ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Special Issue 6, April 2017

Fuzzy Based Flow Controller in straight microchannels

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***Abstract*—Study of microfluids through microchannels is widely used in biomedical research applications. The flow rate of the microfluids has to be controlled in order to obtain accurate research results. It depends on the area of the channel, pressure and viscosity of the fluid. This paper describes the design of a fuzzy based flow controller and its advantage over the conventional PI flow controller since Fuzzy logic is more user friendly than the conventional controllers. Transfer function of the process is derived based on the process parameters and rules for fuzzy controller are based on this transfer function. The simulations are done in MATLAB/SIMULINK and the fuzzy controller is based on Mamdani model. The simulation results show the significant advantages of the designed fuzzy controller in terms of reduced peak overshoot and settling time.**

Keywords—Microfluids,Flow rate, Viscosity ,Fuzzy Logic,PI controller,Transfer function,Mamdani model.

I. INTRODUCTION

Microfluidics deals with the study of the behavior of fluids in micro-channels (micrometer sized channels).Microchannels are used to transport many chemical samples and also materials like DNA, cells, proteins for biomedical applications. The sample is passed through the channel by applying pressure to various ports, where they are collected and analyzed with the reactants. The volume of fluids within microchannel is very small, usually several nanoliters and therefore the amount of reagents and analytes required is quite small. That is the use of microfluidic channel has scaled down the fluidic processes to microscale with the advantage of smaller reagent volumes, shorter reaction times, and lower cost.

In order to control flow in micro channels, we can either use a conventional type controller or a fuzzy controller. Common types of conventional controller used for flow is PI controller and PID controller. PI and PID controllers are designed on the basis of manually-tuned conventional control system and are simple in structure. Fuzzy Logic controller has the ability to emulate human thinking, knowledge and reasoning into the control system and allows better control performance in the control system.

For process like flow in microchannel, where design improvements and maintenance of process involving chemical and biological materials is largely involved, a fuzzy controller can be advantageous because of their ability to give better stability, lesser error and faster responses of the control.

II. METHODOLOGY

A fuzzy logic system (FLS) can be defined as the non linear mapping of an input dataset to a scalar output data. A fuzzy system consists of four main parts- fuzzifier, rule base, decision making unit and defuzzification interface. First step is to fuzzify the data or create membership values for the data and put them into fuzzy sets. Each set of data has to be divided into ranges. The ranges for each set determine how well the controller works. In a controller the fuzzifier is used to determine the level of membership by connecting a measured signal from the system to the fuzzifier input.

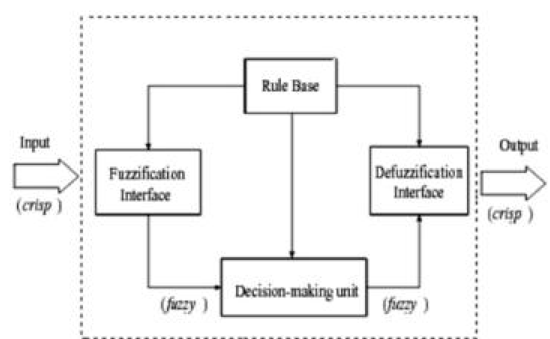

Figure 1: Fuzzy controller block diagram

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The rule table is then created to determine which output range are used. The table is an intersection of two inputs. The fuzzy controller uses fuzzy equivalents of logical AND, OR and NOT operations to build up fuzzy logic rule. Defuzzification is the final step in which the fuzzy variables are converted into a real signal. The typical way of defuzzification is by using Mamdani's center of gravity method. Mandani's principal takes the input values and finds where they intersect their sets. The intersection creates a cuts-off line known as the alpha cut

We fire our rules to find the corresponding output rule.

The rule is then cut off by the alpha-cut, giving us several trapezoidal shapes. These shapes are added together to find their total center of gravity.

III. System Design

A fuzzy based flow controller is to be designed for the microfluidics flowing through straight pipes .The generic structure of the whole system is shown in Figure 2.

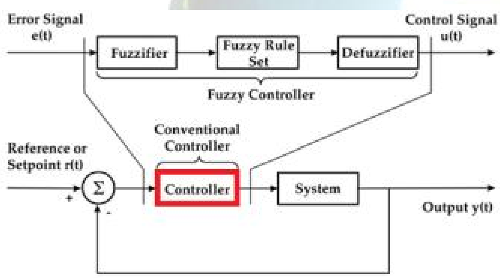

Figure 2 : Process control using Fuzzy controller

The output of the process is fed back to a controller which is fuzzy based. In the controller the set point and the fed back output is compared and the resultant signal provides the basis for controller action. Here the aim is to keep the output flow rate at a desired value.

