

# 3D Printed Hair: Fused Deposition Modeling of Soft Strands, Fibers and Bristles

Gierad Laput   Xiang ‘Anthony’ Chen   Chris Harrison  
Carnegie Mellon University, Human-Computer Interaction Institute  
5000 Forbes Avenue, Pittsburgh, PA 15213  
{gierad.laput, xiangchen, chris.harrison}@cs.cmu.edu

## ABSTRACT

We introduce a technique for *fur*bricating 3D printed hair, fibers and bristles, by exploiting the stringing phenomena inherent in 3D printers using fused deposition modeling. Our approach offers a range of design parameters for controlling the properties of single strands and also of hair bundles. We further detail a list of post-processing techniques for refining the behavior and appearance of printed strands. We provide several examples of output, demonstrating the immediate feasibility of our approach using a low cost, commodity printer. Overall, this technique extends the capabilities of 3D printing in a new and interesting way, without requiring any new hardware.

## Author Keywords

Computer Aided Design; CAD; Fabrication; Additive Manufacturing; Plastic; Extrusion; 3D Modeling.

## ACM Classification Keywords

H.5.m. [Information interfaces and presentation]: Misc.

## INTRODUCTION

Advances in additive manufacturing techniques, e.g., 3D printing, have made it possible for people to accurately and relatively cheaply fabricate objects with unprecedented levels of flexibility and customization. Recent and continued developments in 3D printing have dramatically reduced deployment costs, making it more accessible to novices, hobbyists and people outside of professional communities.

Conventional additive manufacturing techniques are designed to print models with precise form and rigid material properties, which limits the scope of objects that can be modeled. Professional-grade setups are often capable of mixed-material printing (e.g., the Objet Connex can print objects with silicone flexibility), though these machines are expensive (typically tens of thousands of dollars, excluding materials). Recent work in the HCI domain has explored the

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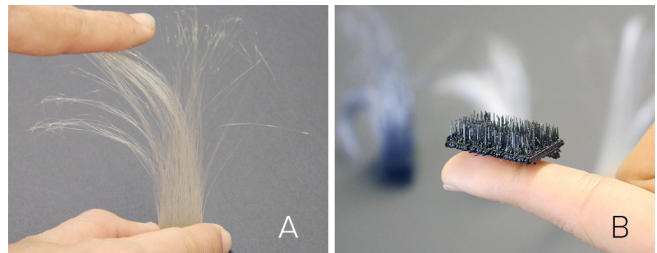


Figure 1. Fine flowing hair (A). Short and stiff bristles (B).

use of fabrics for printing soft and non-rigid objects [6,14], but these efforts required custom, special-purpose printers.

In this work, we introduce a technique for 3D printing soft strands, fibers, and bristles (Figure 1), using conventional fused deposition modeling (FDM). Our work was inspired by the peculiar phenomenon that occurs during the operation of a handheld glue gun: when a person extrudes hot glue material and moves the gun away, a “string” of residue often forms unintentionally (Figure 2). The shape, length, and thickness of the resulting stringy material varies based on how much glue was extruded and how fast the user moves away from the extrusion point. This artifact often annoys users, but in this work, we exploit the phenomenon.

The operating principles of a glue gun are similar to FDM-based techniques. By emulating the stringing behavior using FDM printers (which happen to be the most affordable class of 3D printers in the market today), users can easily add strands of hair, fiber and bristle to their 3D printed models as easily as a material property selection.

Our technique is straightforward and easy to integrate with existing 3D printing workflows. Users can specify regions of their model where they want to incorporate hair, and our approach automatically generates the machine instructions (i.e., G-code). Moreover, users can easily specify parameters, including length, thickness and hair density. By using different filaments, hair color can be controlled as well. Our work makes the following contributions:

- A technique for fabricating soft hair strands, fibers, and bristles using fused deposition modeling;
- A set of design parameters for controlling properties of single strands and/or hair bundles;
- A set of post-processing techniques for refining the behavior and appearance of printed strands; and



Figure 2. Our work was inspired by the “stringing” phenomenon that happens when operating a hot glue gun.

- An illustrative set of example printed output that demonstrates how our technique can incorporate printed hair into existing 3D printer output.

