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Development of a Mechatronic Syringe Pump to Control Fluid Flow in a Microfluidic Device Based on Polyimide Film

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Abstract. With the advancement in microfluidic technology, fluid flow control for syringe pump is always essential. In this paper, a mechatronic syringe pump will be developed and customized to control the fluid flow in a poly-dimethylsiloxane (PDMS) microfluidic device based on a polyimide laminating film. The syringe pump is designed to drive fluid with flow rates of 100 and 1000 µl/min which intended to drive continuous fluid in a polyimide based microfluidic device. The electronic system consists of an Arduino microcontroller board and a uni-polar stepper motor. In the system, the uni-polar stepper motor was coupled to a linear slider attached to the plunger of a syringe pump. As the motor rotates, the plunger pumps the liquid out of the syringe. The accuracy of the fluid flow rate was determined by adjusting the number of micro-step/revolution to drive the stepper motor to infuse fluid into the microfluidic device. With the precise control of the electronic system, the syringe pump could accurately inject fluid volume at 100 and 1000 µl/min into a microfluidic device.

1. Introduction

Microfluidic is a multidisciplinary field that investigates the behavior of fluid in micro and nano metric scale [1]. The applications of the microfluidic devices are such as the bio-sensing, immuno-sensing, microcapsules fabrication [2-3]. The channel in the microfluidic device can be used to control the movement of fluid in micro or nano metric volume to achieve functionalities in flowing, mixing, ceasing flow of fluid, purging and dispensing. Usually, poly-dimethylsiloxane (PDMS) is the polymeric material used for the manufacturing of microfluidic device [4]. In the laboratory, an infusion pump is used to inject small volume of liquid into a microfluidic device. Control parameters such as the speed of the slider, flow rates produced, viscosity of the fluid are the key factors in controlling different functionalities of flow. Instead of building the microfluidic device on glass substrate, a different method is presented in this paper in which, a microfluidic device with an input, splitting into two channels and an outlet will be fabricated on polyimide film. The advantage of fabricating a microfluidic device on polyimide laminating film is that the process eliminates the requirement of oxygen plasma bonding for adhesion of PDMS microfluidic to the glass substrate. For the electronic control system, a customized linear slider is attached to the plunger of a syringe. The syringe pumps the fluid into the microfluidic device through linear motion generated by the linear slider and a stepper motor.

2. Methods and materials

2.1. The microcontroller configurations and circuitry for control of syringe pump.

An Arduino-uno microcontroller board was used as a control system for a uni-polar stepper motor which was coupled to a syringe pump system (Figure 1). The Arduino-uno controller board was built with 14 input/output digital pin in which, 6 of the pins can be used as the pulse width modulation output, 6 analog inputs, 16 MHz crystal oscillator, universal serial bus, power input and a reset button. For the input connections, eight digital input pins were connected to a 4 × 4 keypad membrane in which 4 pins were for rows and column, respectively. Six analog pins of the microcontroller were connected as outputs to a 16 × 2 liquid crystal display (LCD). Two output pins were assigned to an EasyDriver stepper motor module (SparkFun Electronics, Inc). The LCD and keypad were attached and powered directly by the Arduino-uno which has an operating voltage of 5 Vdc. A separated power source of 8 Vdc for the stepper motor was obtained from a power adapter. Hence, the power to the controller is separated from the power to the motor to avoid damage due to the over current originated from the stepper motor. For the moving mechanism, the stepper motor moved the slider to either infuse or diffuse a 5 ml syringe. The stepper motor received signal from the motor driver (L293D) which was controlled by the Arduino microcontroller. The microcontroller sends a signal to the EasyDriver to drive the stepper motor.

