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Hardware article

The Perry project: A versatile low-cost syringe pump for dispensing in automated synthesis systems

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ABSTRACT

Syringe pumps are used in applications such as chemistry, medicine, or microbiology offering high-precision dosing or a way to ease the workload of tedious tasks. Further, high-performance syringe pumps are crucial to automating laboratory tasks. The Perry Pump is demonstrated with syringe sizes ranging from 1–20 mL and includes a reservoir, which enables larger volumes to be used. The lowest volume demonstrated is 20 μL at 5.5 μL/s, while the largest is 20 mL at 0.145 mL/s. The Perry Pump is designed with the intention of easy to 3D-print, limited metal parts, and a high versatility and tolerance to chemicals.

Specifications table

Hardware name	Perry Pump - A Versatile Syringe Pump for Automated Synthesis
Subject area	• Engineering and material science • Chemistry and biochemistry • Biological sciences (e.g. microbiology and biochemistry) • Educational tools and open source alternatives to existing infrastructure
Hardware type	• Biological sample handling and preparation • Mechanical engineering and materials science
Closest commercial analog	KFTechnology, KDS single-syringe pump, series 100
Open source license	CC-BY-SA 4.0
Cost of hardware	366 EUR (90 EUR without solenoid valve)
Source file repository	https://doi.org/10.17605/OSF.IO/RNT7Q

1. Hardware in context

Syringe pumps are widely used in laboratories to facilitate continuous dosing of liquids over set time periods. This introduces flexibility in the lab as automation eases the workload. Additionally, using syringe pumps, the precision of dosage is increased significantly compared to eye measurements. While the idea of syringe pumps is not novel commercial solutions tend to be expensive, upwards of 1800 EUR [1], which poses a financial strain on the simple task of moving liquids. Disregarding commercial solutions, home-brewed solutions are readily available [2–5], each presenting great alternatives to commercial solutions. The PERRY pump finds itself differentiating from current solutions by offering a lower minimum dosing volume and low and highly precise flow control. The design offers excellent chemical resistance, hereby balancing an affordable price while using high-quality components and materials where needed.

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In our process of developing a modular automatic synthesis machine [6], we encountered the need for a stripped-down version of a syringe pump that offers versatility and cheap readily available production options. The pump is a continued development to the one presented in our original work and a continuation of an Open Science syringe pump [7]. As a result, a syringe pump was developed where the bulk of the pump body is 3D-printable with relative ease and the purchased pieces are minimized as much as possible. To facilitate versatility, the syringe pump is made to fit Braun 2-component disposable syringes of various sizes. In addition, this allows for the dosing resolution to be high regardless of volume (from 30 μL to 20 mL). Our design is intended to fit into the context of a synthesis machine and a predefined operational space, where the system that operates the pumps utilizes an Arduino Mega with a Ramps 1.4 shield and Marlin firmware. Everything is further controlled through serial communication with Python, but the pumps can easily be used in other contexts if the user has a basic knowledge of machine code and serial communication. Due to the context of the developed pump, convenient features are incorporated, allowing the pump to be hung in the fume hood and stay out of the way during operations.

2. Hardware description

The syringe pump consists of a 3D printable body fitted with a NEMA 17 stepper motor. The motor connects to a T8 lead screw that in turn runs a sled up and down the syringe pump body through a brass lead screw nut. The sled is stabilized using two 8 mm smooth stainless steel rods through two LM8SUU ball bearings. As the pump is designed in the context of a synthesis machine, there was a specific need for retrieving solvent directly from reservoirs, so we designed an extension to the pump body allowing attachment of a three-way solenoid valve. To connect the valve and the pump with the solvent reservoir, we used narrow tubing akin to what is used in HPLC systems. By using narrow tubing the presented syringe pump allows dosing repeatedly and directly from solvent reservoirs, even with 1 mL syringes. Note that the use of a three-way valve is not a necessity for the pump to operate the syringe piston, it just makes everything significantly easier in the context of the synthesis machine. If the valve part of the pump is excluded, the pump works similarly to commercial solutions [1], albeit at a significantly lower price. We estimate that the Perry Pump with a high-grade solenoid valve costs approximately 366 EUR (approximately 90 EUR without), making it available for most research budgets. In our use of the syringe pump, we had the need for either resistance to organic solvent or completely metal-free environments, thus we chose a fairly expensive valve (142 EUR) with specialized HPLC fittings. The solenoid valve works through a signal from the printer microcontroller, which is activated through a G-code either activating a hotend or a fan port on the microcontroller. As a result, basically any three-way solenoid valve goes, as long as the printer provides sufficient voltage to open the valve. The syringe size and type are exchanged by replacing two 3D printable fitters that (1) fixes the syringe body to the pump body and (2) fixes the syringe plunge to the driving sled. The use of syringe fitters makes the pump body "one size fits all" and enables us to use both 1, 2, 5, 10, and 20 mL syringes, which satisfies our need for versatility. For the pump design, Autodesk Inventor was used and all printable parts are made in poly(lactic acid) (PLA). Thus, the Perry Pump is giving the following benefits to the community:

- It is a versatile syringe pump that can be used for various volumes and precision. The current arsenal contains 1, 2, 5, 10, and 20 mL.
- The setup has limited metal parts, and all parts can be 3D printed in one go. (min. 200 by 200 mm bed size)
- The Perry pump is operational as a standard syringe pump or can be used in continuous operations by incorporating a three-way valve. The valve can be applicable for water (23.6 EUR) or chemical-resistant (142 EUR) (see Section 4).
- The Perry Pump offers exceptional precision, which makes it usable for dosage of standard solutions, automated routines, or other places within chemistry, biology, medicine, food, or engineering sciences.

