# Micro-Syringe Pump Prototype Driven by Stepper Motor for Microfluidics

C. A. Dávalos Saucedo[#1], G. R. Márquez[#2], M. J. Briones Reyes[#3], M. Alonzo Macias[*2]
[#]Tecnológico Nacional de México: Academia de Investigación, Instituto Tecnológico José Mario Molina Pasquel y Henríquez, Unidad Académica Lagos de Moreno, Jalisco, México.
[*]Escuela de Ingeniería y Ciencias, Tecnológico de Monterrey, Epigmenio González 500, San Pablo, Querétaro 76130, México.
[1]cristian.davalos@lagos.tecmm.edu.mx, [2]giovanna.rossi@lagos.tecmm.edu.mx,
[3]manuel.briones@lagos.tecmm.edu.mx, [4]alonzoma@tec.mx

***Abstract*—Portable and precise pumps are highly demanded for microfluidic applications. This project aimed to design and develop a micro-syringe pump, an advantage of this kind of device is that it can reach the minimum necessary control and precision to use it to drive fluids through a microfluidic device's microchannel, seeking the required specifications and considering that the design has a single axis motion. All the micropump characteristics were designed to reach the technical parameters to get in various preliminary tests a precise performance using a microfluidic device. In this case, it was driving a fluid mixture of pectin and protein necessary to obtain a film-forming solution, useful in many applications in different industries, such as food to produce edible coatings or biodegradable films. The main elements used to develop the micro-syringe pump were a stepper motor with a satisfactory resolution meeting the design requirements, a control module, and pieces as a structure of the micro-syringe pump. Then they were printed using a 3D printer with Polylactic Acid (PLA) biopolymer and designed and assembled, reaching good results on preliminary tests conducted using a mono-channel microfluidic device.**

***Keywords—Micro-syringe pump, Microfluidics, Prototype, Stepper Motor.***

## I. INTRODUCTION

Microfluidics devices can develop many tasks in different industries: food, drugs, cosmetics, chemical and biological. The fabrication of microfluidic devices involves materials such as polymers and glass, these devices are designed with micro or nano-geometric features achieving the manipulation of small volumes of fluids, but the primary approach is to control accurately small volumes of liquids. The precision of flow control is critical in many technologies where it is necessary to handle a low-quantity sample or for accurate process operations such as infusion or manipulation for droplet generation, particle manipulation, drug delivery, and micromixing. Specifically, in a microfluidic laboratory, we can find pressure pumps, peristaltic pumps, and syringe pumps to deliver fluid in microfluidics devices [1] [2]. Among traditional methods of fabrication of microfluidic devices are photolithography and microprinting (soft lithography), although they are not widely spread because of their high cost and fabrication time.

Moreover, new strategies exist to obtain high-precision microfluidic parts without intricate tooling and equipment, making producing microfluidic devices cheaper, faster, and more accessible than conventional fabrication methods. Enhancements made in additive manufacturing and other techniques allow to achieve low-cost and technical requirements to get microfluidic devices for regular use in many operations successfully; some materials are polymethyl methacrylate (PMMA), polycarbonate, polystyrene, and especially polydimethylsiloxane (PDMS) materials, we can find circuits made using a wide variety of materials that is the case of polylactide (PLA), acrylonitrile butadiene styrene (ABS), polyamide (PA) as a filament for use in a 3D printer. Even this looks like a good alternative has many inconveniences, such as 3D printing filaments that do not meet requirements for physical, chemical, and mechanical parameters needed for microfluidic devices construction, the temperature must be relatively low (under 60-80 °C) to avoid structure losses also due to the low adhesion and lack of other necessary properties makes them unsuitable for the production of microchannels and microelectronics elements on the polymer films surfaces [2] [4]. On the other side, there are different materials successfully used in microfluidics device fabrication, for instance, polyethylene terephthalate (PET) in hot embossing/bonding PET technique [3] [5]. These alternatives for microfluidics rapid-fabrication guarantee the implementation of applications, for example, PET laminated technique; results demonstrate the pertinent use of PET laminates microfluidic devices to develop studies in fields such as biochemical, micro-organs providing understandings on relevant biology fields [4] [6]. In this work, a prototype of a micro-syringe pump was designed and developed to be used with circuits designed in laminated PET, obtaining good preliminary results, complying with the evaluated requirements of precision and necessary stability in terms of the delivery rate, volume, time and accuracy [7], a genuine water-based fluid used in this work to test: the pumping operation for instance with a standard mixed solution of pectin and protein used as a film forming solution to produce edible coatings or biodegradable coatings. Preliminary micro-syringe pump tests using a PET laminated microfluidic device.

