

## 3d Printer Heads for Extrusion of Biologicals Gels

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**Abstract.** Processing biological materials with 3-dimensional (3D) printers has attracted increasing interest in several research areas. At the same time, off-the-shelf solutions are increasingly available in a wider variety to meet the current market demand. However, most of the available bioprinters are closed source, thus, modifications are quite challenging or require an avoidable consultation process with the manufacturer. Furthermore, the entry prices for basic machines amount to several thousands of euros. Whereas, high-end 3D bio printers with a vast array of features are available for several hundred thousand euros. Due to the immense potential of this tool in the field of biotechnology it is important to extend the availability of this technology for research purposes in terms of adaptability and price.

This ongoing work focuses on open-source 3D printer heads with the ability to extrude biological materials. The print heads include several techniques to process low as well as high viscose biomaterials such as agar and gelatin. Additionally, obstacles such as continuous substrate tempering or integration into existing 3D printers are addressed. The work presented is open source and thus freely adaptable to any user's specific needs. Our goal is to process a diverse range of biomaterials with different print techniques.

### Introduction

The expiring patent for Fused Deposition Modeling (FDM) in 2009 reduced the prices of such machines from over \$10000 to less than an a tenth of the price [1, 2]. This led to a higher demand in in the consumer market. Subsequently, the last decade strongly contributed to making 3D printing a consumer friendly and affordable craft. Nowadays basic FDM machines are available for around \$100 and depending on the set of features (e.g. multiple extruders, print volume or movement set up) the machines can still cost several thousand dollars [3]. Aside from the well establish FDM systems, resin-based 3D printers are on the same rapid developing path. Digital light processing (DLP) printers can already be bought for less than \$ 300. These machines provide a more precise print quality compared to FDM. While FDM printers' precision are primary defined by the nozzle' diameter (usually ranging from 0.2 to 0.8 mm) DLP printers are defined by the minimum pixel size of the UV light emitting display. The display of budget-friendly DLP printers provide a resolution of 534 pixel per inch within an print surface of 7475 mm<sup>2</sup> and a height of 165 mm [4]. Aside from the strong hardware development under open source aspects, the substrates for 3D printers are also on a steady development to achieve key feature in medical or mechanical application. FDM printers gain increasingly interest in the dental practice and several filaments for corresponding dental applications were developed [5-7]. Substrates for 3D resin printers are also in constant development, e.g. water-based UV resins are available with a higher cost while simplifying and decreasing the costs of the pre and post process of the print [8, 9].

The field of bioprinting is strongly gaining knowledge from the development in the field of 3D printing. The increase of accessibility, cost reduction and improved print process had a positive effect

in the field of research and industry. Bio printers were developed with the help of 3D printed parts by research groups [10, 11]. Further, the market size for 3D bioprinting was valued at \$965 million in 2018 and is expected to be worth \$4.1 Billion by 2026 [12].

## Requirements

The goal of the presented work is to develop an open source 3D bioprinter which enables to use multiple print techniques. Among them are two different kind of extrusion methods and an ink jet system. Additionally, to improve the substrate flow from a reservoir to the extrusion a tube tempering system was developed.

**Extrusion systems.** Two extrusion systems were developed with different criteria in mind. One should deliver the substrate without any direct contact of the system and the other should operate with high precision. The first prototype was inspired by peristaltic pumps. In Fig. 1 the computer design as well as the first manufactured prototype is shown. The main advantage of this extruder is the contact free extrusion. However, the disadvantage of this system is the peristaltic pump typical pulsatory extrusion. Even though an adapted damper reduces partially this effect, the variation of line thickness due to the uneven extrusion during the initial tests are currently insufficient for the necessary shape-retaining during 3D printing. One method to improve a more stable extrusion is to increase the number of contact point. This can be achieved by increasing the number ball bearings in the system, which will be performed in near future.

