



# Laboratory 3D printing system

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## Abstract

Present work describes the results of the development of the universal system, which capable to utilize varies 3D printing methodologies. The main goal of the study is to provide cheap, versatile and easy expandable equipment for multiple purpose research in the field of material science. 3D printing system was experimentally validated for fused deposition modeling, hydrogel, liquid dispensing and drop-on-demand printing, as well as 3D photopolymerisation by UV laser and/or LED light using different types of materials.

**Keywords:** 3D Printer; Drop-On-Demand; Laboratory Equipment; Rapid Prototyping; Syringe Dispenser.

## 1. Introduction

For 30 years of its development, three-dimensional (3D) printing has gone a long way from the method of rapid prototyping to a full-fledged production process. Various 3D printing technologies has become an indispensable field in various fields from engineering and aviation to printing live fabrics. [1]

One of the significant limitations of expanding research in the field of 3D printing is the extremely high cost of installations, ranging from thousands to hundreds of thousands of dollars. Also commercial 3D printers quite space consuming, not much of them designed as on-the-table device. In addition, existing commercial samples, in most cases, do not fully correspond to the research tasks, because are intended for a single printing method and a given set of materials. On the other side cheap and simple home printers in mass focus on only one printing method - fused deposition modeling (FDM). In most of cases, such as inkjet printing [2-4], different kind of bioprinting [3-5], laser sintering [6], gel printing [7] or even FDM [8,9] research teams develop their own setup. In many respects, it is connected with the problems in adapting, modifying or expanding the functionality of 3D printers, whose design and software are proprietary of commercial companies.

Therefore, great interest is the work on the creation of open source laboratory multifunctional 3D-systems with a variable configuration. Requirements for laboratory 3D printers are fundamentally different from those for industrial or home systems. Instead of a large working volume of thousands and tens of thousands of cubic centimeters and printing speeds, compactness, versatility, and, most importantly, simplicity and openness of both the hardware and software platform come to the fore.

## 2. Universal 3D printer design

### 2.1 Requirements for the design of universal 3D printer

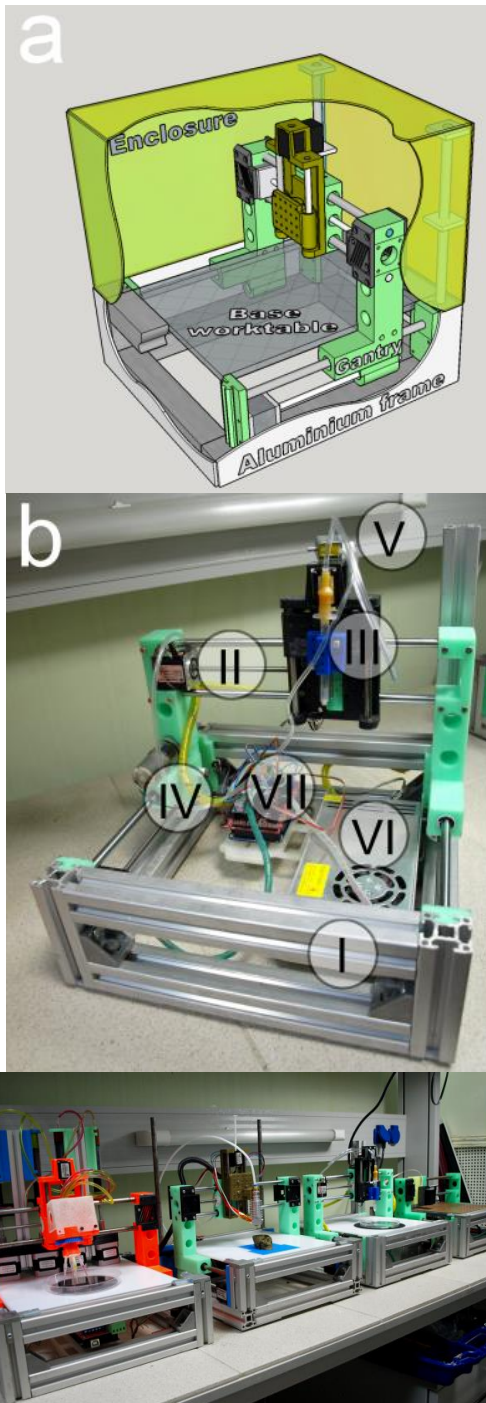
The main goal of this work was the development of a universal, low-cost laboratory 3D platform that can be easily reproduced and