The actual function of the pumps operates as other syringe pumps reported, which utilizes 3D printers as the control system. In our setup, the syringe pumps are installed as replacements for the extruders on a 3D printer, as the x, y, and z dimensions are occupied for movement functions. If, however, the pumps are used in a context separated from the synthesis machine, various 3D printer microcontrollers can be used to operate the pump through all axes.

3. Design files summary

See Table 1 for design files. The **Perry Body** (Fig. 6) and **Perry Valve Fixture** (Figs. 10 and 11) are the main body. The **Perry Plunger** (Figs. 3–5) is the sled that runs back and forth, which compresses or elongates the syringe. The **Perry Plunge Fitter** (Fig. 12) and **Perry Syringe Fitter** (Fig. 12) can be found in 1, 2, 5, 10, and 20 mL syringes and fixates the syringe in the main body. Finally, the **Perry Hanger Left** and **Perry Hanger Right** (Fig. 9) have to be printed twice each, and they are fastened on the back of the **Perry Body** to make the Syringe Pump mountable, further it keeps the wires from the motor in place. **Python GUI** and **Pronterface** (Fig. 13) are respectively a custom-made interface or a free open-source software capable of controlling the Perry Pump.

Table 1
Design Files for the Perry pump.

Design filename	File type	Open source license	Location of the file
Perry Body	stl, ipt	CC-BY-SA 4.0	OSF [8], GitHub [9]
Perry Valve Fixture	stl, ipt	CC-BY-SA 4.0	OSF [8], GitHub [9]
Perry Hanger Left	stl, ipt	CC-BY-SA 4.0	OSF [8], GitHub [9]
Perry Hanger Right	stl, ipt	CC-BY-SA 4.0	OSF [8], GitHub [9]
Perry Plunger	stl, ipt	CC-BY-SA 4.0	OSF [8], GitHub [9]
Perry Plunge Fitter 1 mL	stl, ipt	CC-BY-SA 4.0	OSF [8], GitHub [9]
Perry Plunge Fitter 2 mL	stl, ipt	CC-BY-SA 4.0	OSF [8], GitHub [9]
Perry Plunge Fitter 5 mL	stl, ipt	CC-BY-SA 4.0	OSF [8], GitHub [9]
Perry Plunge Fitter 10 mL	stl, ipt	CC-BY-SA 4.0	OSF [8], GitHub [9]
Perry Plunge Fitter 20 mL	stl, ipt	CC-BY-SA 4.0	OSF [8], GitHub [9]
Perry Syringe Fitter 1 mL	stl, ipt	CC-BY-SA 4.0	OSF [8], GitHub [9]
Perry Syringe Fitter 2 mL	stl, ipt	CC-BY-SA 4.0	OSF [8], GitHub [9]
Perry Syringe Fitter 5 mL	stl, ipt	CC-BY-SA 4.0	OSF [8], GitHub [9]
Perry Syringe Fitter 10 mL	stl, ipt	CC-BY-SA 4.0	OSF [8], GitHub [9]
Perry Syringe Fitter 20 mL	stl, ipt	CC-BY-SA 4.0	OSF [8], GitHub [9]
Python GUI	Python	CC-BY-SA 4.0	OSF [8], GitHub [9]
Pronterface	Free open-source software	GNU GPLv3	https://www.pronterface.com/

4. Bill of materials summary

See Table 2

Table 2
Bill of materials for the Perry Pump.

