**Building a 3D printer**

An Automatic Manufacturing Systems I. project

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Purpose and introduction:

3D printing is a relatively new technology as the first 3D printer was made in 1984. It developed in close relation with material science and electronics. Immensely high prices of the technology were pushed down by now as it became more widespread. There are 12 established ways of 3D printing. As of 2016 from edible chocolate through spaceship parts functioning and implanted human organs were printed. Some consider DNA printing also a 3D printing process. Despite these successes the technology still lacks several improvements and is in its infancy.

Requirements:

My main goal is to create a 3D printer, the outcome of a 3D printer development can be the combinations of nothing, destruction and printing. Most of all the parts that a 3D printer prints define the printer design. Lacking resources like high precision machining, time, hard to obtain and/or expensive materials DNA printing and spaceship parts are out of question. I set myself an easier achievement as a requirement for this project by intending to print out a plastic matchbox car that:

* Has to be structurally coherent.
* Accurate to its blueprint to a level of +/- 1 mm/cm axial tolerance.
* In two hour.

If these conditions are fulfilled then I have a “decent” printer. The measure of a 3D printer can be its accuracy, its speed, and the physical properties of the workpiece it can produce. These are a compound result of electronic solutions, mechanical accuracy, chemical reactions and external physical actions, so the goals set above are considered ambitious for a solo project.

Features:

My 3D printer will have a cartesian coordinate system axis set. Will be able to use 1,75 mm plastic filament as the printing material. Will print from a computer using a data connection. Will use a common CAM file format, and a common communications interface. Additionally it will have a detachable print head for the functionality of extension/conversion of the device to a CNC router machine in the future.

Functional description:

plastic filament

CAM file

3D

PRINTER

INPUT:

OUTPUT:

MY DEVICE:

The plastic filament is going to be of PLA (polylactic acid), a biodegradable thermoplastic said to have the scent of fresh baked waffles when heated to its melting point of 173 – 178 °C.

Figures of the setup/architecture:

X axis

Z axis

Y axis

plastic filament

filament holder

heated injector

heated bed

The basic conception:

Electrical and electronic block diagram:

CONTROL

CIRCUIT

G code

interpret-er

PC

CAD/

CAM

software

PSU

X axis

power

electronics

Y axis

power

electronics

Z axis

power

electronics

XYZ Axis end stop

sensors

Injector heater

pow. el.

Bed heater power electronics

X axis

stepper

motor

Y axis

stepper

motor

Z axis

stepper

motor

Injector heater

module

Bed heater

module

Injector heater

sensor

Bed heater

sensor

E-STOP

230V (AC)

5 V DC

12 V DC

230 V AC

230 V AC

DCOM1-5

SENS

0-2

DCOM0

PREG1-5

Implementation description:

The Hungarian market is not in favor of automatic manufacturing systems projects as the price driven approach of my fellow-countryman formed it to its present-day form with the background of no natural resources and week inland industry. Coupled with the illusion of the gentrification by the upsurging service sector we are cheerful receivers of import products. The sells usually don’t deal with so specialized needs and the machine shops only serve firms. So it’s obvious that international deals have to be managed to get most of parts required for success. The drawback of it is that there’s always a percentage of chance that the order will not arrive or will not arrive in time. Like it gets struck in a custom bureau or in the bottom of a container for months. The stated shipping time of [www.ebay.co.uk](http://www.ebay.co.uk) from United Kingdom to Hungary is 5-9 days. I expect some more days till the package gets from Budapest to Dunakeszi. Two weeks of shipping time is not negligible in a 3 month project.

As visible on the figure of the basic conception the build-up is cartesian. Other options were cylindrical, spherical and humanoid the problem with them is that they look straightforward and modern, they more challenging so they wouldn’t fit in my three months time interval. The problem is that if the joints are implemented with motors, the force acting on first motor that carries the weight of the others will be too large, also the swinging mass would be too large causing oscillations. Neglecting these oscillations would result in the robotic arm being more of a toy than a real robot. Oscillations could be eliminated by placing the motors by the first motor and transferring the force through drive shafts and pulley systems but this way the flexibility of the complex force transfer system would cause the nonlinearity and complicated custom mechanical parts would be required. Let’s observe that with the cartesian setup there’s supporting elements holding against the axial forces. While the mentioned other classical kinematic chains transform some of the forces into torsion and there is only support from one side in a form of a joint. The structure between the joints bend and/or oscillate as a result of this. These would result in the deflection of the manipulator which in this case would be the 3D printer head, the extruder. The longer the arm, larger the deflection would be. Staying with the simpler cartesian design, the algorithms behind movement is also simpler and more likely to fit in the three months of development and realization, as there are no rotations and redundancies.

