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MULTI-MATERIAL 3D PRINTER EXTRUDER CONCEPT

Abstract: *Since the RepRap (Replicating rapid prototyper) project, FDM (Fused Deposition Modeling) 3D printing technology has come a long way. As the machine evolves so does the range of materials we can print with and the applications in which we can use them. 3D printers can create intricate objects with great precision, but most of them are limited to only one material. If a machine is capable of printing with a multitude of materials with different properties this opens new possibilities. There are some manufacturers who developed 3D printers that can print using more than one material, but each printer has advantages and disadvantages. In this paper, we will take a look at a new multi-material extruder concept. We also look at four different approaches of multi-material 3D printing and compare them with our new concept. Finally, we will look at applications for multi-material 3D printing.*

Key words: *3D printing; Additive manufacturing; Multi-material; layered manufacturing; CAD/CAM.*

INTRODUCTION

Developed in the late 1980's 3D printing produces a 3D model based on a digital file through an additive process. With the starting of the RepRap project the technology became known to the public and started to evolve.

3D printing holds the future of converting 3D models with complex structures and proprieties to their physical equivalent. It can change the way we innovate and materialize our ideas by allowing engineers and hobbyists to rapidly create and iterate their projects. This technology has the power to create previously impossible or very difficult and expensive to manufacture objects. Multi-material 3D printing is the next step in the development of additive manufacturing technology that will build our future and change our lives. It already has a huge range of applications and with every advance, new ones emerge inspiring future research and influencing the industrial market.

Currently, there are many research projects that use the potential of multi-material 3D printing. These research projects include the development of responsive, versatile smart components, 3D printable origami structures, prosthetics, actuators and sensors [1] and many others.

2. CONCEPT

The extruder is designed to be compatible with any 3D printer that has a similar design with the Prusa i3 model. The printer needs to have parallel X-axis guiding rods with a distance between their centre of 46 mm.

The extruder assembly has three 3D v6 Remote Hotends that are mounted on a spinning rod placed at a 70-degree angle from the build plate. The shaft is driven by a servomotor which is controlled by Raspberry Pi 3 SBC (Single-board computer) that has a camera module attached to it. The camera module is mounted under the assembly, as shown in figure 1, and it focuses the live printing head. When the extruder has to be changed, the camera memorizes the position by taking a photograph and stores it in its memory, then the servomotor spins the shaft in the direction of the desired extruder. In order to perfectly position the extruder the camera will send live images to the SBC for processing, using computer vision algorithms to determine when the position matches perfectly with the position of the previous extruder.

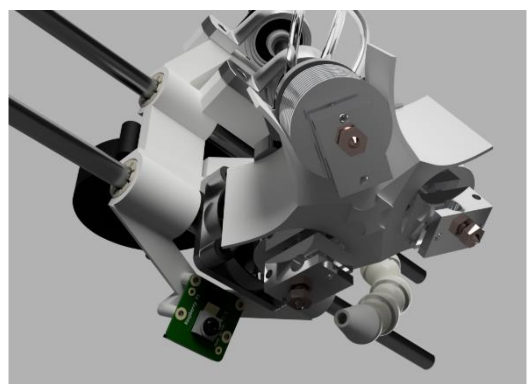


Fig. 1 Camera module.

The camera module can be used not only for determining the position of the extruder, but also for calibration and print quality analysis. Before every print, the printer can perform a calibration sequence outside the print area in order to determine the number of steps each stepper motor should make for a certain distance in the X and Y direction. The distance is measured using a checkerboard pattern, as shown in figure 2, stuck on the calibration surface. Also, it can analyze the deposited material and adjust the extrusion multiplier to get the optimal extrusion speed ratio.

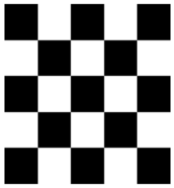
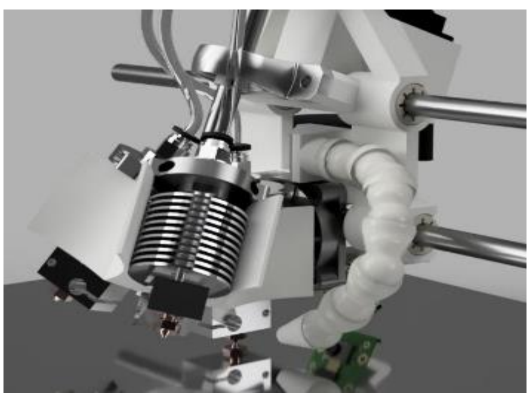
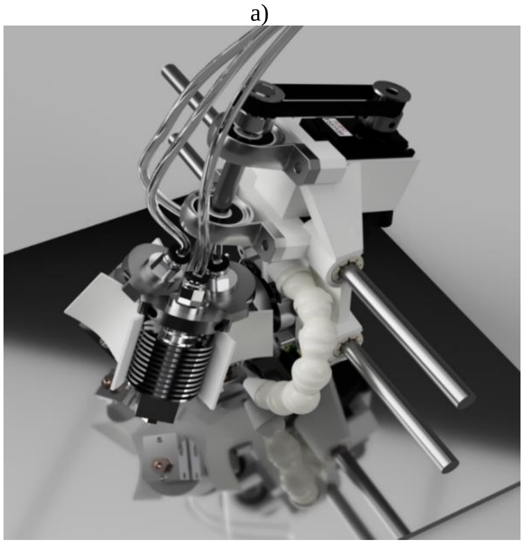


Fig. 2 Checkerboard pattern.

