

Building Delta Style FDM 3D Printer

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Abstract

This paper deals with the topic of 3D printing. The primary aim was to build a real printer with a stiff construction minimizing clearance. The design of the 3D printer and its parts was highly influenced by the RepRap project, especially by the Rostock printer based on the delta kinematics, and Fused Deposition Modeling. The solution is formed using the Arduino Mega 2560 platform running Marlin firmware. Our printer uses a newly designed extruder that should prevent a filament from melting in a guide tubule due to a large heatsink. In order to evaluate the accuracy of the 3D printer, multiple tests were performed. The advantages and weaknesses of the modified design presented here can be very helpful for other people who may decide to build their own 3D printer.

Keywords: 3D printing — delta printer — Fused Deposition Modeling — Fused Filament Fabrication — RepRap

Supplementary Material: [Demonstration Video](#)

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1. Introduction

Regardless of how interesting the field of an additive manufacturing combining multiple disciplines is, owning a 3D printer provides many possibilities. It is then easy to obtain new, fully customized things no matter whether they are intended to be design accessories or replacements for some broken parts. According to the aim of RepRap project, a printing machine can be used to fabricate components for a new RepRap printer and thus help to spread the idea of self-replicating.

For the purpose of building a 3D printer, there is a need for many components including physical parts, electronics, host software and firmware. In order to create a single working complex, the selection of sufficient components, constrained by delta kinematics (see subsection 3.1), must be done. The solution requires mechanical and software calibration, that is why an evaluation done by measuring is a sufficient way

to discover properties of a result. Furthermore some aspects like quality of a surface, bridging and others require a visual inspection.

The base for this work is the *RepRap* project¹. The word “RepRap” is short for **replicating rapid-prototyper** [1] which nicely expresses the main idea established by Adrian Bowyer at University of Bath in 2005 [2]. Therefore RepRap is a desktop 3D printer able to replicate its parts made of plastic. Another advantage, making the project available to masses, is that it is open-source. The downside of this approach may be right in the usage of plastic due to its flexibility and lesser accuracy (e.g. when used as a cogwheel). Our own solution is not constructed of printed components. That is why it cannot be named RepRap, but RepStrap (from bootstrap) [3]. As is common in the project, our printer was designed to use Fused Filament Fabrication

¹The project’s web page can be found at <http://reprap.org/>

(FFF) technology (see subsection 2.3).

In particular the result differs from Rostock solution² in the chosen material — brass, dural, carbon instead of plastic — which should result in more rigid construction. It also includes an unique extruder, 24 V power supply instead of 12 V (because of stepper motors' torque) and active cooling preventing motors and their drivers from overheating. Common features are mainly delta kinematics, the base of a firmware and electronics and principles of extruder.

Due to his experience in mechanical engineering, modifications of physical parts and their fabrication were performed by Ladislav Mošner Sr. He was also responsible for construction of substantial parts of a physical construction. We both were finding proper components to buy. I was in charge of a physical construction minorly, but I made electronics' modifications and installation, raised firmware, performed its adjustment and made it communicate with the host software. As regards testing, I wrote a Python 3 script for semi-automatic precision experiments and carried them out.

2. Background

3D printing is a process during which physical three-dimensional objects are created according to a pattern in the form of a digital model [2]. Using additive techniques results in gradual fabrication and the final object is created layer by layer. The way of building new layers is highly affected by the selected technology and the raw material used [4].

2.1 From a digital pattern to its physical copy

3D printing is a process which must go through many stages. They are displayed in Figure 1. At the begin-

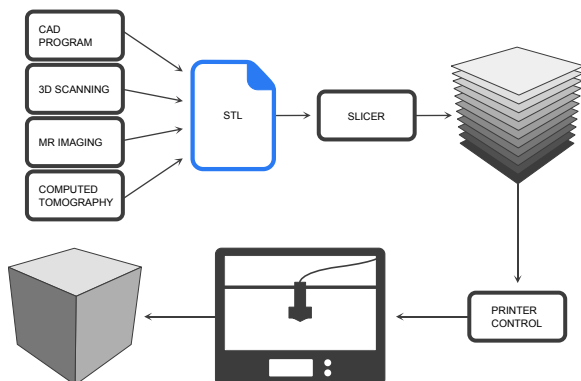


Figure 1. Phases of 3D printing process.

ning there is a need for obtaining a model. Often it is created with a CAD³ program, but there are other

²Rostock printer description: <http://reprap.org/wiki/Rostock>.

³Computer-aided design

possibilities such as magnetic resonance imaging, computed tomography or 3D scanning [4].