The frame will be built mostly based on threaded rods as with nuts the location of the joining elements can be precisely set along the threaded rods this way accurate orthogonal structure can be built if before fixing the joints their position is measured and adjusted. Also posterior corrections are easier. The joints will be made of hardwood preferably treated, premade plastic joints and/or metal. Plastic joints and hardwood might not seem stable enough but they are easier to work with and if large enough bulk of them is used as a support they are solid. Degradation of wood is not also not a concern in three months interval, but treated wood is available too that infused with resins, antioxidants and antifungal hereby lasting for years. The good thing with a 3D printer is that when a printer is up and functioning new and possibly better version of its parts can be printed out with it.

As the widely available RC servo motors lack proper documentation in most of the cases and from second hand sources they lack precision too, suffer from an effect called servo jittering and usually have the maximum rotation angle of 180 degrees meaning they cannot turn around they are out of the question. Despite the fact that they would provide a closed loop control system out of the box which is more bulletproof as there’s feedback from the position of the motor and the also include a driving circuit. On financial grounds magnetic linear motors and piezo motors are out of reach for this project. There are also some concerns with the durability of piezo motors that the crystals might break after a certain amount of work time. Conventional DC motors would require a feedback and the number of poles and gear ration would define its angular accuracy, holding torque would be insufficient. Thankfully inexpensive well documented powerful and accurate stepper motors exist on the international market as everything nowadays they originate from China but they are available from European resellers too. The steppers motor are used from a long time to move the carriages of printers, as they provide large angular accuracy, angular repeatability, high holding torque and require only an open loop control system to operate. So these motors are my choice. A total five of them is required for the materialization of a smart and nowadays very popular build where on the horizontal plane there lies a moving work bed the workplace where printed parts adhere. The heated bed, the workplace moves on one axis because of space-saving and stability purposes. If the vertical support would move it would require more robust parts. The vertical and the other horizontal planar movement remains the same as on the basic conception figure.

The moving heated bed is to be brought to life with one stepper motor, linear bearings and one stepper motor mounted on the frame, and a pulley system between the motor and the carriage. The vertical axis has also a twist in it, or two to be precise two stepper motors are required that move two separate, parallel threaded rods. When they turn they raise or lower two carriages, that support the other horizontal plane axis. This is clever because using one stepper motor it would be difficult to synchronize the two sides, but with two stepper motors connected in parallel they are synchronized and they even synchronize each other electrically. If one is turned a voltage is induced on its connections then a current starts to flow that turns the other motor in sync with the other. Other advantage of it is that a threaded rod is more linear and ideal for holding weights vertically. One sided vertical axis where instead of two pillars only one would require one less motor but would also reduce the accuracy. The second horizontal plane axis is built with also one stepper motor and a pulley system just like the moving heat bed. The carriage of it carries the extruder that also requires a stepper motor to control the amount of filament introduced into the heated nozzle that melts the plastic. The heated nozzle and the heated bed needs temperature sensors.

The motors and the heaters need to be powered and controlled, this and it’s architecture is under research. But an Atmel microcontroller will be used with some power electronics and PC power supply. The communication will be possibly managed on RS232. The PC will run CAD, CAM software that is not made in this project and will send G code and control code, so the Atmel microcontroller has to decode them.

This whole setup is not unlike most of the Reprap machines. Reprap is an open source movement started in 2004 aiming to develop and spread 3D printers that can reproduce themselves.

Verification (test) against requirements:

These 3D printers are basically robots that manipulate objects in space. Their most crucial part is their linearity, if they have uncompensated flexibility in them it is easy to see that they will manipulate the objects inaccurately, in this case resulting in inaccurate 3D prints. Even with the largest care taken during the project there will be some inaccuracy left in the system. The role of the 3D printed part defines the tolerance of it. I estimate my 3D printer will be turn out decent enough and will have of +/- 1 mm/cm axial tolerance. For example when printing out a 1 cm x 1 cm x 1 cm cube the distance between the opposite faces can be minimum 9 mm and maximum 11 mm, when printing out a 1 cm x 1 cm x 1 cm cuboid, the extension of the object in the 3 cm orientation can be minimum 27 mm and maximum 33 mm. I will measure this with a caliper, compare it to the CAD file and document it.