expanded in accordance with the Open Source and PEP-RAP philosophies. As a basic concept of the installation was adopted a design with a fixed table and a system of three-axis moving removable printing devices for various purposes. To cover as many different materials as possible, the basic functionality of the unit included, in addition to the traditional FDM technology, multi-channel pneumatic extrusion and syringe systems for working with gels and viscous liquids, a thermoelectric drop-on-demand system for micro dosing of liquid materials in 2.5D mode and the same diode laser or fiber-optic laser for single-layer sintering or photopolymerisation.

### 2.2 Designing of 3D printer

The main attention during 3D printer designing was paid to the extensibility, compactness and simplicity of the design. Printer has a fixed table scheme, which is not common for compact 3D printers but allows using a liquid as a printing media. Outer dimension of 3D printer 30x30x30cm<sup>3</sup> (approx. 1x1x1 ft<sup>3</sup>). The scheme and photos of desined 3D printer shown on Figure1.

Mainframe made of aluminum extrusion 30x30mm<sup>2</sup> (1.2"x1.2"), which grants a rigid and stability for 3D printer it provides the ability to mount different additional parts of the construction. Upper cover of the frame serves as base for worktable for which could be used any necessary surface (textolite, silicone heater plate, glass, Petri dishes). Work area of 3D printer 140x140mm<sup>2</sup> and 80mm in height. The kinematics of the 3D printer based on a 3-axis portal scheme with a universal Z-axis fastening. It is made on cylindrical guides with a diameter of 10 mm with linear bearings. All mobile parts of the printer, except for linear guides, are made of plastic on an FDM printer with an accuracy of 0.2mm.



**Fig.1:** From concept to laboratory «workhorse». «a» - concept of printer; «b» – internal sight of pneumatic extrusion 3D printer; «c» – additive workbench (from left to right: 4 channel syringe dispensing system, FDM, pneumatic dispensing system and drop-on-demand system). On figure «b»: I – frame, II – stepper motors and guides, III – z-carriage with 1ml syringe, IV – micro compressor, V – 3 way pneumatic valve, VI – power unit, VII – Arduino MCU.

When designing the printer, special attention were paid to the design of the carriages, so that they could easily be made of light alloy on a conventional three-axis CNC-milling machine, without any modifications. To ensure precise movement, the XY axes are designed on NEMA 14 stepping motors (1.2A, 12N/cm) with integrated screw-nut shafts (4 threads, 5mm thread pitch), which allows for positioning accuracy of at least 50  $\mu\text{m}$ , while significantly cheaper and more compact than ballscrew transmissions. A 20 or 28 mm stepper motor with an integrated screw-nut shaft, depending on the print head, can represent the Z-axis, depending on the design. The electronics of the printer based on the most simple, repairable and well-documented platforms Arduino MEGA + RAMPS 1.4 or Arduino DUE + RAMPS FD. In addition,

these platforms are actively supported and developed by the REP-RAP community, which makes it much easier to work with them. In the basic version (FDM or single-channel printing), the 3D printer operates under the open source firmware Marlin V.1.1. For the use of multichannel printing or mixing nozzles, a modification of Marlin [10] was required, and for inkjet printing custom firmware was developed.

### 3. Print heads and dispensing system

#### 3.1 Fused deposition modelling

Base FDM module based on robust and simple E3D V5 hot end [11] for 1.75mm filament, combined with Bowden extruder. As extended version we prepare an open source screw extruder [12], slightly modified for best fitting to our design (Figure 2).