Designator	Component	Number	Cost per unit - currency	Total cost - currency	Source of materials	Material type
3D Printed Parts (3)	PLA 1.75 mm filament (1 kg)	1 set	14.7 EUR	14.7 EUR	Amazon.de	Plastic
8 mm stainless steel smooth rod	8 × 140 mm	2 pieces cut to 140 mm	8.39 EUR	8.39 EUR	Amazon.de	Metal
T8 stainless steel trapezoidal lead screw	T8 × 115 mm	1	7.35 EUR	7.35 EUR	Amazon.de	Metal
8 mm lead screw brass nut	8 mm brass nut	1	–	–	Amazon.de incl. w. T8 × 115 mm	Metal
Linear bearings - LM8SUU	LM8SUU	2	3.15 EUR	6.29 EUR	Amazon.de	Metal
5 mm to 8 mm Flexible coupling	5 × 8 mm Flexible coupling	1	2.5 EUR	7.34 EUR[a]	Amazon.de	Metal
3 mm hexagonal nuts	3 mm nut	10	0.51 EUR	5.1 EUR	Amazon.de	Metal
M3 20 mm bolts	M3 × 20 mm	4	0.2 EUR	9.55 EUR[a]	Amazon.de	Metal
M3 16 mm bolts	M3 × 16 mm	2	0.12 EUR	5.89 EUR[a]	Amazon.de	Metal
M3 10 mm bolts	M3 × 10 mm	4	0.14 EUR	7.03 EUR[a]	Amazon.de	Metal
M3 6 mm bolts	M3 × 6 mm	4	0.15 EUR	7.34 EUR[a]	Amazon.de	Metal
NEMA 17 stepper motor	NEMA 17	1	11.03 EUR	11.03 EUR	Amazon.de	Metal
Burkert 6606 solenoid valve[b]	Three-way valve	1	142.2 EUR	142.2 EUR	RS components	Other
1/4"-28 UNF tube fitting	Tube fittings	3	7.54 EUR	75.4 EUR[a]	Cole-Parmer	Plastic
1/16" OD PTFE tubing	Tubes	1	58 EUR	58 EUR[a]	Darwin Microfluidics	Plastic

[a] Please note that these packs come in larger quantities than what is needed, but the full price is added for transparency.
[b] As mentioned, any three-way solenoid valve would work here, however, the Burkert 6606 is a robust chemical-resistant valve. Alternatively, a SMC solenoid valve (23.6 EUR) can be used instead (https://dk.rs-online.com/web/p/magnetventiler/8388660?gb=s).

5. Build instructions

The following section includes a detailed step-by-step guide. It should be noted, that the biggest safety concern is the lack of endstops or other sensors to inform the pump of its position. Commands exceeding the physical limits of the pump can cause critical

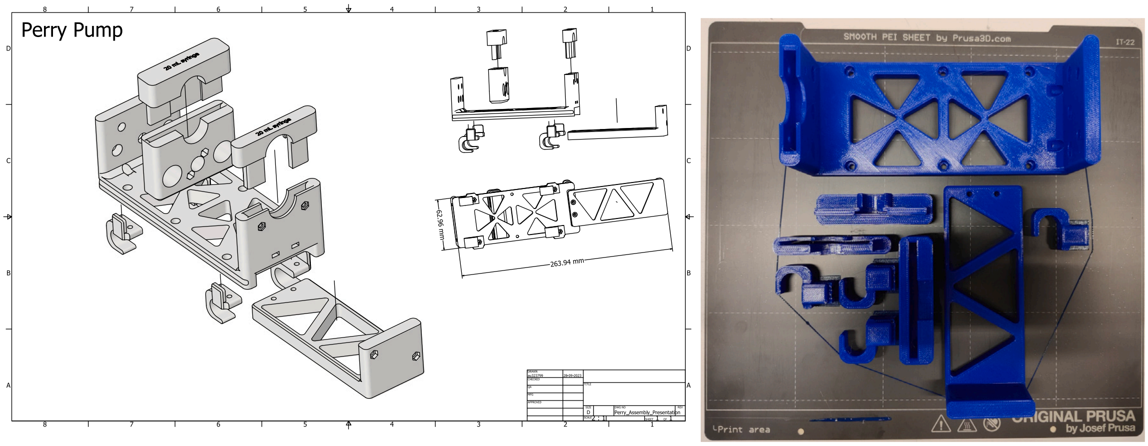

Fig. 1. Left: Exploded view of the design files needed for the Perry pump. Right: A full pump body set, with accompanying syringe fitters (5 mL), valve fixture, hangers, and plungers.

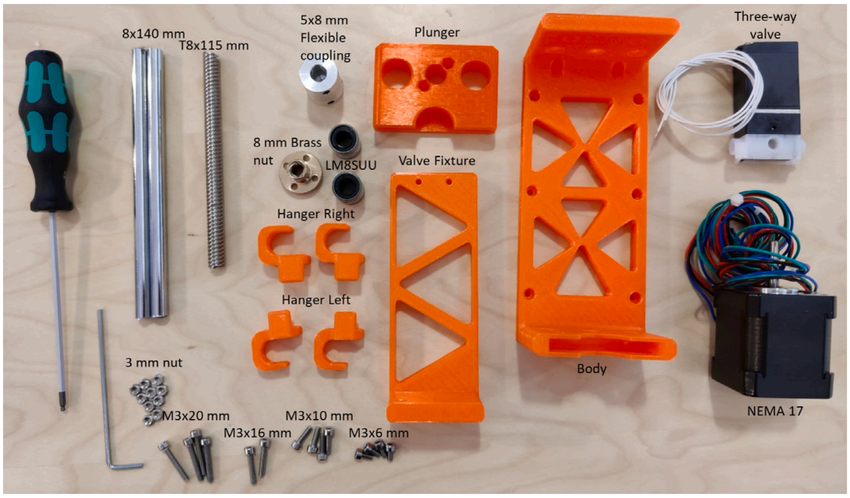

Fig. 2. Overview of the parts needed to assemble the pump, excluding syringe fitters.

damage to the pump system resulting in solvent spill. For safe use, start the pump operation with the plunger completely suppressed. An exploded view of the manufactured parts can be seen in Fig. 1 (left), the benefit of the design is shown where the entire pump body with a set of syringe fitters can be 3D printed in one session on a common bed size of 200 × 200 mm.