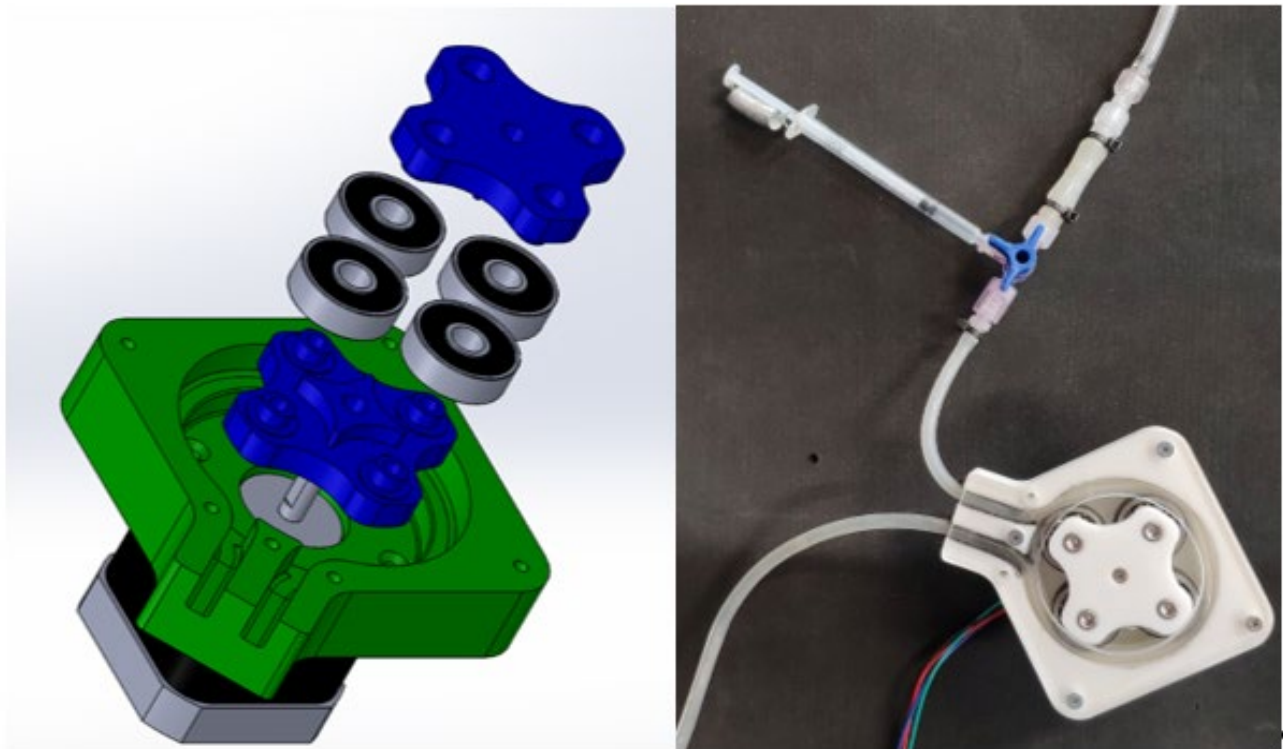


Fig. 1 Peristaltic extruder pump in exploded isometric view (left). The pump consists of 4 ball bearings, M4 screws and nuts, bearings holder (blue) and tube holder (green) which is mounted with M3 screws on the stepper motor. On the right side the manufactured prototype with a pulsation damper connected via Luer T valve is shown. The damper consists of an 1ml syringe and a spring.

The second extruder shown in Fig. 2 was inspired by single screw extruders and designed to extruder more precise and without pulsatory behavior. In comparison to the first one the substrate has contact with manufactured parts, such as the screw itself. In comparison to existing bioprinter (e.g. the previously cited “Large volume syringe pump extruder for desktop 3D printers” by K. Pusch, et al. [11]) these extrusion set-ups utilize a substrate reservoir which can be refilled mid print. Thus, print with volumes bigger than 50ml are accomplishable.