The filament is fed to the extruder using a bowden tube extrusion system. Each material has its own independent tube and the stepper motors are controlled using the SBC. In order to diminish the number of cooling fans, all three hotends are cooled using a single 40 mm fan mounted as close as possible to the cold-end of the live extruder. The other two extruders are on standby and the heating elements are turned off until one has to go live. After a hotend swap, the changed hotend must be cooled off in order to avoid the degradation of the filament. Because we are using a single fan, we have to cool both the idle and the active extruders by directing the air flow through a series of air channels, shown in figure 1.



a)



b)

Fig. 3 a - Flexible cooling tube b - Full assembly.

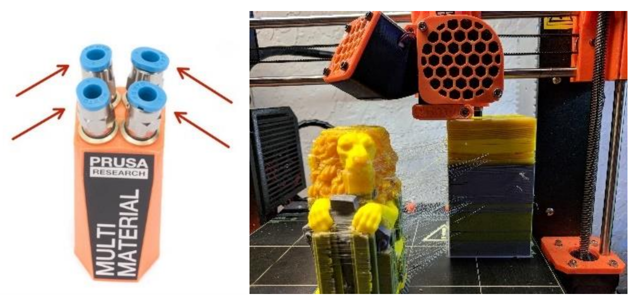
In order to cool the extruded material a turbofan is used and the air flow is directed through a flexible tube, figure 3a. The tube is ideal because its structure is flexible so it will not stay in the extruders way when it rotates, also if something goes wrong the fan duct will not be able to move the printed object from the build plate.

3. OTHER MULTI-MATERIAL EXTRUDERS

3.1 Prusa I3 Multi-material

The Prusa i3 was part of the RepRap project and is an open-source fused deposit 3D printer. It was designed by Josef Průša in 2012 and is now the most used commercially available 3D printer. Being an open-source project, the printer has many variations produced. In September 2017 Prusa released their latest model Prusa i3 MK3 and with it, they announced a new multi-material upgrade for their 3D printers. This system is the second iteration of the MM (multi-material) upgrade and since at the time of writing this article the new upgrade is still in development we will analyze the first version.

The Prusa i3 multi-material upgrade 1.0 is capable of printing with up to four different materials extruded through a single hotend. Each filament is fed using a bowden system and the material intersects at the Y splitter, shown in figure 4a. When the filament has to be changed a stepper motor retracts the filament from the hotend until it reaches the Y splitter and then the filament is moved back and forth slightly as it solidifies and takes on the diameter of the steel-plated tube, then the new filament is fed through the splitter to the hotend.



a) b)

Fig 4. a - Y-splitter and b - Purge block.

The process is simple but it has some disadvantages one of them is the possibility of clogging the splitter and the other is the need of priming the nozzle after each filament swap. The priming is done on the build plate with a purge block which is next to the printed object. A purge block is a solid block of extruded material, as shown in figure 4b, and it has the same hight as the printed object and the width and length are calculated based on the number of filament changes on each layer. On large prints and detailed four materials prints, the block has a higher weight than the printed object and it is a waste of material and printing area on the build platform.

3.2 Palette

Mosaic Palette is a 3D printer upgrade that can change every printer into a multi-material 3D printer. It started as a Kickstarter campaign and now some 3D printer manufacturers want to implement a similar technology for their printers.

The Palette is a filament joiner, it can process up to four different materials with the same printing temperature and sends to the extruder a single multicolour, multi-material filament. It reads the file that is loaded in the 3D printer and then calculates the length of each individual filament needed on every layer. In order to have a continuous string of filament, it measures the length of the extruded filament and when it has enough, let's say green filament, and the next colour is blue, it cuts the loaded filament then feeds the next one and fuses them together. This device can transform any 3D printer in a multi-material one, but it can not print without a purge block. In figure 5, we can see the main components of the Palette.

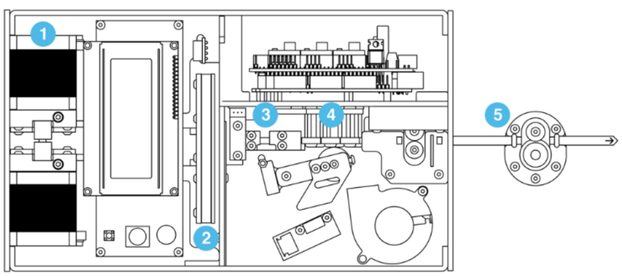


Fig 5. Palette components:
1 – stepper motors that push the filament; 2 – cutter wheel that cuts the filament; 3 - hitting tube where the two filament fuse; 4 – guiding wheels used for keeping the filament strait while it cools off; 5 – scroll wheel measuring device which measures the length of printed filament

The 3D printer doesn't always print the length of filament they were supposed to so the Palette has a feedback system that measures the length of the filament being printed and adjusts accordingly.