Once the design files in Section 3. "Design Files" have been 3D printed, and the items in Section 4. "Bill of Materials" has been received, it should look like Fig. 2, and the step-by-step building process can be commenced.

(1) Insert two 3 mm nuts into the **Perry Plunger**, flip the plunger, and install the 8 mm brass nut by using 2 M3 × 20 mm bolts (Fig. 3)

(2) Press the LM8SUU into the plunger (Fig. 4), from the side opposite the 8 mm brass nut. Note, this is a tight fit and force can be required.

(3) Connect the 5 × 8 mm Flexible coupling to the T8 × 115 mm. Adjustment of the connector might be needed to make sure the T8 × 115 mm aligns in the final assembly. Ensure even connection to avoid bending. Screw the T8 × 115 mm into the **Perry Plunger** from the 8 mm brass nut front (Fig. 5).

(4) Grab the **Perry Body** and press the 8 × 140 mm smooth rods halfway into the body from the top (Fig. 6). Note, this is a tight fit depending on the layer height of the print, thus twisting the rod in place might be required.

(5) Place the **Perry Plunger** with the attached T8 × 115 mm into the body (Fig. 7). Adjustments of the T8 × 115 mm can be needed to align the plunger and the 8 × 140 mm smooth rods. Carefully press the smooth rods through the LM8SUU and all the way down till they touch the opposite end of the **Perry Body**.

(6) Attach the NEMA 17 to the top of the **Perry Body**. Make sure that the wires protrude in the direction of the ridge along the side of the body (Fig. 8, left). Screw the motor tight to the body with 4 M3 × 6 mm bolts (Fig. 8, middle). Subsequently, fix the

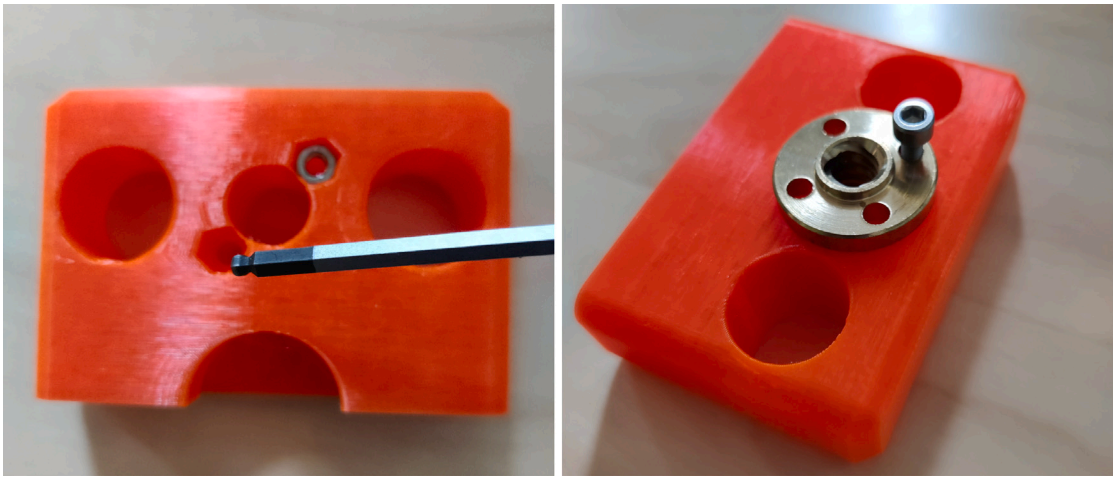

Fig. 3. Installment of the lead screw nut in the **Perry Plunger**. Left: Nuts positioning. Right: 8 mm Brass nut mounted with M3 × 20 mm bolts.

Fig. 4. Fitting the LM8SUU bearings into the **Perry Plunger**.

motor shaft in the 5 × 8 mm flexible coupling. Ensure that the flat part of the shaft aligns with one of the coupling screws (Fig. 8, right). You should now be able to rotate the 5 × 8 mm flexible coupling, causing the plunger to move forward and backward.

(7) Take two **Perry Hanger Left** and two **Perry Hanger Right** and push 3 mm nuts (4 in total) into the hexagonal holes (Fig. 9, left). Install the hangers in the top and bottom holes of the body, using 4 M3 × 10 mm bolts. The hangers should be installed so that the pump can hang with the NEMA 17 facing upwards. When installing the left hangers, make sure to put the wires from the NEMA 17 into the pump body ridge and fixate the wires. (Fig. 9, right).