A. *Transfer function*

In order to design a controller we need to derive the transfer function of the process. A transfer function is the ratio of the output of a system to the input of a system, in the Laplace domain considering its initial conditions and equilibrium point to be zero

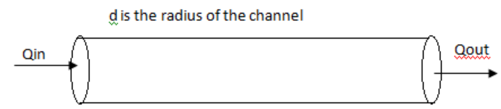

Figure 3:Modelling a microfluidic flow

Assumptions:

In the channel the fluids are injected at a flow rate of Q_{in} m^3/sec which is the input to the system. The output is the discharge flow rate, Q_{out} m^3/sec.

1. If $Q_{in} = Q_{out}$, the volume inside the channel remains constant.
2. If $Q_{in} > Q_{out}$, the volume inside the channel rises.
3. If $Q_{in} < Q_{out}$, the volume inside the channel decreases.

Based on mass balance equation

In - Out = Accumulation

In this case, the accumulation manifests itself as an increase or a decrease in volume.

Accumulation is the change in volume with time.

Qin - Qout = $\Delta V/\Delta t$

Volume, V = area x height = A x h.

Volume inside the pipe is the only variable which means that $\Delta V = \Delta h \times A$.

Writing the equation in differential form, we have:

Qin - Qout = A dh/dt

Next, consider the output flowrate, Qout. The driving force for the discharge flow is the volume of fluid in the channel which is given by ρgh. Let R be the resistance /force excerted by the channel onto the fluid.

Qout = $\rho gh/R$

R has units of Newton seconds/metre^5

Therefore, the above equation can be rewritten as follows:

$Q_{in} - \rho gh/R = A\, dh/dt$

$$AR/\rho g\, d\Theta_0/dt + \Theta_0 = R/\rho g\ \Theta_i \qquad (1)$$

The above equation has the first order characteristic where the output, Θ_0, is equivalent

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to height, h; the input, Θ_i, is equivalent to the flow in, Qin.

Let
$\tau = AR/\rho g = (\pi d^2 R)/4\rho g$
$K = R/\rho g$

Then the accumulation equation (1) can be rewritten as

$$\tau (d\Theta_0)/dt + \Theta_0 = K\Theta_i$$

Rearranging in terms of the output over the input gives the following:

$$(\Theta_0 (s))/(\Theta_i (s)) = K/([1+\tau s])$$

This is the transfer function of the the process.

B. Fuzzy Logic controller:

Fuzzy logic controller (FLC) contains two inputs variables, the error and change in error of the microchannel with three membership functions in each variable. The FLC system contains one output variable, the flow rate with seven membership functions. Fig. 4 shows these variables with the corresponding units.The Mamdani's model in MATLAB is used to design a fuzzy controller for the process. Fuzzy rules for the simulation were defined according to the transfer function of the process.

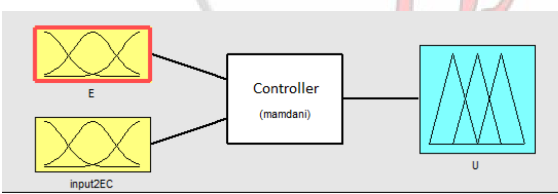

Figure4: Fuzzy logic interference system editor

In the Fuzzy Logic Inferring System (FIS) editor the ranges to the membership functions (MFs) are assigned according to the actual and the desired values of the input and the output variables. The range of all output and input variables is from -6 to +6.

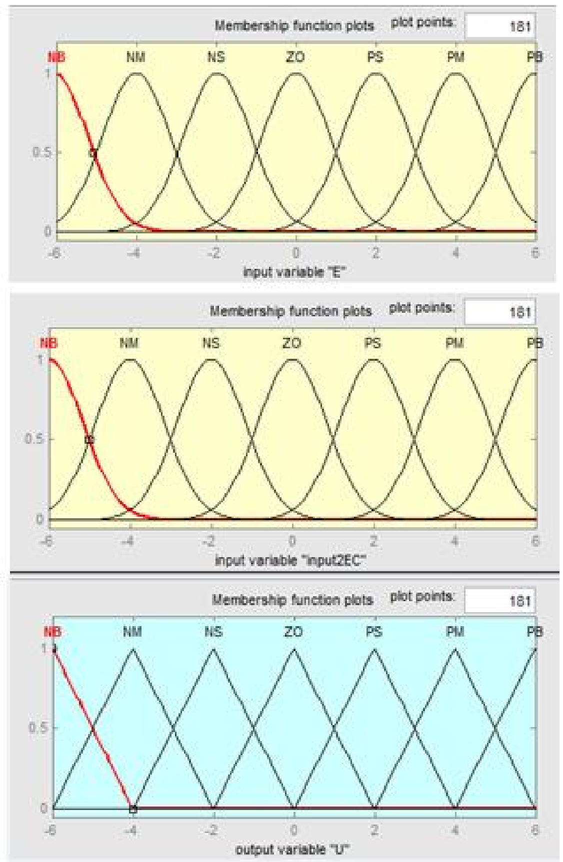

Figure 5: Graph of MF with input range

Fuzzy logic rules are developed for two input variables with six MFs for each input variable and corresponding MF is defined for volume flow rate [5].The flow rate for each rule is defined based on the process transfer function. The MATLAB simulation results obtained are based on the FLC rules. These rules are defined in MATLAB Rule editor and evaluated in MATLAB Rule viewer.