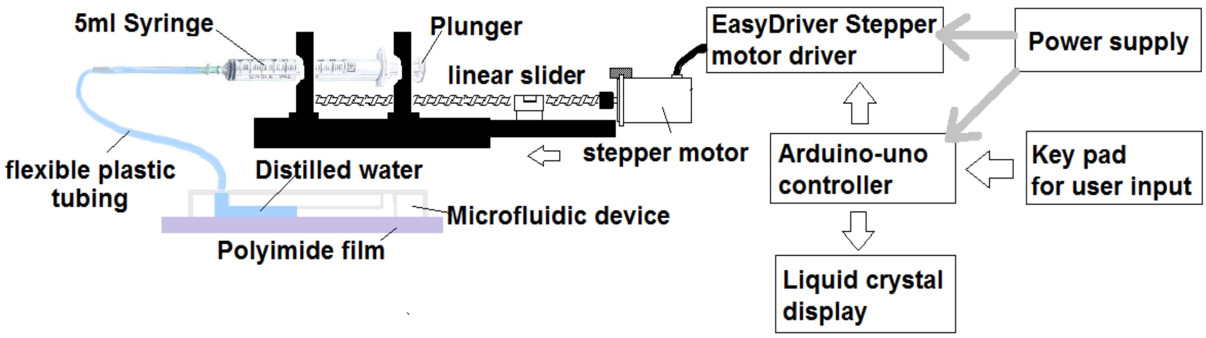

Fig. 1. The block diagram of the mechatronic syringe pump system

2.2. Programming the control system.

For the part of programming, the speed of the stepper motor was determined by the micro stepping algorithm set in the program. In programming stepper motor of this project, the micro step method was applied for controlling the speed of the motor. The speed of the stepper motor can be set either by rotation per minute (rpm) or changes in the micro stepping. The uni-polar stepper motor rotates 1.8 degree per step. Eight micro steps were enabled by using an EasyDriver. The stepper motor takes 2.54 ms for a single step. Hence, the step time is divided by a factor of eight yielding 317.5 µs for a single micro step in the EasyDriver. To achieve 0.06 s for a revolution, 190 micro steps per revolution will be used. For the flow rate, it would be 1000 µl/min or 16.7 µl/s. For the flow rate of 100 µl/min or 1.67 µl/s, the total steps used were 1900 micro steps per revolution. The pushing force to the plunger of the 5 ml syringe pump was originated from the rotation of the stepper motor via a lead screw functioning as a linear slider.

A LCD was programmed to display the menu for selection of fluid volume and initiation of the infusion process. Table 1 shows the instructions that could be displayed on the LCD. The 4 × 4 keypad is pre-designated with input selections. The user can select flow volume either 100 or 1000 µl. The volume of the distilled water dispensed from the syringe pump was determined using a measuring cylinder.

Table 1: The functions for every interface in the main menu system

Interface	Functions
Main Menu	As the main interface for the main menu system.
Start Infusion?	Prompt the user to initiate infuse program to drive fluid into the syringe.
Fluid Volume(ul) >	System interface for the selection of fluid volume in microliter.
Confirm Program?	Program to confirm for the system before send the data to the microcontroller to start the syringe pump system.
Diffusion	Program created to drive out all the remaining unused fluids in the syringe pump.

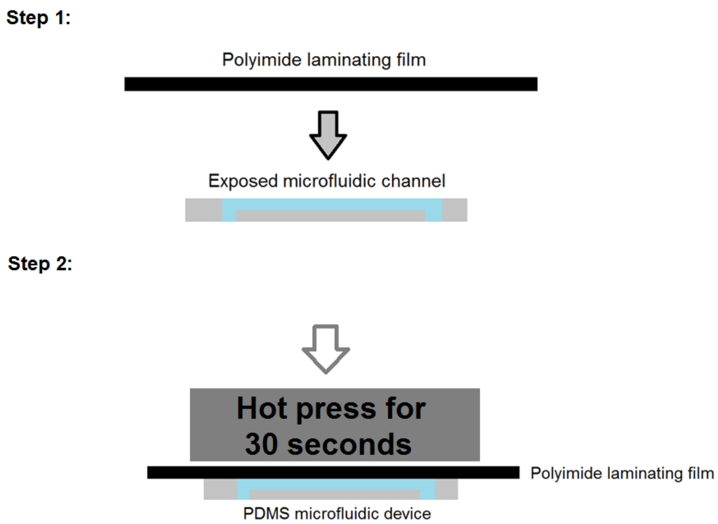

Fig. 2. The two steps process for adhering PDMS microfluidic device to a polyimide laminating film

