Compact four-channel syringe pump with radial distribution

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Abstract

In scientific experimental setups, especially in microfluidics and organ on a chip, it is commonly required to precisely control the flow rate under certain conditions or dispense small volumes. Syringe pumps are often a reliable solution for such goals. In this manuscript we present a novel design to use in experiments where different conditions with the same flow rate are required. We show how the design we propose archives both good accuracy and repeatability in a wide range of flow rates and small error between each one of the four syringes due to its radial distribution. Finally, we present how it can be manufactured combining 3D printing and laser cutting and an example of application.

Metadata Overview

Main design files:`https://github.com/FrancisCrickInstitute/Four_channel_syringe_pump`
Target group: Microfluidics, biomedical sciences, chemistry.
Skills required: 3D printing – easy; laser cutting – easy; through hole soldering - easy.
See section "Build Details" for more detail.

Keywords

microfluidics; multi-syringe pump; flow control; volume dispensing

Introduction

Syringe pumps are a commonly used tool to precisely control flow rate in scientific experiments. Over the last decade, several research labs, individual researchers or even makers have developed rapid manufactured syringe pumps. This list includes a LEGO based design [1], the model from the from the Janelia research campus [2], Jakob Voigts design [3], the Poseidon syringe pump system developed on California Institute of Technology [4], the Open-source syringe pump from the Michigan Tech's Open Sustainability Technology Lab [5], the 3D Printed Syringe Pump Rack by Aldric Negrier [6] or the DIY Syringe Pump by David Florian [7]. All previously mentioned designs actuate a single syringe and therefore, they don't allow to have multiple syringes actuated by the same motor in a small footprint. The cost of the multi-channel commercial options can vary within a huge range of options in dual syringe pumps, from a dual syringe pump AL2-220 (996 GBP) to a SP200iZ (6,230 GBP) syringes with a dispensing accuracy of $\pm 1\%$. In this paper we present a low cost (183 GBP) design that actuates four 10 mL syringes by the same actuator with a small footprint (24 x 14 x 8 cm), which can be easily embedded inside an experimental environment (microscope chamber or incubator). Our device also provides open hardware and software making it easily adapted to custom user needs. Finally, our syringe pump takes the advantage of using the highly reliable and precise stepper motor control provided by the teensystep library [8] to achieve high performance flow control.

System Architecture

The four-way syringe pump is physically composed by a board that controls a stepper motor angular position or velocity. The stepper motor's shaft is mechanically coupled with a lead screw-rail linear system, which moves a car where the syringe plungers are attached all within a compact footprint (Figure 1). The flow rate can be manually selected using a rotary encoder and visualized on an OLED screen (Figure 2b). There are two limit switches that stop the pump from moving outside its range.

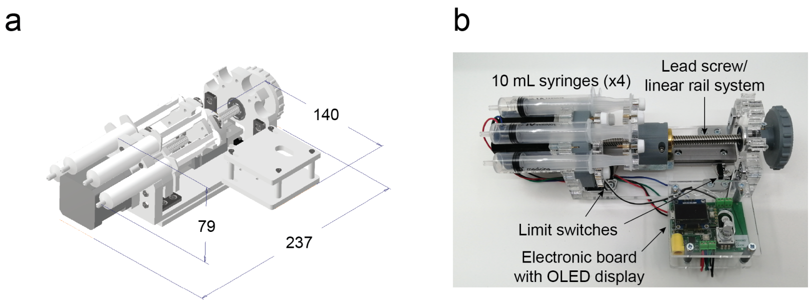

Figure 1: **Device overview a.** Device dimensions in mm. **b.** Device completely manufactured.

Electronics

The pump has a main board based on the Teensy 3.2 development board (Freescale Semiconductor MK20DX256). The flow rate can be selected rotating the mechanical incremental encoder (Bourns PEC11R). The rotary encoder can be pressed to change the pump state to active. When this happens, the pump will start dispensing the fluid at the previously selected flow rate. The OLED display (SSD1306 128x64 Pixels) constantly shows the flow rate selected and the volume and flow rate that are being dispensed. The stepper motor is controlled by a Micro-stepping Driver A4988 (Allegro MicroSystems LLC) with five selectable step modes: full step, 1/2, 1/4, 1/8, 1/16. There are two connections for limit switches (Youmile micro switch) which provide safe end stops in both ends of the pump's linear rail.

