Fibritary: Rotary Jet-Spinning for Personal Fiber Fabrication

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ABSTRACT

The development of personal fabrication technologies has enabled end users to model and prototype desired objects. 3D printing technologies have eased our access to solid models, however, it is still a challenge to develop thin fibers rapidly at personal levels that may help enriching textures of models. We propose a system and method inspired by cotton candy making, which uses rotary jet-spinning to extract thin plastic fibers at high speed. We report our exploration of the proposed method where we studied various plastic materials, the effects of the rotation speed, and the hole size of the fiber exit.

KEYWORDS

Personal Fabrication; Rapid Prototyping; Rotary Extrusion; Fibers; Hair; Texture; Jet-Spinning

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CHI'19 Extended Abstracts, May 4–9, 2019, Glasgow, Scotland UK

ACM ISBN 978-1-4503-5971-9/19/05.
https://doi.org/10.1145/3290607.3312934

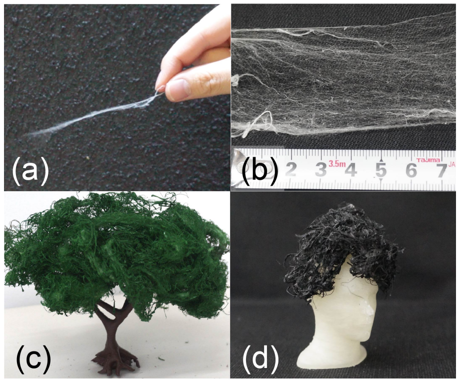

Figure 1: Our method uses rotary jet-spinning and the heat to extract thin fibers. (a) An example generated fiber that is blown by a wind. (b) A net structure formed by the fibers. (c) Example usage of the extracted fibers; a tree diorama. (d) Another example usage of the extracted fibers; a person with long curly hair.

The method allows plastic fibers to be extracted at micro-scale, and we propose various examples of use cases. Our approach can be used in combination with traditional 3D printing techniques, where soft and/or hairy models are required to design the texture of a 3D model.

INTRODUCTION

3D printing technologies have been developing, and various methods are being proposed. Researchers in the field of human-computer interaction (HCI) has been working on effective novel techniques that enable us to prototype unique objects and textures. One technique is the extraction method of thin fibers, and initial attempts were introduced as 3D printed hair [7], where the printer head is manipulated to extrude the filaments as fibers. However, it is still challenging to develop thin fibers in high-speed due to the limitation of a mechanical structure of the machines. There are many methods to generate thin fibers, which may have potential to be brought to HCI to improve the quality of fabrication. One technique that we paid attention to, is heat-aided rotary jet-spinning [11]. This technique was originally developed as a method to create cotton candy by melting and extracting sugar. Some researchers have been working on consumable machines to extract fibers based on the methodology as a rapid and promising way [6]. Since cotton candy machines are typically at a table-top size and somewhat inexpensive, we assumed such technique to be significantly appropriate for fabrication at personal levels.

In this paper, we attempt to make use of the technique based on heat-aided rotary jet-spinning for personal fabrication. We report our exploration of the method, where we studied the effects of the rotation speed, material type and the exit size of the fibers extracted. Our results show that thin fibers can be generated rapidly with personal machines, and we present applications that soft/hairy models are required as a part of a 3D model (Figure 1). We aim to introduce this effective methodology for fabrication in HCI context, where we believe the method can be expanded to be used at personal levels, subject to rapid prototyping.

Our contributions are concluded as follows.

- We introduce the use of a method for producing plastic fibers in high-speed, which is based on a heat-aided jet-spinning technique.
- We explored the method and three parameters of the system: the materials, rotation speed, and hole size of rotary jet-spinning. The results show that the system can produce thin fibers at personal levels for various use cases.
- We propose example use cases, where our method can support and be combined with traditional 3D printing technologies. The method allows users to rapidly design models with hairy or fluffed texture surfaces, and including interactive use cases.

RELATED WORK

When using fused deposition modeling (FDM), the precise control of the extrude can lead to unique expressions, and recent work is attempting to expand the technique of the printing method [9], including applications to print 3D trees [2]. Methods such as 3D Printed Hair [7] has been proposed, to generate fiber parts in a 3D model. Further, Cilllia [10] was a method to create 3D printed hair, which proposed further applications for texture design and actuation. Related to the method of our work, Flufy [5] was an attempt to automatize the approach of cotton candy making and to create 3D models based on candy.