## RELATED WORK

Our work spans several areas, including hair synthesis, 3D graphics and fabrication. We now discuss key related work.

### Fiber Bridging

Fiber bridging, which extrudes “bridges” of material across gapped endpoints, has been demonstrated in the maker community [1,8]. With sufficient density, the bridges form into bundles of fibers. The technique is chiefly aimed at bridging points in a model without support material, and is not intended to create true strands. In our experiences, the bridged material is fairly rigid (more bristle-like than hair-like). Moreover, to produce strands with a single terminus, one of the support bridges must be cut off; if using a tool such as scissors, the fiber ends are flat. Conversely, our technique creates *fine* to *coarse* strands with *tapered* ends.

### Industrial Techniques

Several industrial techniques exist for incorporating hair and bristles into everyday products. For example, strands of synthetic nylon can be inserted into injection-molded plastic models, where they fuse with molten material in the cavity [3]. Similarly, bundles of fibers can be mechanically sutured into e.g., brush blocks [5]. Most toupées and wigs are fashioned using a clever combination of real hair and synthetic material. These need precise measurements from a professional wig master, in addition to the laborious hours required to manually knit thousands of hair strands [16]. In general, fiber insertion is usually a finishing step in the manufacturing process, and requires special-purpose machines and tools.

### 3D Rendering

Hair in the digital domain has primarily been focused on hair generation and rendering in virtual environments [17], especially in the gaming and film industries. There have been efforts to better digitize real hair, e.g., early work in the 1990s enabled hair reconstruction from multiple still images [7]. Recent advances in photo-realistic hair reconstruction [13] has enabled e.g., 3D self-portraits [10] where different hairstyles can be previewed. Recent work by Echevarria et al. [4] demonstrated how to capture a person’s hairstyle and 3D print it into a photo-realistic figurine. Im-

portantly, the work focused on modeling general contour, coloration and shading, without any actual strands of hair.

## HCI & Fabrication

Finally, our work also intersects with recent efforts to expand the capability of fabrication technologies through an HCI lens. For example, LaserOrigami [12] extended traditional laser cutting by introducing a melting and bending capability, enabling non-planar outputs. In a similar vein, WirePrint [11] enables low-fi fabrication by approximating the structures of objects using printed wire meshes. Lastly, there have also been efforts to create novel 3D printers, for example with felting needles [6] and layered fabric [14].

## 3D PRINTED HAIR

We now describe the basic techniques for printing hair using an unmodified FDM printer. We used a desktop FDM printer assembled from the Printbot’s Simple Maker’s Kit [15], which costs roughly \$350. We used Repetier Host (repetier.com) to simulate the printing process, which was invaluable for rapidly iterating design parameters. Finally, our setup uses Polylactic Acid (PLA) filament, a popular print material. Of course, other material types can be used (e.g., ABS). The steps here serve as a baseline.

### Growing Hair: Extrude and Draw

The basic approach for simulating hair with FDM printers is to extrude tiny bits of plastic material and then immediately and quickly move the extruder away. This creates the “string” effect, “drawing” hair that extends across the direction of travel. This process can be customized programmatically in g-code. For example, the following snippet extrudes 5 units of material at a feed rate of 2000 (i.e., 5mm at 33mm/s), and then shifts the extruder away to  $y=60$ :

```
G1 X30 Y30 ; move to extrusion point
G1 E5 F2000 ; extrude
G1 Y60 ; draw hair
```

This process can be programmatically repeated to generate multiple threads of hair. There are several controllable parameters for this process.

**Extrusion Amount and Feed Rate**—We experimented with a range of extruding amounts: if the printer is extruding too little material, the hair tends to break early when drawn; when extruding too much, the residual material will “clog” the extrude point, affecting its surrounding appearance, or even causing occlusion problems. Additionally, the amount of filament extruded and the speed at which the extruder head moves away both affect the resulting hair. Typically, extrusion feed rate should be slow. In our experiments, an extrusion feed rate of 500<sup>1</sup> units for a drawing distance of 50 units achieved the best results (50mm at 8.3mm/s).

**Drawing Distance**—The travel distance of the printer head after extrusion limits the length of hairs that can be drawn.