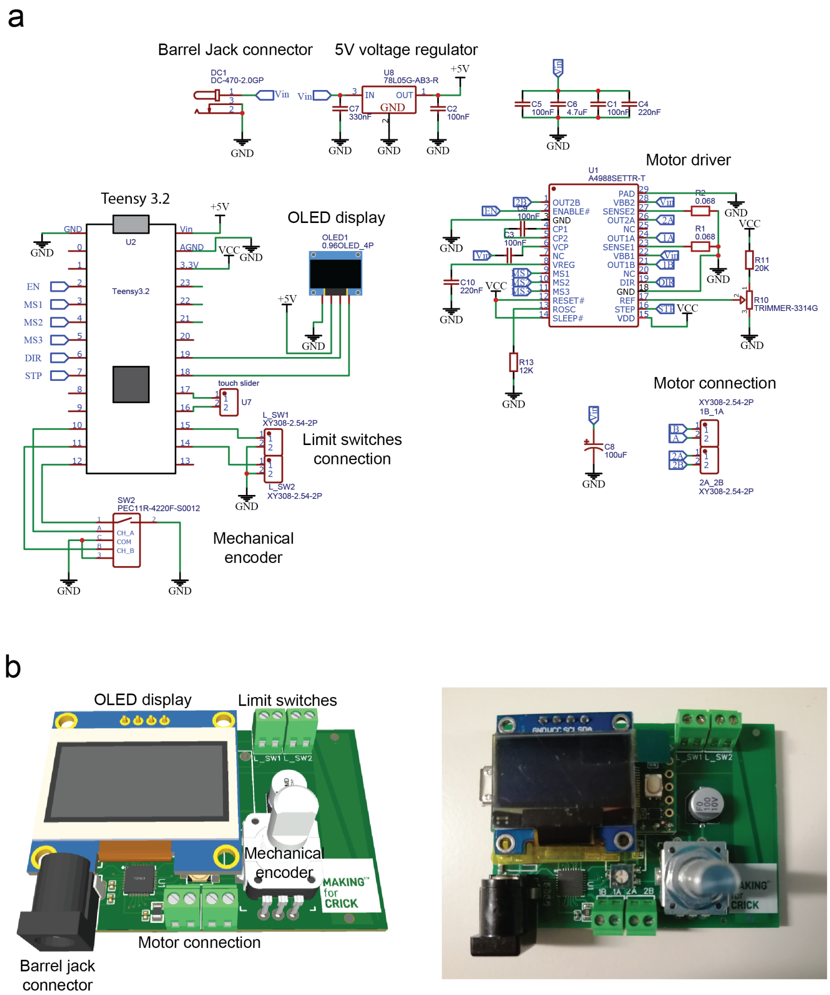

Figure 2: **Electronics.** Electronics.**a.** Electronics Schematics **b.** PCB CAD model and main connections (Left) and manufactured board (Right).

Mechanical parts

The device is actuated by a stepper motor (JoyNano Nema 17 1.7 A 59 N · cm) which is coupled with a lead screw (COEUGE T8 20 cm) and it moves across a linear rail system (Igus TS-04-15-300). The pump construction is based mostly on parts that can be manufactured by a standard laser cutter and four components which are 3D printed. In that way the device can be manufactured in a single day. The materials used are Polymethylmethacrylate (PMMA) for the laser cut parts and Polylactic Acid (PLA) for the 3D printed parts. Stainless-steel brackets hold the main structure in place giving rigidity to the syringe holders (Figure 3).

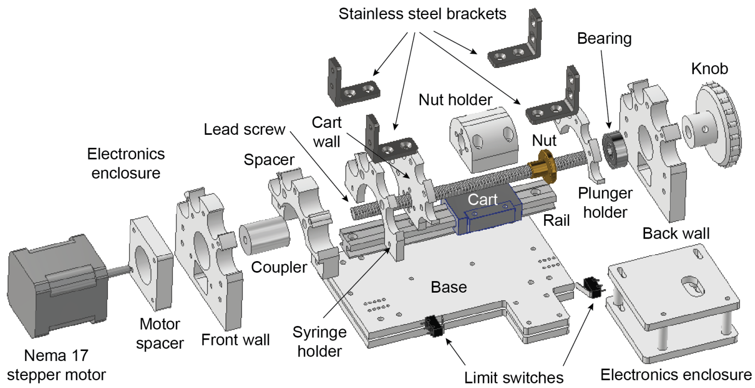

Figure 3: **Exploded view of the main mechanical parts, screws are not considered on this figure.**