Structural coherence will be tested by taking the model into the hand and visual inspection. If it stays in one piece it passes the test. A photo will be made from it for the documentation. This test looking to be childish at the first glance is very important because fused deposition of materials can result in the material being struck to the workspace, in this case the printer bed. Also improper layer deposition because of level mismatch and temperature errors can result in separation of layers. So there is a very high possibility that the print will not be staying in one piece.

The other factor is the time, which is by the 3D printers inversely proportional to the accuracy of printing. More complex prints can take days even with commercial machines. Time will be measured via a stopwatch and also to be documented. If time from the start of the print to the end of the print is less than two hours it is accounted as a pass.

Time plan:

My time plan is represented on the following Gantt chart where \* meaning milestones.

January:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| process/time: | 1-3. | 4-10. | 11-17. | 18-24. | 25-31. |
| Thinking on possible projects. |  |  |  |  |  |
| \*Sufficient amount of ideas collected |  |  |  |  | \*31. |

February:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| process/time: | 1-7. | 8-14. | 15-21. | 22-28. | 29. |
| Selecting the best project idea. |  |  |  |  |  |
| Best project idea selected and presented. |  |  | \*16. |  |  |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Preliminary mechanical and electronic conception, parts list. |  |  |  |  |  |
| \*First set of parts ordered (from internet). |  |  |  |  | \* |

March:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| process/time: | 1-6. | 7-13. | 14-20. | 21-27. | 28-31. |
| \*First set of parts bought (in local shops). | \*2,3 |  |  |  |  |
| Electronic design. |  |  |  |  |  |
| \*First set of online ordered parts acquired. |  |  | \*16. |  |  |
| \*Reordering, shopping non arrived parts. |  |  | \*17,18. |  |  |
| Mechanical building. |  |  |  |  |  |
| \*Completion of mechanical building. |  |  |  |  | \* |
| Stepper motor driver building, programming, testing. |  |  |  |  |  |
| \*Functional stepper motors. |  |  |  |  | \* |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Heater circuits building, programming, testing. |  |  |  |  |  |

April:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| process/time: | 1-3. | 4-10. | 11-17. | 18-24. | 25-30. |
| \*Functional heater modules. | \* |  |  |  |  |
| \*Receiving reordered parts. | \* |  |  |  |  |
| Main electronics assembly. |  |  |  |  |  |
| \*Preparing slide show. | \*2,3 |  |  |  |  |
| \*First demo. |  | \*5 |  |  |  |
| Writing control software. |  |  |  |  |  |
| \*USB communication. |  | \* |  |  |  |
| \*Working G code interpreter. |  |  | \* |  |  |
| \*PC CAD CAM compatibility. |  |  |  | \* |  |
| \*First print. |  |  |  |  | \* |
| Testing. |  |  |  |  |  |

May:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| process/time: | 1. | 2-8. | 9. |  | **∞** |
| Testing verification. |  |  |  |  |  |
| Preparing slideshow. |  |  |  |  |  |
| Presenting slide show. |  |  | \* |  |  |
| Lifecycle support. |  |  |  |  |  |

Budget plan:

|  |  |  |  |
| --- | --- | --- | --- |
| **Part** | **Quantity** | **Price (HUF) (total of n pieces)** | **Inland** |
| 3PCS 45Ncm Nema 17 Stepper Motor 2A 4-wire 1m Cable for DIY 3D Printer CNC Robot | 2 | 24420 | N |
| 3D printer joint pack | 1 | 12210 | N |
| cuboid hardwood 1m | 1 | 2000 | Y |
| hollow iron bars 1m | 3 | 2000 | Y |
| threaded rods 1m | 2 | 9000 | Y |
| Linear rods 1m | 3 | 9000 | Y |
| linear bearings | 15 | 9000 | N |
| extruder nozzle | 1 | 8500 | N |
| extruder mechanics | 1 | 5000 | N |
| screw, bolt, nut set | 1 | 6500 | N |
| screws, bolts, nuts | 1 | 4000 | Y |
| stepper motor bridges | 5 | 10000 | N? |
| voltage regulator/distributor | 1 | 10000 | N? |
| Atmel developer board | 1 | 10000 | N? |
| pc power supply | 1 | 7000 | Y |
| PCB heatbed | 1 | 2500 | N |
| raw PCB | 1 | 2500 | Y |
| temperature sensors | 2 | 6000 | N |
| 1 kg PLA filament | 1 | 8500 | N |
| 1 kg ABS filament | 1 | 8500 | N |
| timing belts and pulleys | 4 | 10000 | N |
| ball bearings | 4 | 3000 | N |
| wires |  | 5000 | Y |
| extra expenses |  | 10000 | N |
|  |  |  |  |
| **Total:** |  | **184630** |  |