<sup>1</sup> In G-code, the convention is to describe feed rate as units per minute.

It also limits the range of the hair thicknesses that can be achieved. More specifically, as the extruder moves away, the extruded material first deforms to a hard and thick strand. As the drawing continues, there is less and less material left at the extrusion head, pulling the thread increasingly thinner, and thus more pliable.

**Drawing Speed**—In our experiments, we found that it is critical to control how fast the extruder moves: when drawing too slow, the material tends to droop and harden, failing to form a hair-like thread; if it is drawn too fast, the strand tends to break prematurely. For FDM printers, drawing speed can be pre-set or programmatically customized via interpolation (the more interpolated points, the slower the movement, which can cause hair discontinuities).

### Cutting Hair: Pulling, Retracting and Scraping

When generating multiple strands of hair, it is important to terminate the previous strand before extruding the next one. Otherwise the strand may loop back to the model, leading to entanglement and otherwise intractable printing geometries. We explored three techniques for “hair cutting”.

**Pulling**—As the extruder moves away from the initial extrude point, the strand will become too thin and eventually breaks. Therefore, one straightforward method for cutting hair is to move the extruder sufficiently far that strands naturally terminate. In our exploration, we developed a ‘go around’ technique: the extruder first draws the hair along a straight line, and after reaching a target distance (e.g., Y60), follows a rectangular path to return to the starting point.

```
G1 X50 Y10 ; starting point
G1 E10 F2000 ; extrude
G1 Y60 ; draw
G1 X10 ; 1st turn
G1 Y10 ; 2nd turn
G1 X50 ; back to starting point
```

However, this additional travel distance increases print time. Moreover, 3D printers often have small print beds, limiting maximum travel. In response, we combine pulling with two additional methods.

**Retracting**—A simple trick is to retract material, by reversing the filament in the extruder. Retraction works well when the strand is still in contact with not-yet-extruded material in the print head. However, there are also instances where the strand has already detached, and is simply sticking to the extruder itself (e.g., the cavity wall), and in this

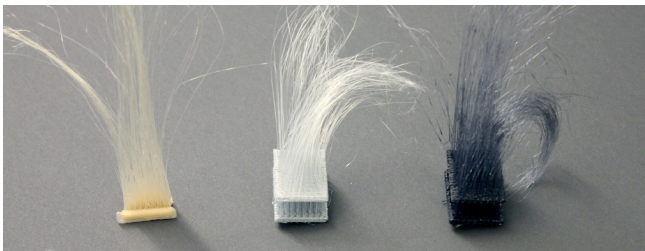


Figure 3. Different filaments can be used to control hair color.

case retraction will have no effect. To address this case, we considered a third approach.

**Scraping**—In addition to pulling and retracting, printed hair can also be cut through scraping. To detach strands from the extruder, we simply scrub off excess material using a surface on the printed model or a sacrificial auxiliary platform. If the latter is 3D printed, we can make the platform the same height as the strands, allowing the extruder to pass directly over the platform in single print-and-scrub pass.

### Printing Dense Hair and Avoiding Collisions

We print hair horizontally (parallel with the print bed) and in a linear fashion. At a single Z-height, strand density is limited by the radius of the extrusion head (which is hot, and will detach or warp existing strands if touched). With our setup, the lower bound was a strand spacing of 0.2mm. However, we can increase density (and avoid strand collisions) by taking advantage of the Z-axis. Specifically, we interlace (i.e., stagger) strand extrusion points for each successive layer, similar to how brick walls are constructed. This configuration is adjustable via a “distribution” parameter. Of course, other patterns are possible. Additionally, it is important to note that because these strands are so thin after they are drawn out, they harden quickly, such that when they detach and lay flat, they do not fuse to other strands.

### PRINTING DESIGN SPACE

Collectively, all of the aforementioned parameters lead to various styles of hair. The properties of printed hair can be varied per strand, or as a collection of strands. In this section, we discuss them in more detail.

**Hair Length**—Once material is extruded at a designated point on the model, the extruder moves away and a string of hair is created, with its length directly coupled to the extruder’s *travel distance*. The maximum length of strands is thus set by the size of the print bed. Our printer had a 100 x 100mm bed, limiting our hair length to approximately 80mm. Shorter hair can be created either by adjusting the drawing distance or via post-processing (see next section).