(8) In the bottom of the body, opposite the NEMA 17, push two 3 mm nuts into the holes (Fig. 10, left). Further, push two 3 mm nuts into the hexagonal holes in the **Perry Valve Fixture** (Fig. 10, right).

(9) Attach the **Perry Valve Fixture** to the indent in the **Perry Body** using the remaining two M3 × 20 mm bolts. (Fig. 11, left) Finally, install the three-way valve to the **Perry Valve Fixture** using the two M3 × 16 mm bolts (Fig. 11, right).

Perry Syringe Fitters and **Perry Plunge Fitters** matching the intended syringe size (1, 2, 5, 10, and 20 mL) need to be 3D printed as well before the Perry pump can be operated. All designed fittings are available on the GitHub page [9]. An image of the pump with all accompanying fitters and syringes can be seen in Fig. 12. By varying the size of the indent in the fitters, the pump body becomes “one size fits all”.

The fitters slide into the pump body and the plunger, fastening the syringe. The fitters do not contain any screws or bolts by default and are secured solely by friction between the plastic parts.

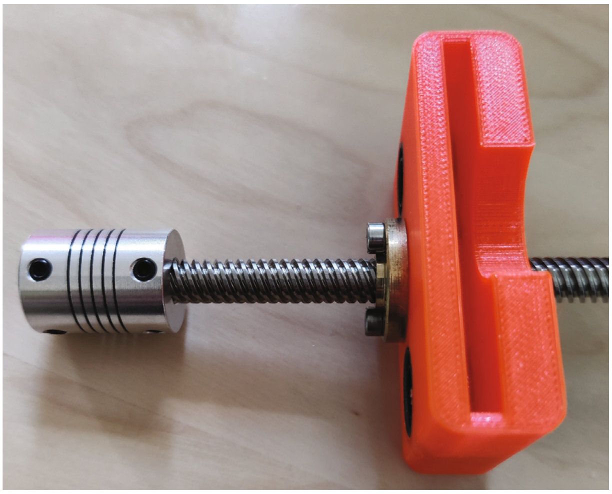

Fig. 5. The T8 lead screw fitting into the **Perry Plunger**.

Fig. 6. Smooth stainless steel rods in the **Perry Body**.

Fig. 7. Installing the **Perry Plunger** on the smooth rods. Make sure that the smooth rods do not protrude from the top of the **Perry Body**, as this will cause the motor mounting to be difficult.

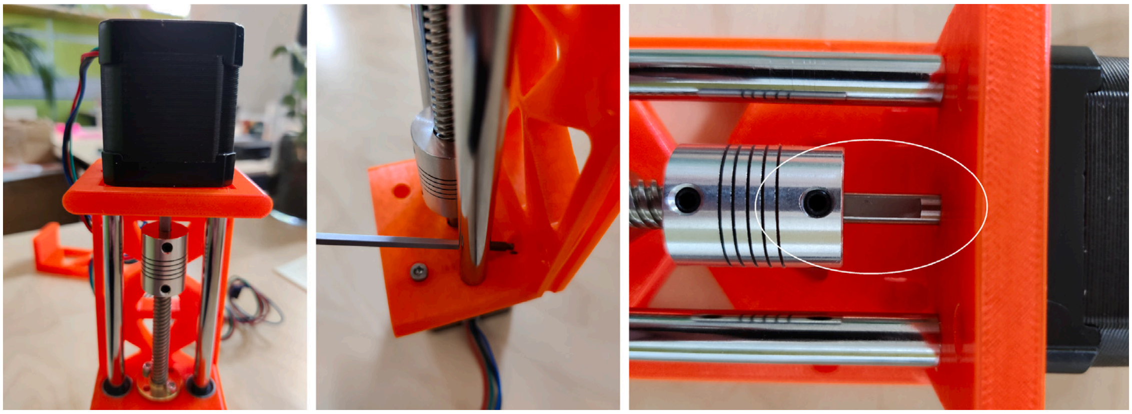

Fig. 8. Mounting of the NEMA 17 motor and subsequent alignment of the flexible coupling. Left: Assembled front view, ensure that the motor wires point either left or right towards the ridge of the pump body's side. Middle: Fastening of NEMA 17 with M3 × 6 mm bolts. Right: Flexible coupling and how to align the NEMA 17's shaft.

6. Operation instructions

Provided that the syringe pump is connected to a 3D printer microcontroller, typically with Marlin firmware installed (e.g. Ramps 1.4 for up to 5 pumps, BigTreeTech Octopus for up to 8 pumps, etc.), the easiest way to control the pumps would be through Pronterface or the custom-made graphical user interface (GUI), see Fig. 13, but solutions from e.g. Prusa and Cura can be used as well. The pump is controlled with regular G-codes (G-code list [10]) and will be exemplified by the G1 movement using Pronterface. The pump addresses can be either X, Y, Z, or E, depending on where it connects. Any negative value will pull the plunger and any positive value will push the plunger; thus G1 E-2 will pull the plunger of pump E two units. Here, a correlation between the movement signal and the volume retracted or dosed must be made to translate the G-code units to volume (see Section 7).