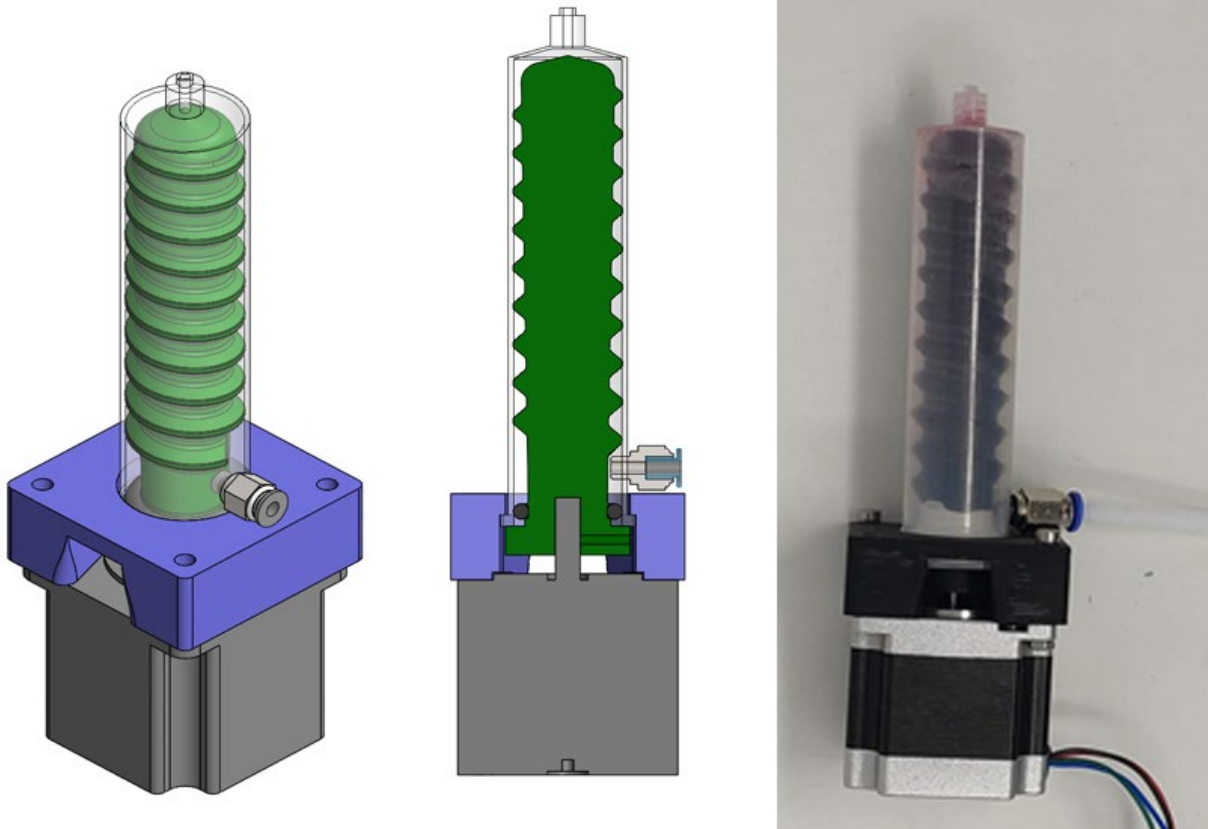


Fig. 2 Screw extruder as CAD image and the first manufactures prototype. The designed screw extruder in an isomeric view (left), as cross section (mid) and the manufactured prototype. The system consists of the screw (green), a stepper motor NEMA 23(gray), a 50ml syringe body with Luer connector (clear), stepper mounting (blue)fixed via M4 screws and nuts, a sealing ring (black) and a pneumatic connector.

**Piezoelectric ink jet.** Render images of the current piezoelectric ink jet prototype are displayed in Fig. 3. This ink jet prototype consists of an 3D printed body which contains the piezo and a sealing top lid. In order to ensure that the system is airtight the piezo is placed between two sealing rings. The bottom sealing ring is embedded into the body to further deduce the chamber volume and provide an airtight seal. Substrate is feed from a reservoir by pneumatic tube system to the side of the main body. After entering the main body, the liquid tunnels below the sealing ring to the tapered volume between the piezo and extrusion hole. The nozzle of 0.1mm diameter is drilled post-printing. Additionally, Fig. 3 displays the correlation between displacement of the piezoelectric element and the applied direct current (DC) Voltage. For adequate displacement of the piezo voltages above 100V DC are necessary. In order to achieve the such voltage, a Cockcroft-Walton multiplier was utilized to convert alternating current to the necessary DC Voltage.