**Fig.2:** FDM printheads: standard E3D hot end for 1.75 polymer filament (a) and screw extruder for polymer powder (b).

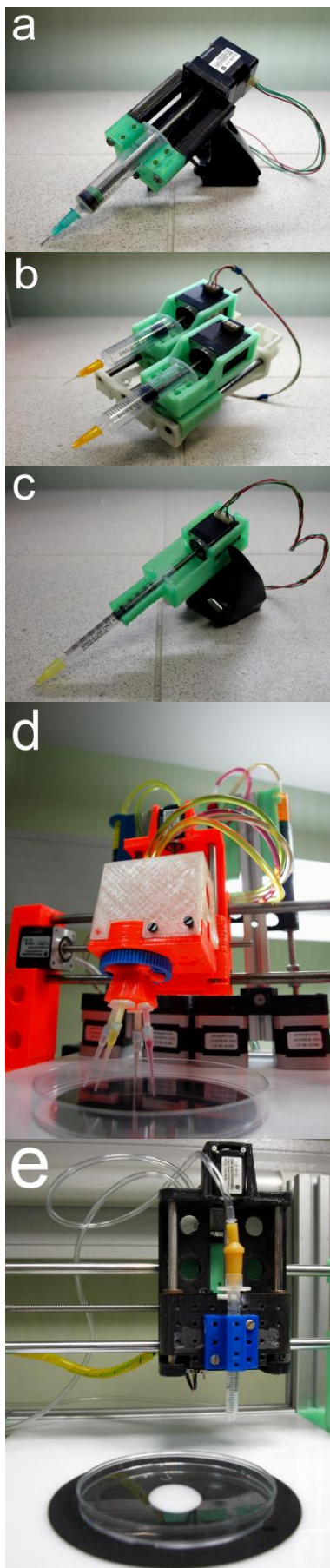
#### 3.2 Syringe dispensing system and Pneumatic dispensing system

Compact syringe dispensing system has completely new design and exists in four different versions:

1. main single channel syringe module with 5ml capacity and 4 kgf/cm<sup>2</sup> max pressure (Figure 3a),
2. dual syringe module with 2x5ml capacity and 1,5 kgf/cm<sup>2</sup> max pressure (Figure 3b),
3. precision single channel syringe module with 1ml capacity and 0,5 kgf/cm<sup>2</sup> max pressure (Figure 3c)
4. 4-channel revolver print head combined with two external dual syringe module with 2x10ml capacity and about 8 kgf/cm<sup>2</sup> max pressure (Figure 3d).

Pneumatic dispensing system (Figure 3e) consist of medical device microcompressor (max pressure 0.1MPa), electromagnetic

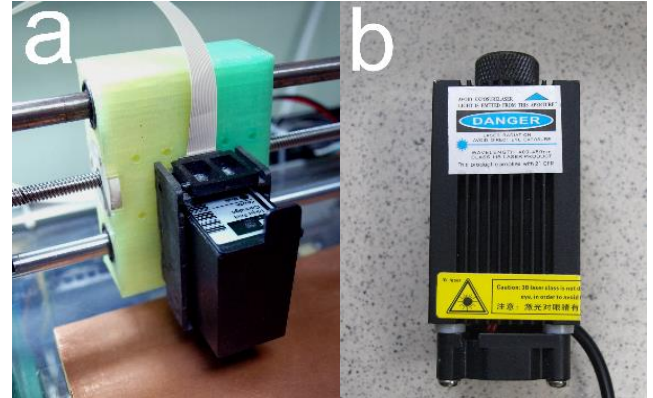
3-ways gas valve and 5mm PVC hosing. As a reservoir, any syringe with volume between 1 and 20 ml could be used.



**Fig.3:** Different types of liquid and gel dispensing module (see in text 2.3.2).

### 3.3 Drop-on-demand system and laser module

Drop-on-demand system (inkjet print head) based on well known, easy to control and reliable C6602 HP (Hewlett-Packard) thermoelectric nozzles cartridge (Figure 4a), which is well described and documented on PWDR open source project [13]. Print head driven by regulated voltage booster (output 12-32V) and two Darlington arrays controlled by main Arduino controller. As a coherent radiation source commercially available 5V 405-450nm laser diode module with measured power 320mW was used (Figure 4b). Module set in passive radiator and controlled by Arduino through MOSFET.