## II. Materials and Methods

### *A. Micro-syringe Pump Design*

The prototype design comparison includes 3 different diagrams evaluated, selecting the optimal design by the technical characteristics of the chosen pieces, Fig. 1

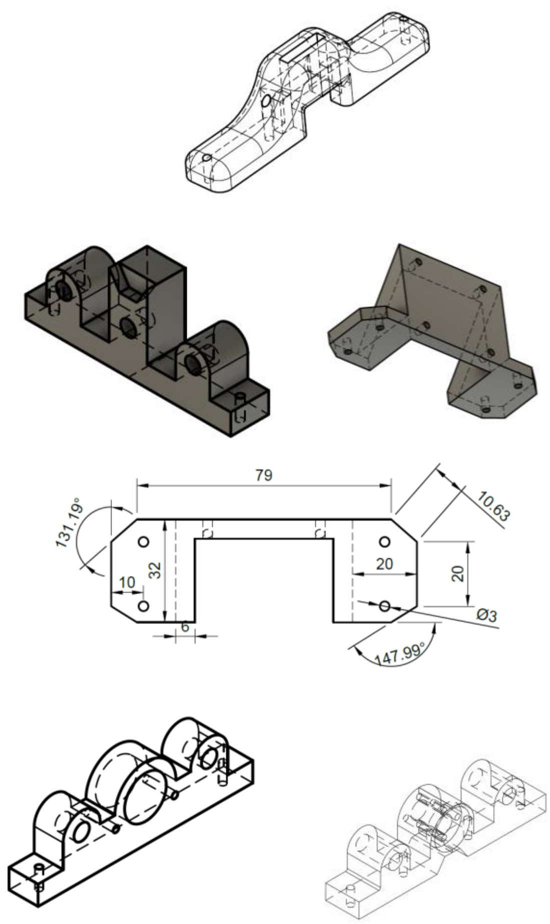


Fig. 1. Different tested and selected designs.

### *B. Assembling of Structure*

The necessary structural pieces to assemble the prototype were defined as 2 linear motion rods 8mm x 300mm that will work as shafts for the mechanism conferring the necessary stability, and one A SUS304 stainless steel lead screw 8mm x 30mm, including the corresponding brass nut Fig. 2.

Fig. 2. Prototype structural pieces.

A stepper motor Shinano Kenshi STP-42D221-03 with an external inertial load 9800g-cm$^2$, positional accuracy 1.8° +/- 5% in full step mode, holding torque 0.314 N-m minimum, 12 voltage of direct current (VDC), detent torque 16mN-m maximum Fig.3, flexible Coupling 5mm to 8mm aluminum casing with hexagon wrench was used Fig.4.

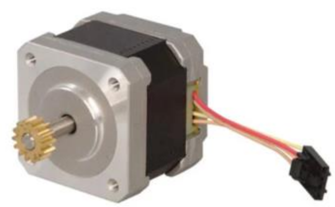

Fig. 3. Stepper motor STP-42D221-03

Fig. 4. Aluminum flexible Coupling 5mm to 8mm.

### *C. Micro-syringe Pump 3D Printed Parts*

All pieces and fixtures were designed using Autodesk Fusion 360 (academic licensed) software. Afterward, a Creality Mod 3 3D printer was used with regular PLA SUNLU PLA 1.75mm +/- 0.02mm as a printing material. Once the pieces were designed, Cura generated G code with optimal values for the 3D printer.

### *D. Micro-syringe Pump Control Module*

A control module was structured using fritzing, where a Raspberry Pi3 (RP3) was used as a controller, three optocouplers (4N35) worked as motor driver enabler, motor rotation direction, and the third one worked as a bridge to connect the step signal from RP3 to the motor driver (A4988) Fig. 5.