The model must be subsequently converted into a suitable format. For the purpose of 3D printing, an STL⁴ format is usually used [5].

Because an additive manufacturing approach is used, the representation of a model must be sliced horizontally. Thus the program responsible for performing this action is called a *licer*.

2.2 Basic technologies of 3D printing

According to [6], 3D printers can be divided into two families: *selective deposition printers* and *selective binding printers*. The first one is based on depositing raw material by squeezing or spraying liquid or powder through a kind of nozzle. Machines of the second group bind raw material with a laser or adhesive.

There are many processes of additive manufacturing [4] which can be classified under mentioned families. However, the only one that can be considered is described in the next subsection.

2.3 Fused Deposition Modeling

In case of RepRap project *Fused Deposition Modeling* (FDM) also referred to as *Fused Filament Fabrication*⁵ (FFF) is the technology which is used the most.

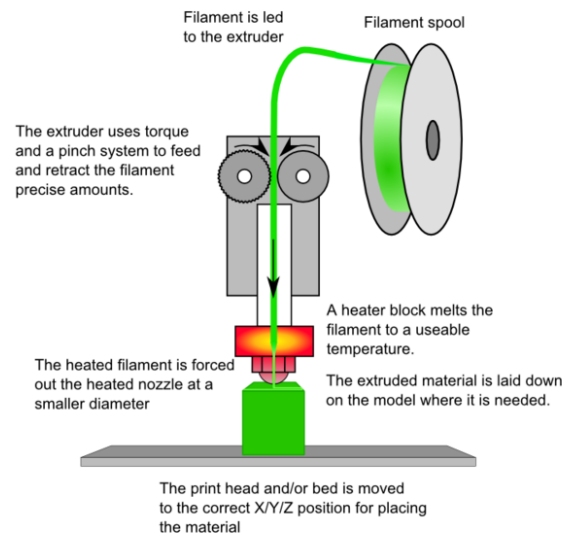


Figure 2. Principle of fused deposition modeling (fused filament fabrication). Reprinted from [7].

As is shown in Figure 2, the process is based on pushing a filament to a hot nozzle where it melts. In the form of liquid plastic, it is subsequently extruded

⁴Stereo lithography

⁵According to http://reprap.org/wiki/Fused_filament_fabrication the term FDM is trademarked by Stratasys Inc, whereas RepRap synonym FFF is legally unconstrained in its use.

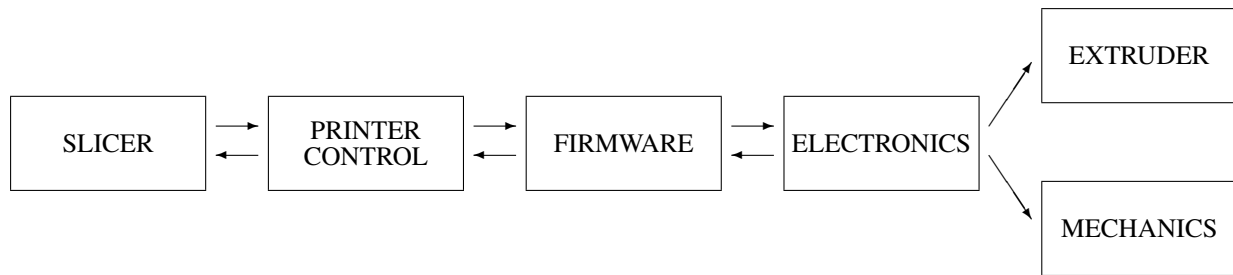


Figure 3. Chain of 3D printer's cooperating components.

and laid down to create a layer of an object. Movement of the nozzle in all directions causes gradual growth of a final printed part [4].

3. 3D printer design and component selection

FDM 3D printers can be divided into communicating components as it is displayed in Figure 3. In following paragraphs, an overview of solution of these particular parts is given.

3.1 3D printer mechanics

The first RepRap printers used Cartesian configuration, which is the most intuitive one. However, in the last few years, different constructions have been examined⁶. One of those is used due to its achievable high speeds — delta. This construction consists of three vertical linear guideways with shifting carriages (see Figure 4). The diagonal rods (green in picture) are connected with a kind of movable universal joints to carriages. They are attached to the end effector (gray triangle) the same way.