2.3. Fabrication of PDMS microfluidic device based on polyimide film

The PDMS microfluidic device was fabricated based on the procedures as described in a previous publication [5]. When the PDMS was polymerized, it was removed from the glass mould and immediately transferred to a polyimide laminating film pre-coated with adhesives. The exposed microfluidic channels were faced down to the adhesive laminating film before the hot press. A hot press was heated to 75 ^{o}C and pressed onto the other surface of the laminating film for 30 seconds (Figure 2). The effectiveness of the microfluidic channel for fluid flowing was tested by infusing fluid into the inlet of the channels.

3. Results and discussion

3.1. The prototype of the mechatronic syringe pump.

Figure 3 shows a prototype of the mechatronic syringe pump. The syringe pump consists of 3 main parts: a 4 × 4 keypad membrane, 16 × 2 LCD and a stepper motor. Before the infusion process, the syringe was filled with distilled water. For fluid volume selections, the user can select fluid volume either 100 or 1000 µl. After the selection of the fluid volume, the confirmation of the selection can be activated by pressing "C" on the keypad. For the infusion process to initiate, the stepper motor starts to turn when the key "A" was pressed and the stepper motor rotates with the pre-programmed speed based on the fluid volume selected.

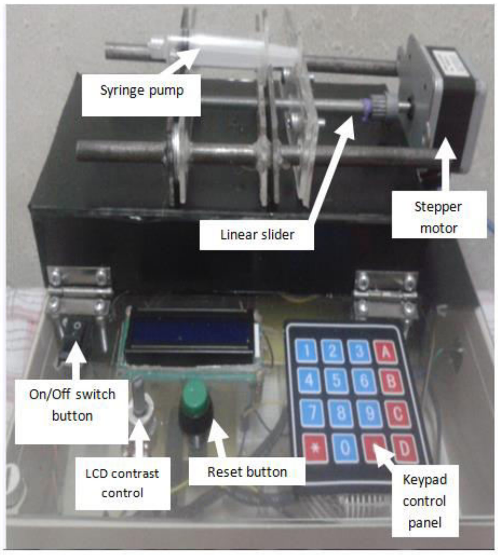

Fig. 3. The prototype of the syringe pump

3.2. Volume of fluid Infused for 1 minute

Fig. 4a shows the target volume (as calculated for 100 and 1000 µl) and measured volume of distilled water out of the infusion pump. The errors for both volume of measurement are at 0.16 and 8 %, respectively (Figure 4b). The error is in an acceptable range if this syringe pump is used for the continuous phase in microfluidic flow and not aiming for precision of fluid dispensing or the disperse phase. The micro step size for the stepper motor was set at 190 steps and 1900 steps with respect to fluid volume of 100 and 1000 µl. This may be associated with the number of steps used to create the thrust for the plunger to push fluid out of the syringe pump. The results suggest that the error could be accumulative as the step size increased to achieve higher volume of dispensing. The friction between the plunger and syringe over a long period of time and the linearity of the linear slider could be the reason in reducing the accuracy of the dispensing of fluid. The result of the measurements is valid for the test fluid of distilled water which is commonly used in the preparation of chemical solution.