**Hair Thickness**—The thickness of a hair strand is controlled by the *extrusion amount*, *feed rate*, and *drawing speed*. Slower feed rates with more extrusion material create thicker strands (bristle-like). Conversely, faster drawing speeds with less material produce thin, fine strands. For example, the hair patch shown in Figure 1A was printed at a drawing speed of 7800 units (~130mm/s) while extruding five units of material at a feed rate of 500 units (8.3mm/s).

**Color**—Hair color is trivially controlled by using different source filament colors (Figure 3).

**Hair Density**—Hair density is controlled by varying the distance between consecutive printed hairs. Printing tightly packed hair strands creates dense patches, while strands printed farther apart will appear sparse. This density can be controlled in X, Y and Z axes for different effects.

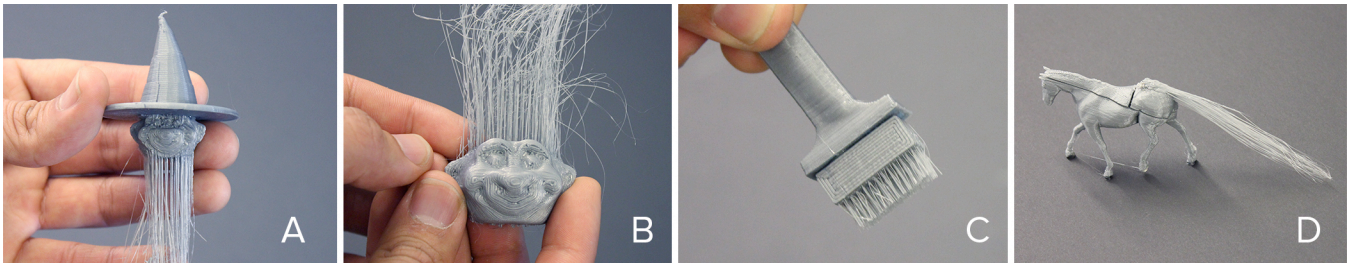


Figure 4. Example printed output with different design parameters and effects: wizard (A), troll (B), brush (C) and horse (D).

**Hair Distribution**—The distribution of hair root positions can be *interleaved*, *random* or *uniformed*. Adjusting these parameters creates varied hair layouts. For example, randomizing root positions at each layer creates more natural looking hair. Conversely, in certain cases, more structured root positions are desirable (e.g., toothbrush bristles).

**Hair Flow**—Finally, hair flow describes the geometry of how hair extends outwards from a surface. In most of our experiments, we print hair extending at a uniform distance and angle (i.e.,  $180^\circ$  or  $90^\circ$  relative to the x-y axis). Variations in hair flow can be achieved by adjusting the travel direction of the extruder as it moves away. For example, it is possible to create, e.g., a “Mohawk” by drawing stands away orthogonally from a curved model’s surface.

#### POST-PROCESSING TECHNIQUES

Several post-processing techniques, which mirror human hair practices, are applicable and extend the design space.

**Cutting**—With our 3D printed hair, cutting is not only used for reducing length, but is also useful in producing strands with different stiffness. Strand diameter tends to get thinner (and thus softer) as it is drawn further from the extrusion point. We found that cutting 2mm from the root produced scrub-brush-like bristles, 10mm yielded softer toothbrush-like bristles, and 20mm and above yields soft hair.

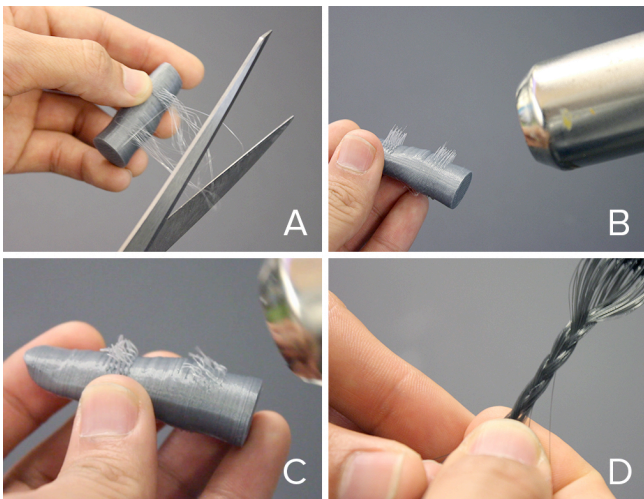


Figure 5. Several processing techniques are possible, including cutting (A), blow heating (B,C), and braiding (D).