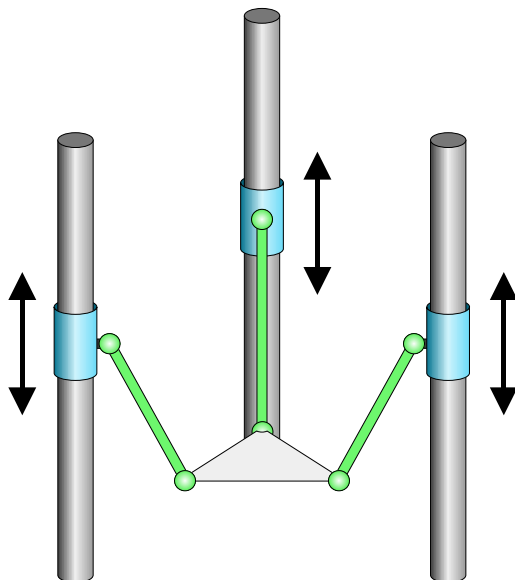


Figure 4. Movement principle of delta 3D printer.

⁶More about different mechanical solutions can be found at http://reprap.org/wiki/Category:Mechanical_arrangement

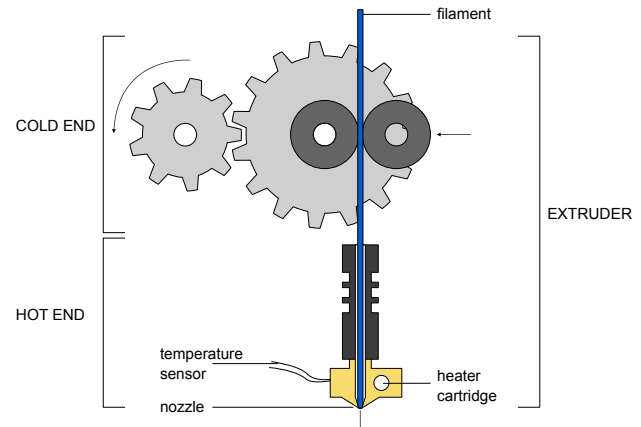


Figure 5. Root components of a print head mechanism.

3.2 3D printer extruder

An extruder is an element of a machine which is responsible for filament shifting — the cold end — and fusing it so that it can be squirt through a nozzle — the hot end. Those parts need to be insulated to stop heat transfer. All the components are depicted in Figure 5. For our own 3D printer a new extruder was created. As regards the hot end part, two heater cartridges were used because of 24 V power supply and for balanced heat spread, as well. The cold end component, which is connected right to the insulator was made of aluminium to prevent a filament from melting somewhere else than in the hot end due to metal's thermal conductivity.

3.3 3D printer electronics

For the purpose of the main processing unit, the *Arduino Mega 2560* including ATmega2560⁷ microcontroller was used. Attachment to a 24 V power supply and connection for other electronics is provided by *RepRap Arduino Mega Pololu Shield* known as RAMPS version 1.4 which plugs on top of the Arduino. The 3D printer is equipped with *NEMA 17* stepper motors that move carriages on smooth rods. Motor control is done by drivers based on *A4988 chips*. For making reference and avoiding crashes *opto end-*

⁷More about Arudino Mega 2560 can be found at <http://arduino.cc/en/Main/ArduinoBoardMega2560>

stops are used. It is intended to print with different sources of material in the future. For this purpose, the montage of a *heated bed* has been suggested. The advantage of a manual control will be achieved by display and knobs — *RepRapDiscount Full Graphic Smart Controller*.

3.4 Host software and 3D printer firmware

The instructions used for a printer control are called *G-code*. RapRap printers are based on RS274/NGC⁸ specification. A firmware is a piece of software running on a microcontroller and able to interpret G-code. According to instructions, appropriate signals are sent toward actuators and heaters. Furthermore, information from sensors (temperature, endstops) are processed. Because it was suggested to build a delta printer, firmware must support these kinematics. For this purpose the open-source *Marlin*⁹ program has been chosen.

Host software consists of two parts — a printer control and a slicer. The slicer is responsible for horizontal slicing given STL file and producing G-code. The printer control maintains connection with a 3D printer, sends instructions and receives responses. Usually GUI is provided for easier making of composition of objects on a print bed. In this case the machine will be controlled by closed-source (but freely distributable) *Repetier-Host V1.0.6*. The slicer can be launched right from this application. The popular *Slic3r* and *CuraEngine* are supported.

4. Realization of the 3D printer

During the realization process multiple changes of the design must have been done to make single parts cooperate. Some components, that Rostock does not include, were added, too.

4.1 Changes in construction

The construction was made of dural and brass parts replacing plastic ones. It resulted in heavier components. That is why counterweights for carriages were added to help stepper motors (see Figure 6). Proposed universal joints had to be replaced by ball joints to avoid one degree of freedom (see Figure 7). The reason for this change originates in possibilities of the firmware and its internal representation of a printer's geometry.