Firmware

The program running inside the pump `(MSTPump_Contstant_flow.ino)` has a boolean variable state set to low. The power from the motor is disabled initially, which is achieved by pulling high the enable pin of the driver. The state variable can change only if the encoder push button is pressed. If both limit switches and the state variable are pulled high, the motor power will be enabled and the motor speed will be set at the associated flow rate selected by the user. The flow rate selected can be changed while the motor is engaged but it will not be made effective until the state goes from low to high again. The flow rate in µL · min^{-1} and the volume dispensed in µL are displayed in the OLED screen.

Validation and testing

The calibration procedure of the pump has been carried on by gravimetric testing. An analytical scale (Sartorius TE124S) has been used to weight five labeled Eppendorf tubes. Then the same scale has been used to measure each of the repetitions for all dispensed volume (10-1000 µL) and flow rate (100-10,000 µL · min-1) conditions. After all the measurements, the weight of the corresponding Eppendorf tube has been subtracted from the measurement leaving only the weight of water. Between experiments, the tubes have been dried out completely making sure any drops of fluid were left. A total of five readings have been taken for each experiment condition (Figure 4). The resolution expressed in minimum volume that can be dispensed using the 8 mm lead screw is 437.5 nL. If needed this can be reduced by changing the lead screw, there are options which range from 1 to 8 mm threads. The firmware has three constants that can be adapted if a physical characteristic of the pump is adapted, they are the number of steps per revolution (3200 steps), the lead size (8 mm) and the syringe area (175). These three parameters are included in the volumetric resolution.

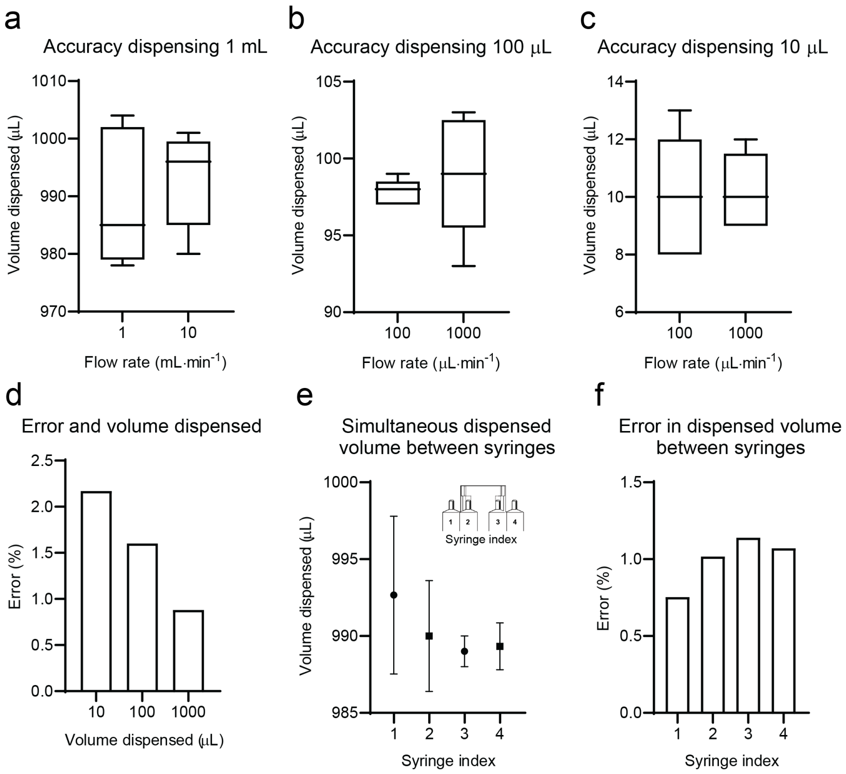

Figure 4: **Pump repeatability.** **a.** Accuracy dispensing 1 mL at 1 and 10 mL $\cdot$ min^{-1}. **b.** Accuracy dispensing 100 µL at 100 and 1,000 µL $\cdot$ min^{-1}. **c.** Accuracy dispensing 10 µL at 100 and 1,000 µL $\cdot$ min^{-1}. **d.** Relationship between error and volume dispensed. **e.** Average, maximum and minimum volume values when dispensing 1000 µL between syringes. **f.**Error in dispensed volume between syringes. Error bars correspond to minimum and maximum values.