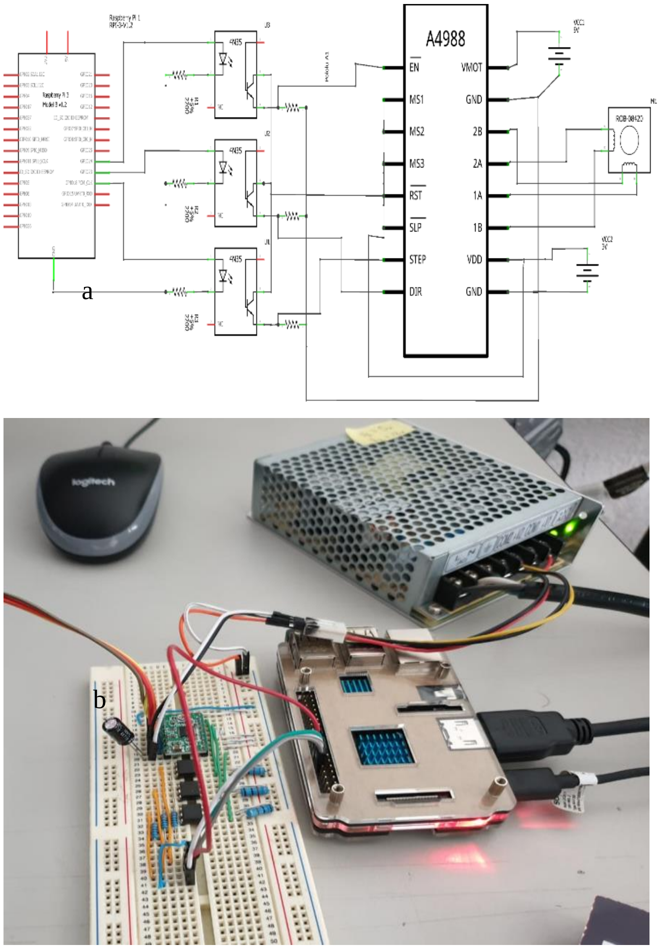


Fig. 5. a) Control module using fritzing. b) Control system assembled

Micro-syringe Pump Scripting and Coding

A Micropython script was developed to be executed in RP3 via a graphical user interface (GUI). The main functions included in the script are syringe selection (controlling up to 2 simultaneously), speed selection based on syringe diameter, movement frequency corresponding to the dispenced volume, and selector of motor rotation direction. The GUI is shown in Figure 6.

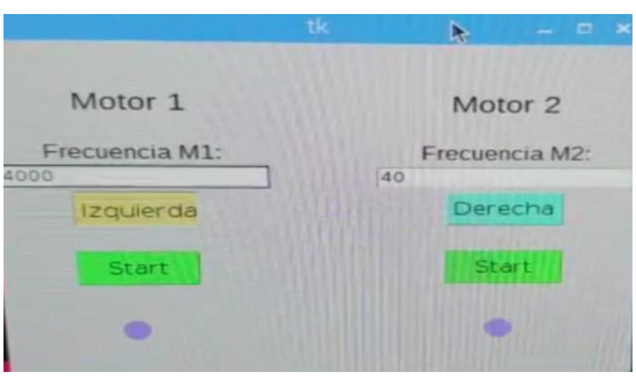


Fig. 6. GUI developed.

## III. Results & discusion

The micro-syringe pump demonstrates in preliminary tests the following specifications: flow range 1µL/h to 5ml/min (5 mL syringe), dispensing accuracy of +/-1% range. Working in these conditions is possible to handle fluids with acceptable precision that allows producing stable operations such as mixing, separation, or only dispensing of fluids. Using a micro-syringe pump represents significant economic savings and optimization in diverse industries. The prototype working properly dispensing a red-colored fluid is shown in Fig. 7.