3.3 Diamond Hotend

This hotend has a unique design and is capable of printing with three different coloured filaments. It was designed to minimise the waste of material and it's able to obtain any colour (hue) by combining cyan, magenta and yellow. The colours are mixed in a small mixing chamber which also helps minimise waste and allows for a fast colour shift. An example of colours obtained with this hotend is shown in figure 6.

Fig 6. Colours obtained using the Diamond hotend.

The nozzle has a diamond shape and three threaded mounting holes for E3D v6 series cold-end that are cooled using a 50 mm fan with an air guide system for efficient cooling. An assembly of the extruder without the air guide is shown in figure 7.

This extruder is easy to calibrate and can be mounted on any 3D printer because of community made mounting mechanisms that allow this particular extruder to be mounted on most DIY (Do It Yourself) and commercially available 3D printers. The major flaw of this extruder is the fact that it's only able to print in three different colours of the same material at a time, making this more of a multi-colour 3D printer extruder than a multi-material one.

Fig 7. Diamond extruder.

3.4 Ultimaker 3

Ultimaker 3 is a 3D printer equipped with two changeable extruders, shown in figure 8, that print one at a time, each one is loaded with a different filament. This approach removes the need for a purge block and greatly reduces the waste of materials but the downside is that it can only print with two materials. A nice feature of this printer is the possibility of swapping the nozzles and they even have a specially designed nozzle for PVA (Polyvinyl Alcohol) which is a dissolvable material.

Fig 8. Ultimaker 3 extruders.

4. COMPARISON

In order to compare our concept extruder with the other four presented extruders, we used an impact matrix with five analysis criteria rated from zero to four. The criteria used are: materials – how many different materials can be printed (one meaning one material and four meaning four materials), nozzles – how many extrusion nozzles does the extruder have (four if it has one nozzle and one for four nozzles) , purge block – how much material is lost in the priming procedure (four if no material is lost and one if the purge block can be heavier then the print), dripping – for multiple nozzles extruders the unused extruder tends to drip material over the print (four if there is no dripping and one for severe dripping). The results are shown in table 1.

Table 1

Impact matrix

Criterias	Concept	Prusa i3 MMU	Palette	Diamond	Ultimaker
Materials	3	4	4	2	2
Nozzles	1	4	4	4	2
Purge block	4	1	3	4	4
Dripping	4	4	4	4	3
Total	12	13	15	14	11

From our table, we can see that the concept extruder is between the Prusa i3 and Ultimaker which are on the top of the market. The Palette scores the most but it is an alternative solution for multi-material 3D printing and the Diamond hotend is second but it can only print with one material at a time.

5. APPLICATIONS

Traditional manufacturing is optimized for mass production and comparing it with additive manufacturing it requires numerous complex steps and many specially engineered machines in order to obtain a product. 3D printing, on the other hand, has the potential of producing functional products using a single machine capable of obtaining more intricate structures and using all the required materials, all of this with a minimum material loss.

Research for multi-material application has been made and the fields in which the technology can be applied are numerous such as medicine [2] [3], military, architecture, inter-planetary travel and aviation and many others.

In the medical field, research has been done in order to use 3D printers to manufacture prosthetic limbs that are cheap to make and easy to manufacture. Using a 3D scanner the lower residual limb is scanned then the socket is designed and pressure analysed until the best socket shape is achieved. The result is a socket made of two different materials, one for the load zone and the other for the rest of it. Hand prosthetics are also easily designed and can even be done by people at home using their own 3D printers.

Multi-material 3D printing can be used in the design of mechanical components. These components can have different proprieties obtained by using different materials in the structure. One example is the self-folding origami elements inspired by the wing structure of an earwig. When an earwig opens its wings they can stay open with little to no muscular power needed, however when they are folded they take little to no space. Potential applications for the self-folding origami elements are foldable electronics and solar sails for space travel [4].

6. CONCLUSIONS

Multi-material 3D printing has the downside of using extra material in the purge block and the design of this extruder started with this in mind. We believe that this new design will greatly reduce the purge block dimensions or even completely eliminate the need for a purge block.

3D printing is not new technology, but right now it's growing faster than ever. Today's FDM (Fused Deposit Modeling) printers are starting to reach their mechanical capabilities and hardware potential, the next step in the evolution of 3D printing is making them smart in terms of user interface and software. This extruder concept tries to connect the hardware and software using "computer vision" and by doing so it can make the user interface a lot more easy to use because of its capability to analyze the deposited material and make corrections during a print. It is a concept and we are working on a prototype so we can test the reliability of the system.

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