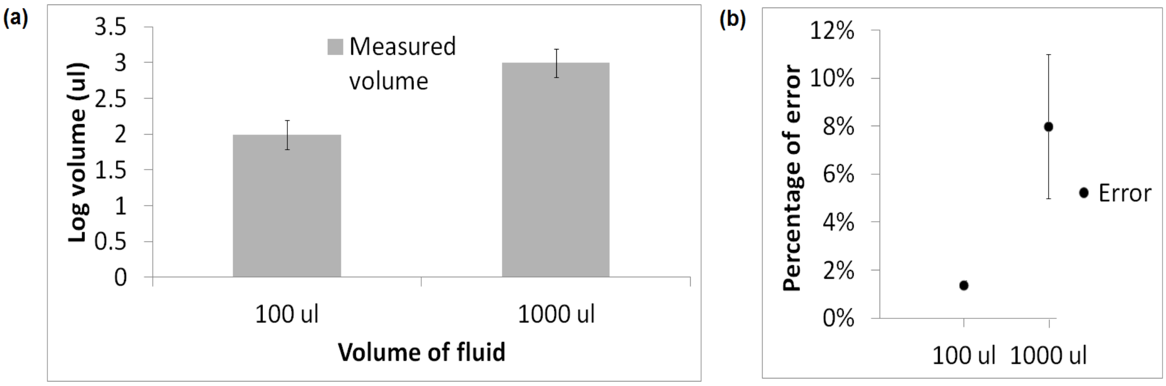

Fig. 4. (a) The bar chart of volume measured for the syringe pump and (b) the error of the measured volume to dispense 100 and 1000 µl per minute. Both error bars indicate the standard deviation of the graph (N=10).

Figure 5 shows a microfluidic device with the backing of polyimide film. This device was connected to the syringe pump as an infusion system to the channels. With the adhesiveness of the laminating film, the PDMS microfluidic can be tightly coupled to the polyimide film without causing leakage of fluid. This technique is simple compared with the use of glass substrate which requires treatment with oxygen plasma cleaning machine for enabling adhesion to the PDMS microfluidic device. The polymeric material gives more flexibility to the design of the microfluidic channel. Holes can be punched through the polyimide film for fluid flow in a multi-tier microfluidic constructs.

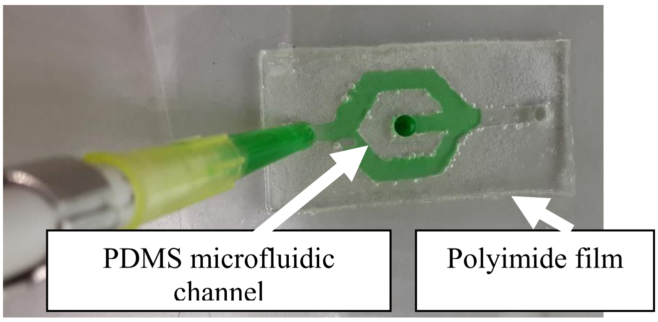

Fig. 4. Microfluidic device based on the polyimide film

4. Conclusion

A syringe pump system has been developed to provide an automatic process for flow control of fluid. The fluid control was achieved by the pushing force exerted by a stepper motor connected to the plunger via the rotation of a linear slider. The fluid control system is able to produce low percentage of error in dispensing fluid into a microfluidic device at 100 and 1000 µl/min. For the microfluidic bonding method, the laminate bonding method was a simple and effective method that can be used to fabricate PDMS microfluidic device easily. The PDMS microfluidic device fabricated was able to flow fluid from the syringe pump without leakage of fluid from the channel.

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References

[1] L. Hung and A. Lee, "Microfluidic devices for the synthesis of nanoparticles and biomaterials," Journal of Medical and Biological Engineering, vol. 27, no. 1, pp. 1–6, 2007.

[2] K. Jiang, P. C. Thomas, S. P. Forry, D. L. DeVoe, and S. R. Raghavan, "Microfluidic synthesis of monodisperse PDMS microbeads as discrete oxygen sensors," Soft Matter, vol. 8, no. 4, p. 923, 2012.

[3] J. Pessi, "Microfluidic approach to preparing polymer microspheres for enhanced oral protein drug delivery," no. August, pp. 1–102, 2013.

[4] S.-R. Lyu, W.-J. Chen, and W.-H. Hsieh, "Measuring transport properties of cell membranes by a PDMS microfluidic device with controllability over changing rate of extracellular solution," Sensors Actuators B Chem., vol. 197, pp. 28–3.

[5] J. Friend and L. Yeo, "Fabrication of microfluidic devices using polydimethylsiloxane", Biomicrofluidics, vol. 4, no. 2, pp. 026502(1-4), 2010.