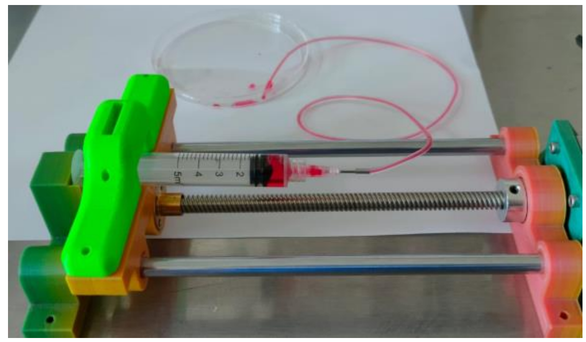

Fig. 7. Prototype working properly.

On the other hand, the GUI can be used by untrained technicians demonstrating that it is user-friendly.

Numerous studies have reported diverse methods and approaches to develop micropumps considering the transmission of mechanical oscillations resulting from their stepper motor into the flow-carrying microfluidic device perturbations. However, in our application, it is not so crucial as in other microfluidic processes, for example, in droplets or foam generation where those effects are noticeable under a rate below 1 ml/h and experiments revealed a linear decay of the relative pressure fluctuations reaching a plateau at higher flow rates above 5 ml/h [8]. The main interests considered in the design were achieving stability on the injected flow reaching flow rates around 5 ml/h due to the microfluidic device channel, and the application needs enough help to avoid fluctuations.

## IV. Conclusions

The control of precise volumes in the industry is a desirable characteristic that allows the creation of stable solutions over time. The design and development of an affordable micro-syringe pump fulfill the design expectations. The mechanism can be adjusted to achieve more stability in the dispensing process, the control module, and the GUI. Moreover, using biodegradable filament to print the components helps reduce environmental pollution, making this process more sustainable.

## Acknowledgment

The authors are grateful for the facilities granted by the Instituto Tecnológico José Mario Molina Pasquel y Henríquez campus Lagos de Moreno to develop this project and to the Consejo Nacional de Humanidades, Ciencias y Tecnologías

(CONAHCYT) for the support and facilities in the development of this project. This research was supported by PRODEP according to grant 31525 assigned to ITJMMPHCA-11.

## References

[1] X. Zhang, K. Xia and A. Ji, "A portable plug-and-play syringe pump using passive valves form microfluidic applications," *Sensors and Actuators B: Chemical*, no. 127331, pp. 304, 2020.

[2] C. Byun, K. Abi‐Samra, Y. Cho and S. Takayama, "Pumps for microfluidic cell culture", *Electrophoresis*, vol. 35(2-3), pp. 245-257, 2014.

[3] F. Doronin, Y. Rudyak, G. Rytikov, A. Evdokimov and V. Nazarov, "3D-printed planar microfluidic device on oxyfluorinated PET-substrate. Polymer Testing," no. 107209, pp. 99, 2021.

[4] J. Li, C. Liu, H. Qiao, L. Zhu, G. Chen and X. D. Dai, "Hot embossing/bonding of a poly (ethylene terephthalate)(PET) microfluidic chip", *Journal of Micromechanics and Microengineering*, vol. 18(1), pp. 015008, 2007.

[5] M. Levis, N. Kumar, E. Apakian, C. Moreno, U. Hernandez, A. Olivares, F. Ontiveros and J. Zartman, "Microfluidics on the fly: Inexpensive rapid fabrication of thermally laminated microfluidic devices for live imaging and multimodal perturbations of multicellular systems", *Biomicrofluidics*, vol. 13(2) pp. 024111, 2019.

[6] T. Matsubara, J. S. Choi, D. H. Kim, and J. W. Kim, 2022. A Microfabricated Pistonless Syringe Pump Driven by Electro‐Conjugate Fluid with Leakless On/Off Microvalves. *Small*, vol. 18(15), pp.2106221, 2022.

[7] M. Haque, A. Matin, X. Wang and M. Kersaudy-Kerhoas, "Effects of syringe pump fluctuations on cell-free layer in hydrodynamic separation microfluidic devices", *Physics of Fluids*, vol. 33(7), nº 073317, pp. 1-5, 2021.

[8] G. Gonzalez, I. Roppolo, C. Pirri and A. Chiappone, "Current and emerging trends in polymeric 3D printed microfluidic devices", *Additive Manufacturing*, vol. 55, pp. 102867, 2022.