**Fig.4:** Hewlett-Packard C6602 thermoelectric nozzles cartridge (a) and laser radiation source with wavelength 405-450 nm (b) that was used in universal 3D printer during validation experiments.

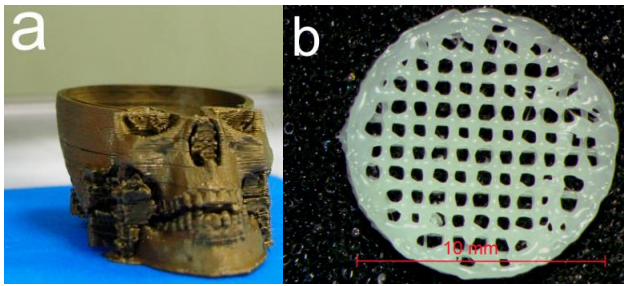
## 4. Validation performance of the developed system

Validation tests of the developed system were running under such conditions:

- all 3D prints ran on same 3D printer with no change in design between tests;
- the digital models was chosen to ensure comparison of the print result with the results of similar published works;
- firmware Marlin v.1.1 [10], excluding Drop-on-demand system tests where custom firmware was used; software Repetier-Host v.1.0.6 [14], excluding Drop-on-demand system tests where custom software were used;
- slicer software CURA Engine [15], excluding Drop-on-demand system tests where custom slicing software were used;
- all 3D printing experiments ran on room conditions ( $T=23^{\circ}\text{C}$ , humidity 40%).

### 4.1. FDM module validation

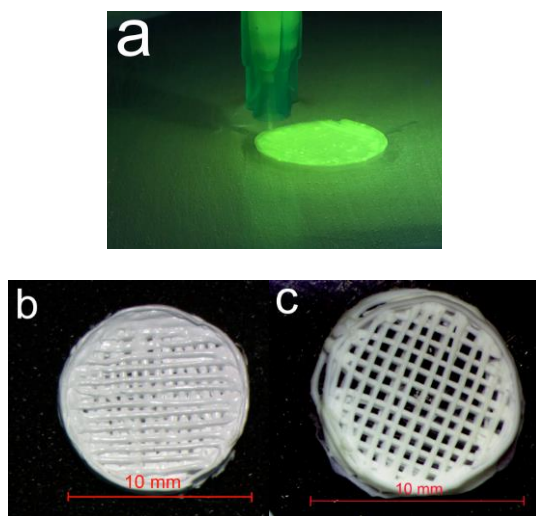
FDM module was tested on printing a complex model of human skull with 400mk brass nozzle and 200mkm layer height without support and infill. Commercially available bronze PLA (polylactic acid) filament was used as material as it provides good visualization. Screw extruder tested on printing disk with internal grids with 600mk brass nozzle and 250mk layer height. Specially synthesized poly- $\epsilon$ -caprolactone copolymer powder with low melting temperature ( $68^{\circ}\text{C}$ ) was used as a material for printing experiments [11]. As it shown on picture, 3D printer showed good print quality in both cases (Figure 5).



**Fig.5:** A result of test 3D printing test model with FDM technique. «a» - bronze PLA material, standard 1,75mm filament extruder; «b» - poly-ε-caprolactone copolymer material, screw extruder.