The question then arises: how can one make short lengths of soft hair? To achieve this, we must begin extrusion earlier, so that the correct strand diameter is reached at the desired root location. For some objects, this “true root” might start in the interior of the model. If this point lies outside the model, a sacrificial root platform must be printed.

**Blow Heating**—The thermodynamic properties of the print material means we can apply external heat to soften printed hair, which enables post-printing manipulations, such as introducing kinks or waves. We also noticed that without tension, short lengths of hair tend to curl.

**Manual Curling**—Another post-processing curling approach is to do it manually, such as by wrapping strands of hair around a pencil and applying gentle heat.

**Braiding**—Finally, it is also possible to braid and style long strands. Figure 5D shows a simple French braid with ~240 threads of printed hair. Other manipulations are possible, such as ponytails and buns, and hair accessories like clips and ties are applicable.

#### EXAMPLE OUTPUT

The design space of 3D printed hair is diverse. We now highlight five output examples, each with distinctive design parameters and post-processing effects applied (see also Video Figure).

**Wizard**—Figure 4A shows a 3D printed wizard with a long distinctive beard (à la Gandalf). To achieve this, we modified a 3D model of a bust, rotated it by  $90^\circ$ , and extruded hair strands from the chin. The strands are dense, straight, and have medium thickness.

**Troll**—We emulate a troll doll by creating long, thin and straight patches of hair on its head. We used a randomized hair distribution with a premature rectangular return path, which pulled strands to the side near their termination for a “crazy hair” effect (Figure 4B).

**Brush**—We created a brush (Figure 4C) with extra stiff bristles by increasing the extrusion amount and decreasing drawing speed. This left strands approximately 5cm long, which we then cut back to 5mm, leaving only short, straight and stiff bristles.

**Horse Tail**—To create a 3D printed horse (Figure 4D), we broke a horse model into smaller parts, allowing maximum

space for extruding a long and fine tail. The latter used an increased drawing speed and reduced extrusion material. The resulting hair could be further shaped or braided.

**Finger**—Hairs on fingers are sparse, short, slightly curly, and generally grow in two patches, above and below the major knuckle. Individual strands were separated by at least 1.2mm, for a sparser appearance. Once printed, the extruded strands were cut short (Figure 5A) and curled by blow heating (Figure 5, B and C).

### LIMITATIONS AND FUTURE WORK

Like all techniques, our approach has limitations. Foremost, the maximum length of printed hair is bounded by the size of the print bed. Also, depending on the printer used, extruder movement speed and material feed rate might also limit the designs possible. Printing time is another issue. Although we significantly improved printing speed by using horizontal strand printing (X/Y extruder translations are generally much faster than Z movements), the overall speed is still fairly slow. This is primarily due the necessity of having to print one strand at a time, rather than many in parallel. This means high-density hair patches are time consuming to print.

As discussed previously, the physical design of the extrusion head introduces limitations. Because of heat radiated from the extruder, it cannot get too close to existing strands without damaging them. This greatly limits density, particularly in the X- and Y-axes. However, it is possible that a more needle-like extrusion heads could mitigate this.

Additionally, our approach works best for printing straight hairs. The geometric complexity increases dramatically if the printer outputs curly hair directly (especially if the curls are 3D, e.g., helical). We did not identify an elegant method for having the extruder navigate through this without collisions, which would destroy the print. For the time being, this remains an open problem. Fortunately, with post processing, curls are readily achieved.

### CONCLUSION

In this work, we introduce a technique for 3D printing strands, fibers, and bristles, by exploiting the stringing phenomena inherent in FDM-based printers. We offer a set of design parameters for controlling properties of single strands and/or hair bundles. Our printed examples demonstrate that our approach is feasible and requires low overhead, allowing users to introduce hair components as a new design material for their 3D printed models.

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