Hybrid print head for low-cost 3D printing electronics

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Abstract

This project builds a drop-in paste extruder printhead using 3D-printed and off-the-shelf components, allowing desktop FDM 3D printers to print embedded electrical circuits using thermoplastic filament and conductive paste.

1. Background

- Additive Manufacturing, commonly known as 3D printing, has seen recent increasing accessibility making it a low-cost solution for rapid prototyping and manufacturing.
- Traditional Fused Deposition Modelling (FDM) is used in most consumer-level 3D printers, although material choice is limited.
- The integration of a paste extrusion-based printhead into an FDM desktop 3D printer significantly expands the range of the materials and applications of 3D printing.
- In particular, the use of conductive materials in 3D printing enables embedded actuation, sensing, and power, eliminating the need for external wiring and interconnects.

2. Objectives

1. The electrical and mechanical design, fabrication, and testing of a **paste extrusion-based print head, which will be mounted onto a desktop FDM 3D printer**.
2. The printing of specimen test pieces involving **both insulating thermoplastic and electrically conductive pathways**, demonstrating potential capabilities.
3. The **characterisation, modelling, and design rules** for such hybrid printing.

3. Methodology

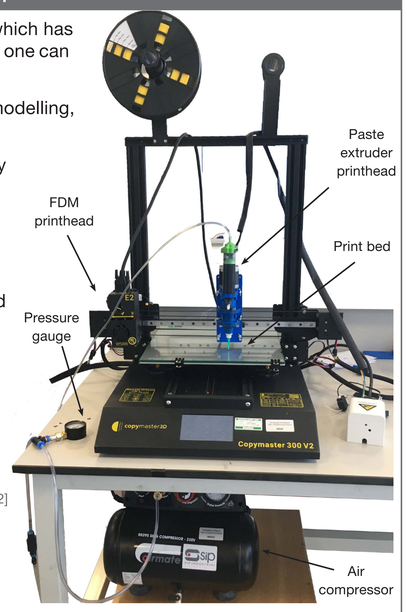
1. Several preliminary designs using different extrusion mechanisms are built and tested.
2. An extrusion mechanism is taken forward and the design is refined through iteration.
3. The design is installed onto the 3D printer and used to print embedded circuits.

4. Equipment

- A Copymaster 300 V2 3D printer was used which has two independent filament print heads, so that one can be replaced with a paste extruder.
- SolidWorks was used throughout for 3D modelling, and Cura as the slicing software.
- Conductive paste used was **Electric Paint** by Bare Conductive.
  - A non-toxic, water-based material which uses conductive carbon.
  - Rheological testing showed shear thinning behaviour and visco-elastic liquid characteristics.
  - Priced at £300/L, with reasonable resistivity (0.45 Ω·cm) c.f. conductive filaments (1.42 Ω·cm[1] - 0.006 Ω·cm[2])

Photo of the conductive paste.

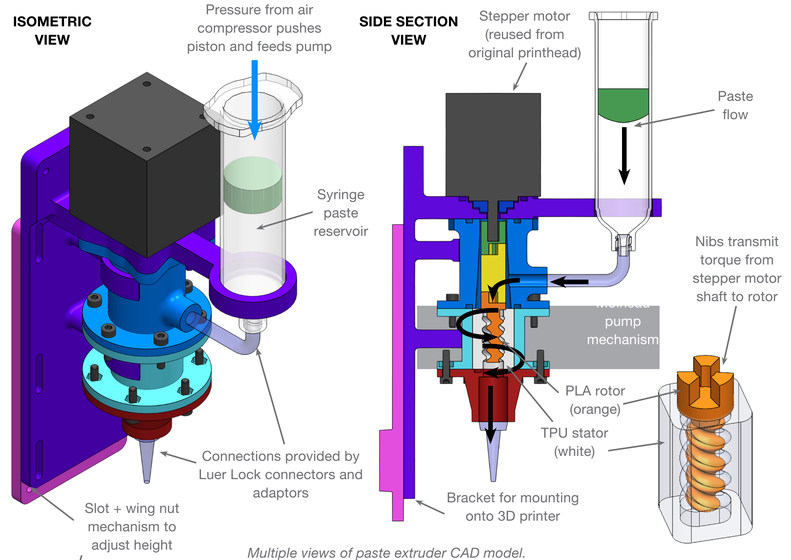
1 Amolen's conductive PLA [1]
2 Multi3D's Electrifi conductive filament [2]



Schematic of the equipment set-up used.