NB:	Negative Big
NM:	Negative Middle
NS:	Negative Small
ZO:	Zero
PS:	Positive Small
PM:	Positive Middle
PB:	Positive Big

Figure 6: Fuzzy set definition

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EC \ E	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PB	PB	PM	ZO	ZO
NM	PB	PB	PB	PB	PM	ZO	ZO
NS	PM	PM	PM	PM	ZO	NS	NS
ZO	PM	PM	PS	ZO	NS	NM	NM
PS	PS	PS	ZO	NM	NM	NM	NM
PM	ZO	ZO	NM	NB	NB	NB	NB
PB	ZO	ZO	NM	PM	NB	NB	NB

Figure 7: Fuzzy rules for controller

These rules are defined with the IF- AND-THEN logic.

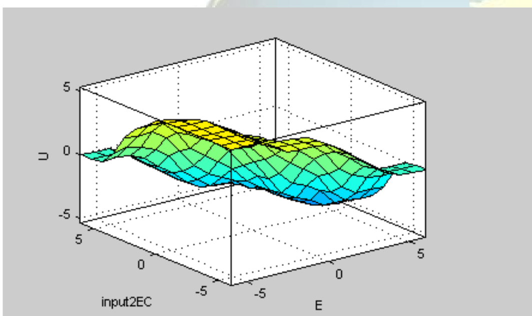

Figure 8:3 dimensional surface viewer graph

IV. Results and Analysis

A fuzzy controller and a conventional PI controller were integrated with the process and the outputs were compared. The output clearly show that fuzzy controller has less rise time and less settling time, which makes fuzzy controller a better option for microfluidic flow. That is the process controlled by a fuzzy controller will have better accuracy when compared to a process controlled by a conventional controller.

	Rise Time	Settling time	Peak time
PI controller	3.6928e-15	7.0003e-15	6.9162e-14
Fuzzy controller	2.3128e-15	2.8427e-15	2.3162e-14

Figure 9: Comparison of results

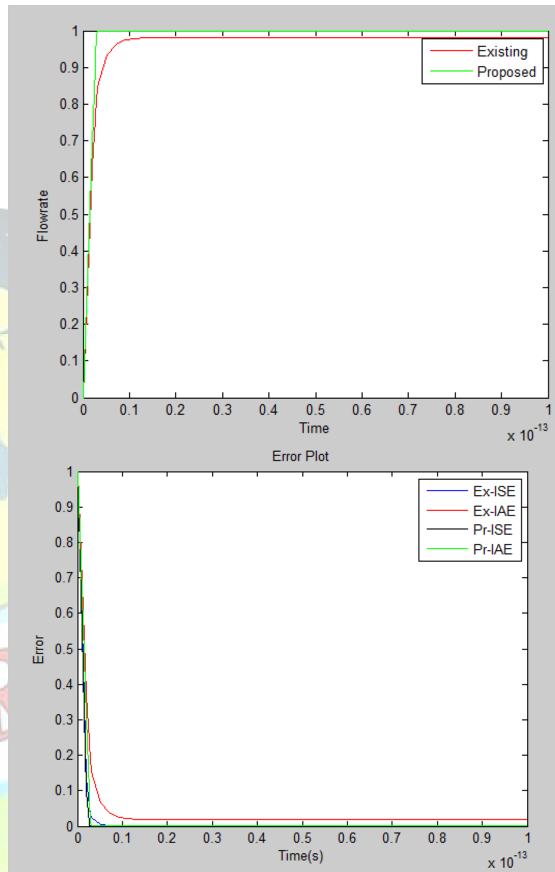

Figure 10:Graph showing the comparison between PI controller and Fuzzy controller

Conclusion

Fuzzy logic control systems are better in terms of precision when compared with the conventional controlles and are easily developed with higher performance and precision. This paper presents a fuzzy based fluid flow control system through the microchannel. MATLAB Mamdani's model was used to develop the fuzzy logic control system. The rules were defined for the flow control through the microchannel based on the process transfer function. This proposed system was verified for some specific values of inputs for the fluid flow.

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