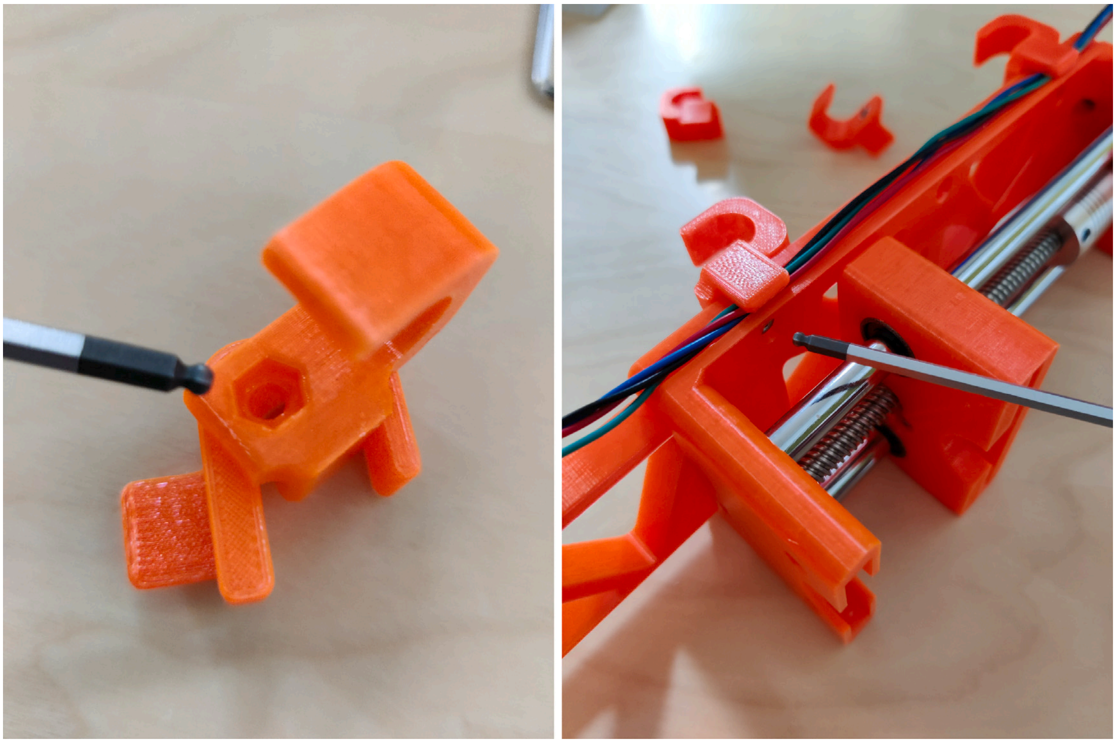

Fig. 9. Installment of the mounting hooks for fumehood monkey bars. Left: Hooks and tools shown. Right: The ridge and the hooks mounted on the side of the pump's body are designed to keep the motor wires in place.

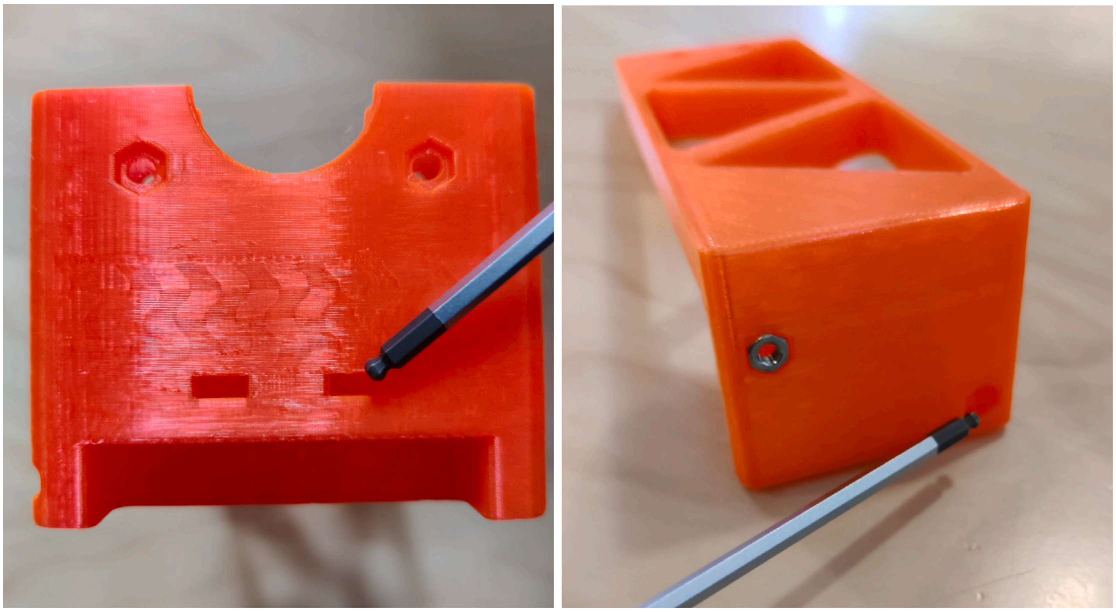

Fig. 10. Left: Fitting of the M3 nuts into the hexagonal holes in the **Perry Body** are made for additional fastening of syringe fitters, if needed. Right: Fitting of the M3 nuts into the hexagonal holes in the **Perry Vale Fixutre**.