⁸Language and its interpreter description are at http://www.nist.gov/manuscript-publication-search.cfm?pub_id=823374

⁹<https://github.com/MarlinFirmware/Marlin/>



Figure 6. The principle of the counterweights' utilization.

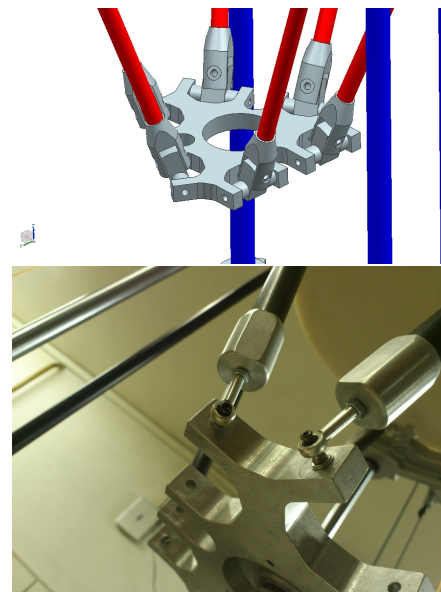


Figure 7. Proposed joints (upper figure) and finally used ones (lower figure).

4.2 Electronics' modification and additions

RAMPS 1.4 input voltage range is 12–35 VDC. It means that suggested 24 V power supply is suitable. However, RAMPS powers Arduino from its input, which accepts 6–20 V. To avoid damage, a link to Arduino's VIN pin was interrupted and different source was used.

For the purpose of a need for maintaining a certain bed's temperature, a current passing through the underlay is controlled by PWM via transistor. According to users' experience they may overheat and fuse terminal. This led to its substitution. A newly soldered transistor has three times as low as resistance between D and S electrodes.

Unlike Rostock, the printer includes fans, which

cool the stepper motors. The motor drivers have their own heat sinks but fans' breeze also dissipate heat from them to secure not reaching junction temperature. Three switches were added to the panel. Because of them a manual control over electrifying motors, fans and heating the underlying bed is provided.

4.3 Modifications of Marlin firmware

The firmware had to be changed to satisfy different needs which arise from construction and electronics. The basic change is connected to the chosen motherboard — RAMPS 1.4 — because different pins' mapping is required by different main boards. Also to ensure that the communication with a host software can work without problems, the baud rate must be set to the same value. Because more types of end stops are common, the firmware is equipped with a possibility to provide pull-up resistors. Because optical ones along with supporting electronics were used, pull-ups were disabled. For temperature measurement thermistors or thermocouples are the options. In this case thermistors were mounted and because there are many of them on the market with different properties, the table with values of AD converter corresponding to real temperatures had to be modified.

Another change of the firmware was connected to the geometry of the 3D printer. Because of the computational purpose of delta style kinematics, multiple values must be inserted. The first one means the distance between the printer's center and the smooth rod center. The next should correspond to length of the diagonal rod measured from one axis of rotation to the second one. The last two values ought to be consistent with offsets of ball joint's middle on the carriage and on the effector.

4.4 Parameters of the resulting printer

The height of the 3D printer is 105 cm, the radius of a circle passing through middles of the smooth rods is 260 mm. The distance between the nozzle tip in uppermost position and underlaying glass is 254.8 mm. A size of a printed object is limited by the heated bed the dimensions of which are 200 mm and 212 mm. So far experiments with speed of 30 mm/s for perimeters and 60 mm/s for infill were performed. The result of printing with PLA thermoplastic is depicted in Figure 8. For the purpose of a horizontal slicing, the Slic3r was used. The pyramid's dimensions are 25×25×25 mm. The height of one layer is 0.3 mm.

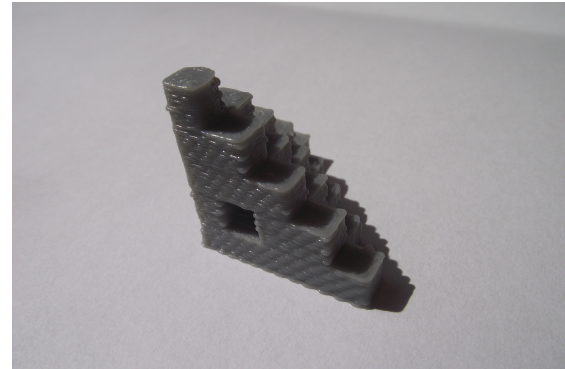


Figure 8. The pyramid printed of PLA.

5. Accuracy tests of the 3D printer

To determine accuracy properties of a new 3D printer, many tests were carried out. An indicator with graduation of 0.01 mm was used instead of a print head to measure distances.

