fabricated micro-channel

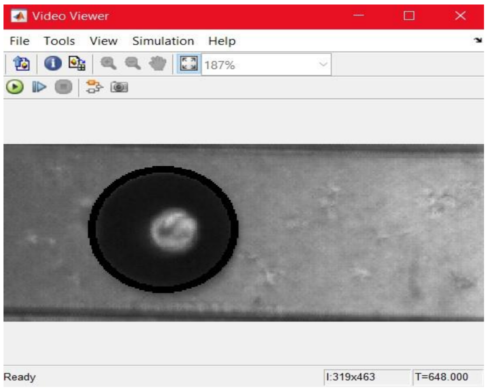

Fig. 3. Droplet size measurement using a high-speed image processing algorithm.

generate droplets using the photolithography method (Fig. 2).

A high-speed camera with a high-speed image processing algorithm is used for measuring the droplet sizes (Fig. 3).

3- Controller Structure

The dynamic model of the DC motor of the syringe pump extracted by the experimental test is as follows:

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = -3952x_2 - 16700x_1 + u \end{cases} \tag{1}$$

where is the motor position. The control input using the sliding mode control approach is as follows:

$$u = b^{-1}\left[\hat{u} - k\, sgn\left(\frac{s}{\phi}\right)\right] \qquad \hat{u} = -\hat{f} + \ddot{x}_d - \lambda\tilde{x} \tag{2}$$

Where:

$$\tilde{x} = x - x_d \qquad \hat{f} = -3952x_2 - 16700x_1 \tag{3}$$

The parameters of the controller are $\lambda = 200, k = 5$, and $\phi = 0.5$.

4- Results and Discussion:

The behavior of the closed-loop system at set points of 82, 90, and 100 micrometers are shown in Figs. 4 to 6. The flow rate of the discrete flow (double-distilled water) was set at 116.2 by the syringe pump.

As shown in these figures, the closed-loop system tracks the desired set points. The response speed of the system is desirable. At first, there are no droplets in the microchannel, so the droplet size is zero.

5- Conclusion

To generate droplets with precise sizes in a T-junction microchannel, a new controller was designed and implemented experimentally. The experimental tests show the good performance of the designed controller. Some

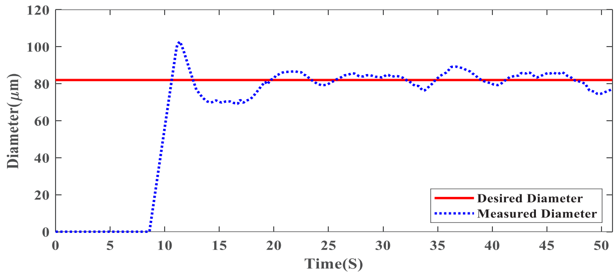

Fig. 4. The behavior of the closed-loop system at a set point of 82 micrometers

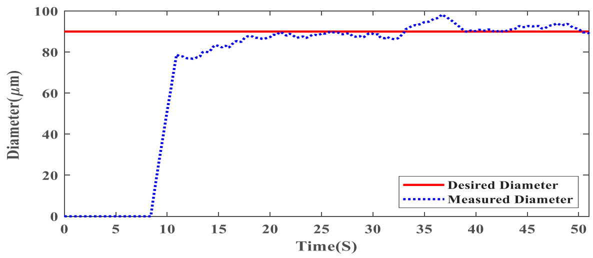

Fig. 5. The behavior of the closed-loop system at a set point of 90 micrometers

fluctuations were observed in the experimental tests, which were related to the vibrations of the electric motor and mechanical accessories of the syringe pump.

To evaluate the performance of the closed-loop system in each test, the Root Mean Square Error (RMSE) values are computed as follows:

$$RMSE = \sqrt{\frac{\sum (y_d - y_i)^2}{m}} \quad (4)$$

The RMSE values are presented in Table 1, which shows the good performance of the closed-loop system.

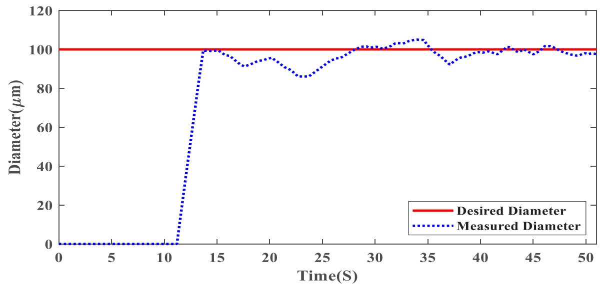

Fig. 6. The behavior of the closed-loop system at a set point of 100 micrometers

Table 1. RMSE values for the three experimental tests

Test	#1 (Fig. 4)	#2 (Fig. 5)	#3 (Fig. 6)
RMSE	3.81	2.3	3.06

References

[1] S. Mottaghi, M. Nazari, S.M. Fattahi, M. Nazari, S. Babamohammadi, Droplet size prediction in a microfluidic flow focusing device using an adaptive network based fuzzy inference system, Biomedical Microdevices, 22(3) (2020) 1-12.

[2] Y.J. Heo, J. Kang, M.J. Kim, W.K. Chung, Tuning-free controller to accurately regulate flow rates in a microfluidic network, Scientific reports, 6(1) (2016) 1-12.

[3] H. Fu, W. Zeng, S. Li, S. Yuan, Electrical-detection droplet microfluidic closed-loop control system for precise droplet production, Sensors and Actuators A: Physical, 267 (2017) 142-149.

[4] O.J. Dressler, P.D. Howes, J. Choo, A.J. Demello, Reinforcement Learning for Dynamic Microfluidic Control, ACS Omega. 3 (2018) 10084–10091.

[5] D. Huang, K. Wang, Y. Wang, H. Sun, X. Liang, T. Meng, Precise control for the size of droplet in T-junction microfluidic based on iterative learning method, Journal of the Franklin Institute, 357(9) (2020) 5302-5316.

[6] H. Kim, D. Cheon, J. Lim, K. Nam, Robust Flow Control of a Syringe Pump Based on Dual-Loop Disturbance Observers, IEEE Access, 7 (2019) 135427-135438.

HOW TO CITE THIS ARTICLE
A. A. Mahdizadeh, M. Nazari, M. Nazari, H. Ahmadi, Sliding Mode Control of Droplet Size in a Microchannel by Adjusting Syringe-Pump Flow: Experimental Study, Amirkabir J. Mech Eng., 54(10) (2023) 451-454.

DOI: 10.22060/mej.2022.20666.7290