#### 4.2. Syringe dispensing module testing and Pneumatic dispensing system

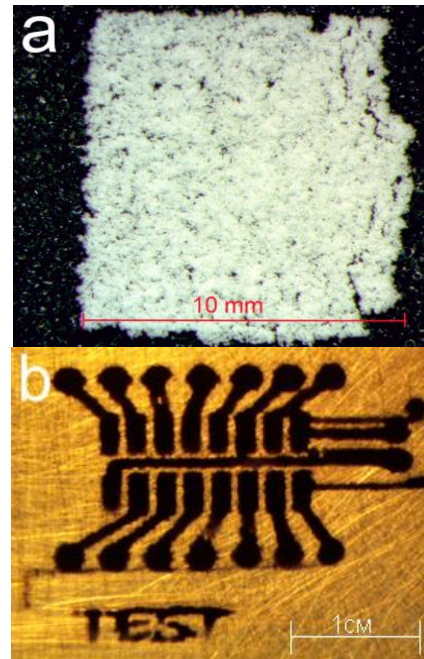
All dispensing module were tested in single channel mode. As a test, material PLA solution on tetraglycol, which has ability hardened in water, was used [16]. Each dispenser printed standard disk with grids infill through 200 mk stainless steel needle. The printing process with PLA-tetraglycol solution in water given on Figure 6a. For best visualization, a minor quantity of UV fluorescent was added. The printed objects in all case were nearly similar and looks like it shown on Figure 6b (syringe dispenser) and 6c (pneumatic dispenser). The printing result clearly shows that designed 3D printing system are capable to effectively work with viscosity liquid and provide printing in liquid media.



**Fig.6:** The printing process with PLA-tetraglycol-fluorescence solution in water (a). Sample obtained with syringe dispensing (b) and pneumatic dispensing (c).

#### 4.3. Drop-on-demand system

Drop-on-demand system was tested on two common tasks: bind a powder layer and ink plotting on the copper surface. As a testing material for binding experiments reaction hardening system includes tricalciumphosphate (powder) - phosphoric acid salt solution (binder) was used [17]. During printing process, a drop (~40pL) was shot every 100mk in tricalciumphosphate powder to form a single layer a square shape (Figure 7a). For inkjet surface plotting standard HP in was used without any additional copper surface treatment (Figure 7b).

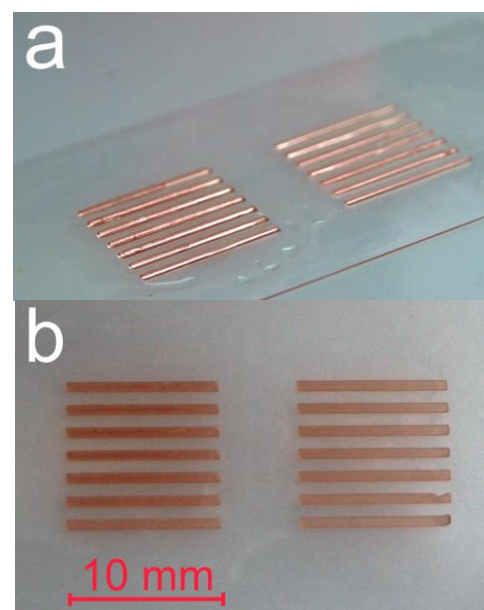


**Fig.7:** Sample obtained with Drop-on-demand system: chemically bonded tricalciumphosphate layer (a) and surface plotting copper surface (b).

Both result, the structure and the surface plotting, shows that the quality of inkjet printing enough to gain a 100mk resolution which is comparable with commercial 3D systems.

#### 4.4. Laser module

Photo curing system was tested on thin layer (~300mk) of photoresistive material (Fun To Do Standard Blend RED, Fun To Do, Netherlands) on glass substrate (Figure 8). The obtained samples resolution are around 500mk, which a not as good as on modern stereolithographic equipment but it mostly depends on coherent beam source. So it can be greatly improved if needed with installing high quality laser and optics.



**Fig.8:** Samples of laser cured photoresistive material, obtained on developed 3D printer with diode laser head.

## 5. Conclusion

As validation experiments show, all tested 3D printing technique including FDM with filament and powder material, viscous liquid and gel dispensing printing, thermoelectric Drop-on-demand and laser photocuring could be provided on developed universal 3D printer. With a cost less than 400\$, open architecture and a very short conversion time (not much then a few hours) to change printing method this machine could become a cost effective and versatile researcher instrument. Following of the Open source and REP RAP philosophy will allow scientists to take a full advantage of the potential of 3D technologies, adding a new experience to their development at the same time.

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