5.1 Surface probing

The first test is about surface flatness of one layer. The measurement was performed by probing single points of 4 concentric circles divided into 16 parts on the underlay. Then the values were interpolated to depict deviation in certain places. The result is shown in Figure 9. In the picture there is a clear trend in Y axis.

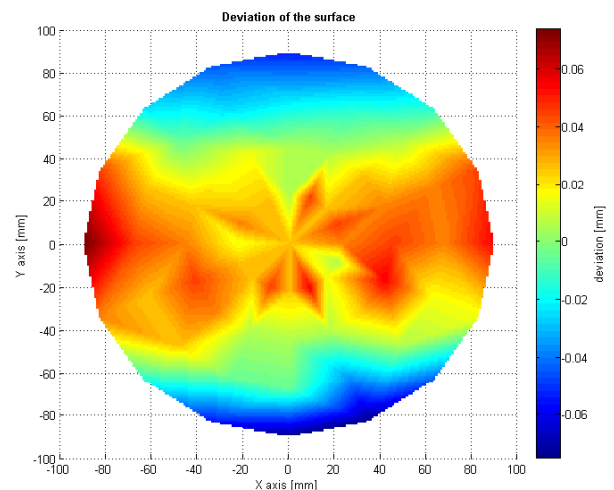


Figure 9. Surface flatness of one layer (Z position constant).

A subsequent test with bed rotated by 90° proved that the main deviation is caused by the bed itself. It means that the divergence which arises from the 3D printer mechanics is small enough to capture the roughness of glass underlay.

5.2 Straightness of a line

In the next test, it was intended to show the deviation of points theoretically in one line. In this case an indicator's probe was horizontally positioned and

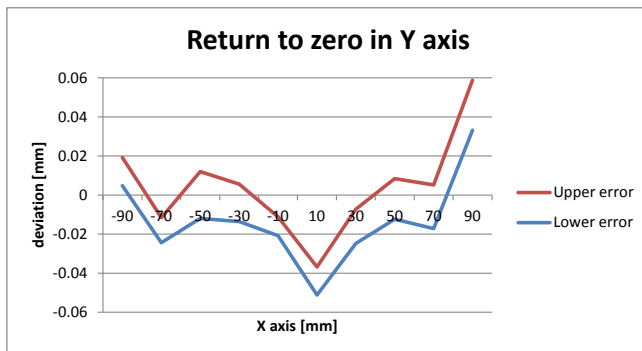


Figure 10. Result of the test when the printer should probe deviation of points in the line after performing certain G-code.

reference was created by the object parallel to X axis. That is why the measured deviation was determined from a value on Y axis. First of all, there were 50 probings to find out about straightness of the object and to determine observational error (reason for 2 curves in Figure 10). Then the test itself was performed. Between two measurements the printer accomplished the given G-code.

In the graph there are visible peaks on both ends of X axis, a low point around the middle and a wavy transfer between them. However, absolute values of the most significant points are lower than 0.06 millimeters. It means that no such mentionable deviation is caused by performing controlled movement between measurements. Nevertheless there is a certain trend with unknown reasons at the moment.

6. Conclusions

The main aim of the work related to this paper was to build an FDM delta 3D printer. In order to create a tougher construction, brass, dural and carbon were used. The 3D printer is equipped with a modified extruder. Some changes in electronics were performed due to power supply. Other components like fans or control elements were added.

The tests which were performed tended to find properties and accuracy aspects of a new solution. As regards flatness of the surface, the difference between the highest and the lowest point is 0.15 mm. As far as the line straightness is considered, 0.11 mm means the range of deviation. According to RepRap members, errors bigger than ± 0.1 mm most probably mean bad calibration. In both experiments the deviation hasn't climbed that high. The first test's error was highly influenced by the surface of the glass. Many firmwares have a feature to probe a bed leveling and accordingly change its behavior. This possibility could improve output of the first experiment.

This paper attempts to show that 3D printers are not suitable just for industrial use, but are affordable for ordinary people, too. It also supports the RepRap, because the included electronics and software are parts which are usually used by project's members. Hopefully there will be a day, when the 3D printer will print components for other ones.

Because new components were used, the result can become a pattern for the next printers. Nevertheless other tests and calibrations will take place so that the potential of construction could be fully utilized. For instance the reason for the line test trend will be explored. There is an assumption that FW internal geometry representation is not fully consistent with the real one.

Acknowledgments

I take this opportunity to express my sincere thanks to supervisor Ing. Michal Španěl, Ph.D. for his constructive advice, ideas and for his time.

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