4. Design overview

- After preliminary builds of extrusion mechanisms, a **Moineau Pump mechanism** (also known as a progressive cavity pump) was taken forward, which is a special type of rotary positive displacement pump:
  - Larger versions are widely used in heavy industry like oil and gas, mining, and wastewater.
  - Consists of a helical rotor rotating inside an outer stator, forming a set of fixed size, sealed cavities which progress axially.
  - Results in a fundamentally fixed flow rate, so that the volumetric flow rate is proportional to the rotation rate, and a comparatively good dynamic response.
- The complete paste extruder assembly was modelled in SolidWorks, and parametrised with global variables and equations.
  - The majority of parts were 3D-printed. A 3D-printed flexible TPU stator and PLA rotor provide a good seal and prevent leakage between cavities.



Multiple views of paste extruder CAD model.

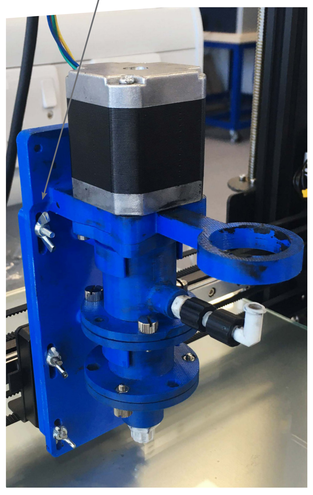


Photo of paste extruder mounted onto 3D printer. Pictured without syringe reservoir.

5. Advantages

- Requires minimal human intervention and can be installed onto existing desktop FDM 3D printers.
- Provides benefits over other drop-in paste extrusion alternatives, with better dynamic response and accuracy, and is lower cost.

	Designed Paste Extruder	Zmorph's Thick Paste Extruder [3]	Voltera's V-One [4]
Type	Drop-in	Drop-in	Electronics 3D printer
Category	Hobby-level	Hobby-level	Professional
Price	~£134	€229	$4,199
Nozzle diameter	0.8mm	2mm	0.25mm
Disadvantages		Poor dynamic response + accuracy	High cost

6. Print results

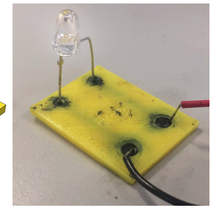
- Paste extruder proved capable of **"retraction"**, a common 3D printer feature, where some material is retracted to prevent leakage as the printhead travels across empty space.
- Both 2D and 3D circuit designs were printed in PLA (using the original filament printhead) and conductive paste (using designed paste extruder head):
  - Conventional FDM process of modelling in SolidWorks and importing into slicing software.
  - 0.8mm Luer tip nozzle used with layer heights of 0.3mm for both materials.
  - Tests were successfully conducted with a basic LED and 9V battery.
- Particular difficulties were encountered with the nozzle tip clogging or air bubbles forming in the paste reservoir.

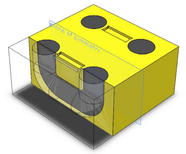
Photo of line prints where not enough paste was retracted.

Design rules

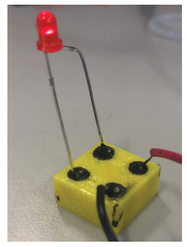
- Air pressure as low as possible.
- Drying time inbetween paste layers.
- Paste enclosed with PLA when possible.
- Larger dimensions and spacing to prevent short circuits.

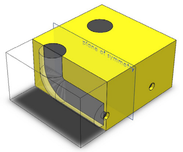
2D enclosed design



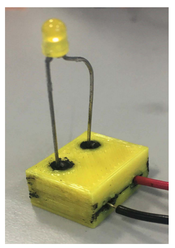


3D U-shaped design





3D L-shaped design



CAD models (with cut-away section views) and photos of printed circuit designs.

7. Summary

- The successful iterative design and development of a **low-cost add-on printhead** primarily constructed from 3D-printed and off-the-shelf parts, lowering the barrier of entry for multi-material printing.
  - Capable of paste extrusion and more complicated capabilities like **retraction**.
  - Fabrication of 2D and 3D enclosed circuits with **working electrically conductive tracks**.
  - The development of **design rules** for integrated printing.
- This project therefore paves the way for future investigations into **multi-material 3D printing.**

8. Recommendations

- Development of design to make it **easier to disassemble and clean.**
- Further investigation into other **more hard-wearing and fatigue-resistant materials** for the pump mechanism.
- More investigation into **modifying the rheological properties of Electric Paint** for more controllable extrusion through additives without affecting electrical properties, or into **other more appropriate conductive pastes/inks/formulations.**

REFERENCES [1] https://amolen.com/products/amolen-3d-printer-filament-conductive-black-pla-filament-500g1-1lb [2] https://www.multi3dllc.com/product/electrifi/ [3] https://www.3dprima.com/parts/spare-parts/zmorph/zmorph-thick-paste-extruder/a-24263 [4] https://www.aniwaa.com/product/3d-printers/voltera-v-one/