Fig. 13 (left) shows the Pronterface's machine control, where the Perry pump can easily be utilized from. Further, Fig. 13 (Right) is the setup used for the automatic synthesis machine [6], where the pump is controlled through Python scripts via the Python GUI [9].

Fig. 11. Left: Installing the **Perry Valve Fixture** on the **Perry Body**. Right: Mounting the solenoid valve on the **Perry Vale Fixture**. The current design of the valve fixture is made specifically for the Burkert solenoid valve but is customizable for other valve types.

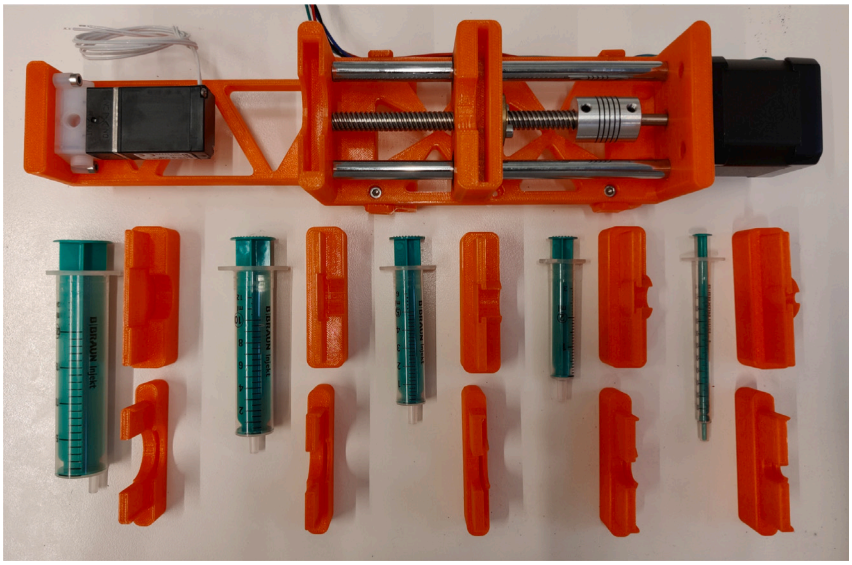

Fig. 12. Perry Pump with all fitters and syringes.

7. Validation and characterization

The Perry Pump has been characterized through calibrations with water, tetrahydrofuran (THF), toluene, and ethanol (EtOH). Water calibrations were done with 1, 2, 5, 10, and 20 mL syringes (Fig. 14, left), while THF, toluene, and EtOH calibrations were done with 10 mL syringes (Fig. 14, right).

Calibrations are shown here with a 1, 2, 5, 10, and a 20 mL syringe (Fig. 14, left). The 1 mL syringe is able to reach a volume flow ranging from 5.5 μL/s to 27.5 μL/s and the 20 mL syringe is able to range from 29.1 μL/s to 145.5 μL/s. Further, calibrations with THF, toluene, and EtOH done with 10 mL syringes are all very similar in response (Fig. 14, right). Thus, once the calibrations are done, the pump is ready to dose with those particular syringes. Minor variations have been experienced between syringes from the same package, however, these can largely be ignored. Another benefit of the same response is, that solvents of approximately the same viscosity are interchangeable, and a calibration with one solvent can be used on another solvent since differences are practically nonexistent. It can be necessary to insert a time break to let the solvent settle if a high-viscosity liquid is dosed in order to retain the precision of the Perry pump.

Safety: There can be a safety concern regarding syringes being used for organic solvents. It is important to use a syringe that is chemical-resistant, also over time, since the syringe will be exposed to the solvent continuously. Further, syringe pumps should be