(3) Application

Use case

In this section we provide evidence where our experimental tool can be useful for researchers.

Concentration gradient generation in a tree-shape microfluidic device

We present one of multiple applications the syringe pump could have. Microfluidic chips to create gradients of concentrations are often used in biomedical sciences. Here we design, manufacture and test a simple microfluidics chip with two inlets a passive mixer and a final straight channel where the gradient can be seen. The mixer channel dimensions are 0.5 x 0.5 mm for all channels except the wider channel (0.5 x 3 mm). The device mould was manufactured on SLA 3D printed mould (Phrozen Sonic Mini 8K) in a 1:10 ratio, wash it with 100% IPA, UV cure it for 1h and bake it for 2h at 65°C. Then we cast Polydimethylsiloxane (PDMS) and bake it for 4h at 65°C. We used a 1.5 mm diameter biopsy punch to make the holes to fit the tubing. We bonded the PDMS device with a microscope slide. In order to do that we first immersed the PDMS part in a 70% Ethanol solution and cleaned the glass slide in 1M HCl before drying both with compressed air. Then both elements were air plasma cleaned for 30 s and baked for 1 hour at 75 °C after contacting both surfaces (Figure 5a). The experiment was performed filling two 10 mL syringes with water colored with two different dyes and one waste reservoir connected with tubing (Microbore Transfer Tubing, Tygon® ND-100-80. 0.020" ID × 0.060" OD; 100 Ft). The selected flow rate was 105 $\mu L \cdot min^{-1}$ (Figure 5b-c). Another potential application would be multiple experimental conditions in parallel with the same flow rate.

(4) Conclusions

In this manuscript we present an affordable, easy to replicate, quickly reproducible tool, which offers high accuracy and repeatability with a wide range of flow rates. With the information and files provided this instrument could also be replicated using other rapid manufacturing methods.

(5) Build Details

Hardware documentation and files location:

Archive for hardware documentation, modifiable design files, software and build files.

Name: GitHub

Persistent identifier: `https://github.com/FrancisCrickInstitute/Four_channel_syringe_pump`

License: GPL-3.0 License

Date published: 30/09/2022

Publisher: The Francis Crick Institute

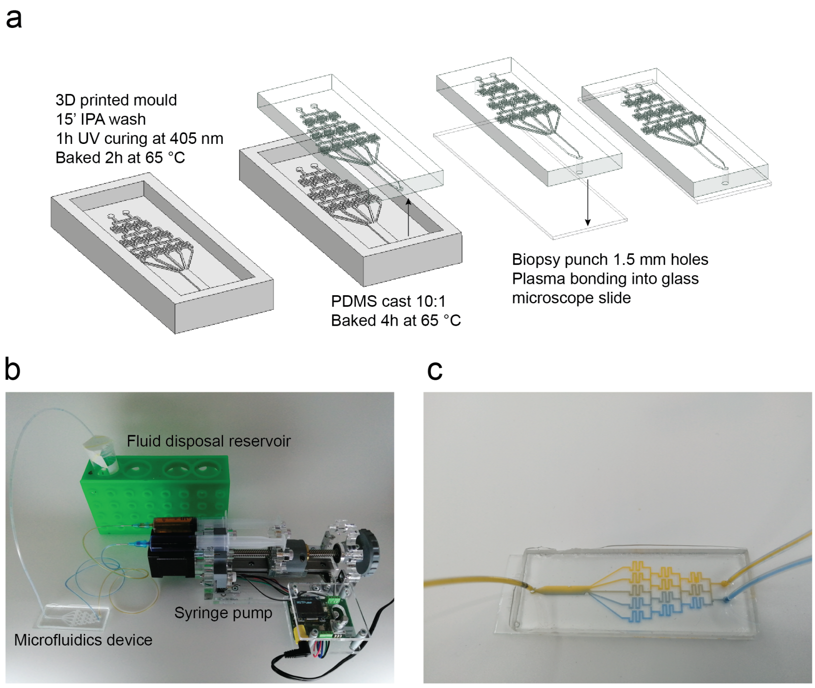

Figure 5: **Gradient chip experimental procedure. a.** Manufacturing process of the microfluidic chip. **b.** Experimental setup. **c.** Microfluidic chip during the experiment.

References

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