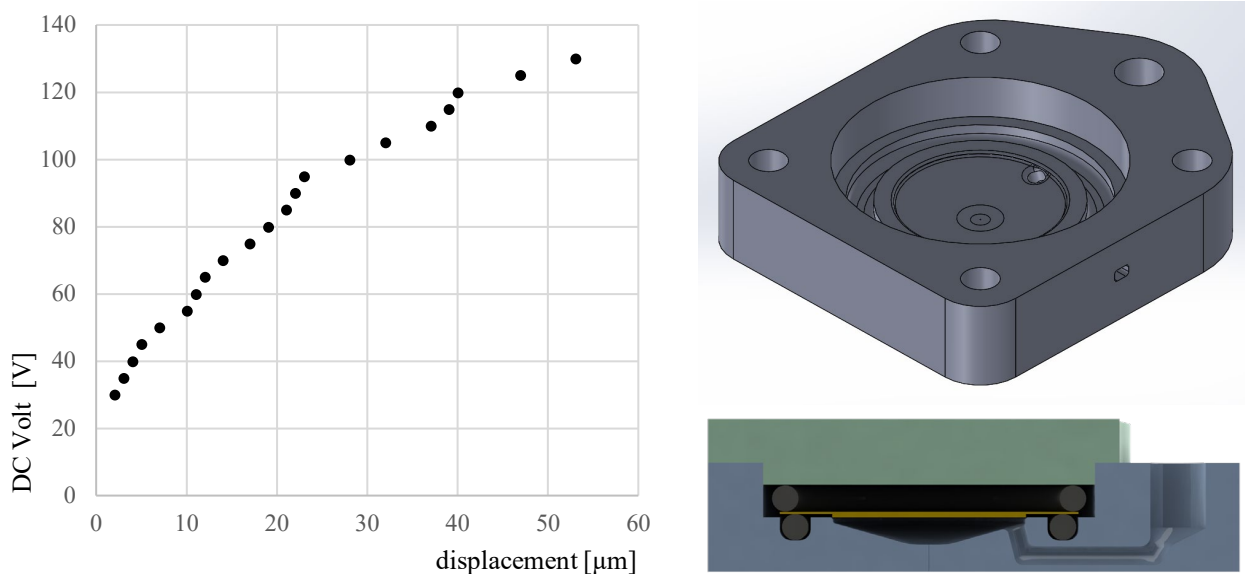


Fig. 3 Displacement of the piezo element in correlation to the increasing DC voltage show in the left graph. On the left render images of the ink jet extruder prototype in the Isometric view (top) and side section view (bottom). The inkjet consists of the main body (gray), and piezo (gold), two sealing rings (black) and a lid (green).

**Substrate tube tempering.** Current processed material is gelatin or other biomaterials which gel temperature dependent. Thus, in order to avoid substrate clogging within the tubes, a heating system for the substrate tubing was developed. The system functions as standalone component and can be added to conventional tubing systems. Without regards to the print process the temperatures can be controlled separately and is further powered by a distinct power supply. An Arduino MEGA manages the setups calculation. Temperature values are display via an LCD display and the desired temperature is set with four buttons for each thermistor and heating element. In order to achieve the necessary precision a program was developed which utilized proportional integral derivative (PID) control loop. The regulatory system enables to set specific temperature in the tubing system. Thus, to keep the temperature slightly above the gelling temperature (e.g. for gelatin). Further, the system utilizes commonly available components as thermistors (NTC 3950 100k $\Omega$ ) to monitor the temperature. For tempering the tube system carbon fiber braided sleeving was fitted the into the silicon tubes. The braided sleeves were controlled as resistor heating elements such as FDM 3D printer use to heat the nozzle or heated bed. Flexibility, wear resistance as well as fast heating and cooling times are the main advantages of the carbon fiber sleeves.

## Summary

The aim of the presented ongoing work is to develop an open source 3D printer which provides different extrusion system for printing different biomaterials depending on the viscosity and substrate set criteria. The two extrusion systems are aimed to process high viscose substrates (e.g. Gelatin or hydrogel mixtures). The ink jet system is aimed to be utilized to print low viscose liquids or apply similar viscose additives onto prior printed surfaces. Currently, the ink jet as well as the screw extruder are in need to be further optimized to function properly. The project aims to provide an easy to modify system where researches can easily develop the tools needed and enables to try new methods to further push the field of bioprinting.

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