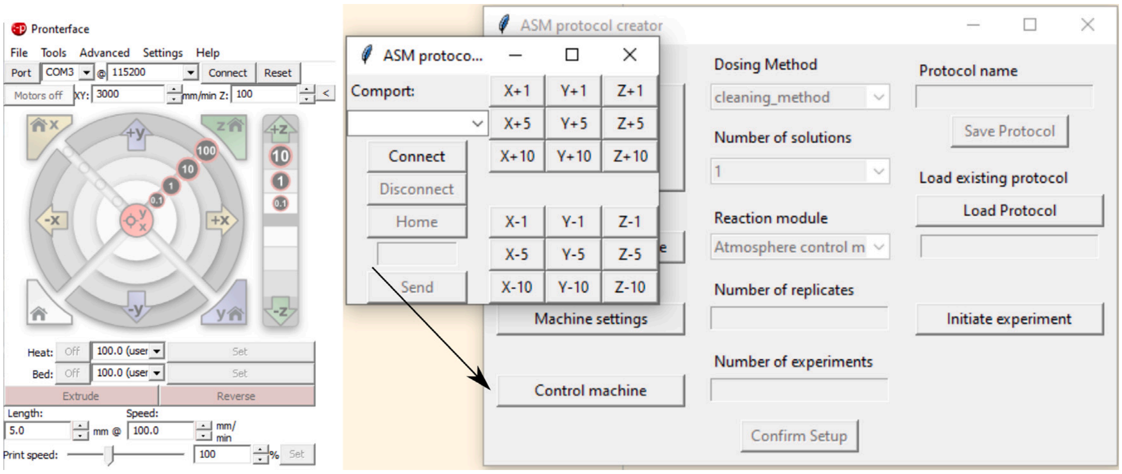

Fig. 13. Left: The Pronterface's control unit. Right: Python GUI for machine control and developed for the purpose of controlling a synthesis machine [6].

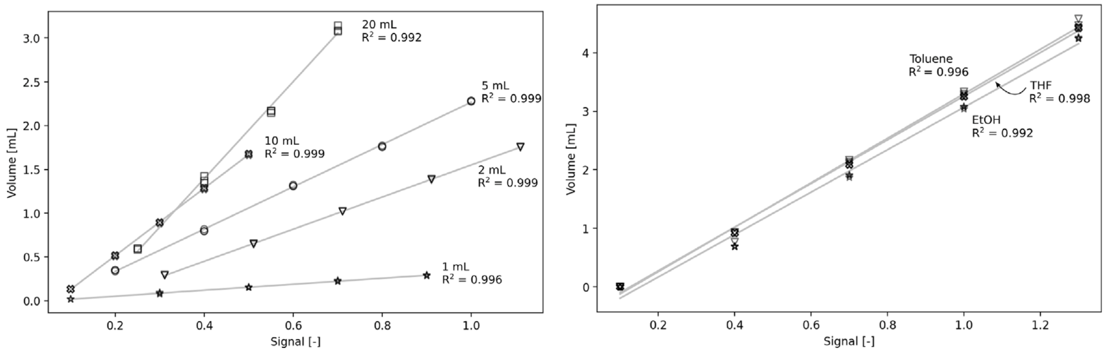

Fig. 14. Left: Pump calibrations with water and different syringe sizes. ($y_{1mL} = 0.342x - 0.018$, $y_{2mL} = 1.835x - 0.284$, $y_{5mL} = 2.416x - 0.149$, $y_{10mL} = 3.852x - 0.256$, $y_{20mL} = 5.541x - 0.822$). Right: Pump calibration of a 10 mL syringe with organic solvents. ($y_{toluene} = 3.801x - 0.503$, $y_{THF} = 3.729x - 0.472$, $y_{EtOH} = 3.625x - 0.558$). The syringe sizes, solvents, and degree of explanation are included in the figures.

used under the same conditions as for manual handling, e.g. fume hood and proper PPE, as spill and splash can occur. Two-part polypropylene syringes have proven particularly useful, while syringes with a rubber piston have shown a tendency to degrade when toluene is used over the course of dosing only 15 experiments. The NEMA 17 stepper motor can easily go above the speed for the upper limit of the volume flow, resulting in a pressure building up in the PTFE tubing and it can result in the tubing being forced out of the fitting when dosing. Thus, either operate at the speed recommended here or consider using something to secure the tubing like a zip tie.

Thus, the Perry Pump is a versatile and low-cost alternative to a commercial syringe pump system. The Perry Pump is made with the design intent of quickly being able to be 3D printed, while the assembly only requires a limited amount of metal parts including nuts and bolts. The total price (366 EUR, incl. Burkert Three-Way Vale) stated here is if everything is bought anew (e.g. boxes of bolts or packages of 10 pieces of UNF Tube Fittings), however, the price will be significantly lower if one already has the components, or aim to build several of the Perry Pumps at once. Should one wish to make and operate the Perry Pump as a classical (first load, then dose) syringe pump and still buy the BOM anew, then the total price is 90 EUR. Further, the high precision available with this setup is demonstrated, and the capability to dose a variety of solvents encountered in the laboratory is demonstrated, with the designed purpose of being used in automated laboratory work. [6]

- Easy production and assembly. Limited metal parts and the design files can be additively manufactured in one go.
- The **Perry Pump** is versatile with prefabricated syringe fitters for 1, 2, 5, 10, and 20 mL syringes and can easily be customized or adjusted to specific needs without the need for screws and bolts.
- Dosing available between 20 μL and 20 mL.
- Dosing speed variable between 5.5 μL/s to 0.145 mL/s by varying the syringe size used.
- Designed to hang in fumehood monkey bars.
- As the **Perry Pump** is designed to function in a synthesis machine, however, it can be operated independently with the Python GUI provided or e.g. Pronterface.

Ethics statements

The authors declare no ethical problems.

CRediT authorship contribution statement

Jakob Rørbæk Saugbjerg: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Thorbjørn Bøgh Jensen:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Martin Lahn Henriksen:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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