In the area of material science and industry, many methods to extract fibers have been developed. One of the commonly known methods is the use of electrospinning [1]. Electrospinning is a fiber production method that uses electric force to collect the melted and charged polymers. Another effective approach for fiber extraction is the use of jet-spinning [11]. The technique was initially developed and commonly used for cotton candy making. Furthermore, the method is considered valuable since it can be used as a mean of recycling plastic introduced by the Polyfloss Factory [4].

This paper attempts to propose the use of jet-spinning fiber generation method to HCI, and to reveal a proof-of-concept study and applications that can be beneficial at personal levels. We chose the jet-spinning method rather than electrospinning or other methods such as melt blow [3], because the method can be more easily deployed for personal usages in home or laboratory. According to Rogalski et al. [11], melt blow requires heated air flows at high velocities with high energy, and jet-spinning allows us to control variety of parameters such as fiber diameters more easily compared with electrospinning.

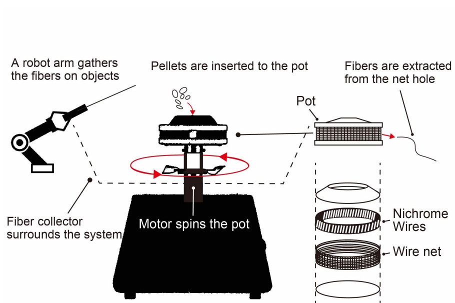

Figure 2: System configuration. The system mainly consists of a motor and a pot that contains and melts the pellets. The motor spins the pot, which has nichrome wires and a wire net with small holes inside.

ROTARY JET-SPINNING EXTRUSION SYSTEM

System Design

The methodology of fiber generation used in our study is inspired by cotton candy making. Our system was based on a consumable cotton candy machine TK-5 (Asahi Industry Co., Ltd.), which costs approximately $ 560. The system mainly consists of a motor and a pot. The pot is consisted of nichrome wires and a wire net surrounding it. The nichrome wires heat the pot, which melts the materials inside the pot. The motor spins the pot that allows and forces the melted materials to be pushed outside passing through the wire net, due to the centrifugal force (Figure 2).

The system is capable of manipulating the rotation speed of a 90 W AC motor at 11 levels, between 3800–6700 rpm. The resistance of the nichrome wire was 15.3 Ω, and the opening size of the wire net was 1.0 mm. In order to take control of the system by computational means, we modified the system from both mechanical and electronic aspects. We enabled to modify the size of the net to explore a

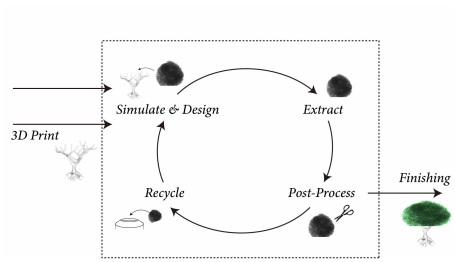

Figure 3: The process of using Fibritary. The user uses the simulation software to explore the design of their model. Then the fibers are extracted, followed by a post-processing process. The material is recyclable and reusable, therefore, the user can retry the process.

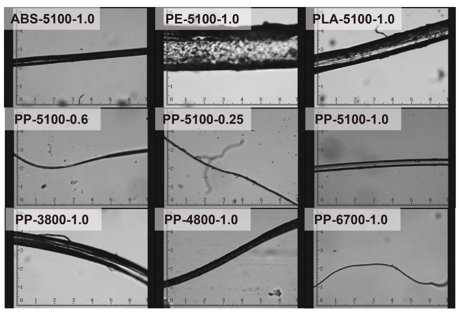

Figure 4: Fibers shot by a 100x microscope. Example images of the extracted fibers of variety of materials, rotation speed and hole size. The caption on each image "XX-YY-ZZ" indicates, XX: material type, YY: rotation speed (rpm), ZZ: hole size of the wire net (mm). The unit for the visualized scale inside the image is 10 μm.

variety of parameters. We also inserted two switching relays (AC100SSR, AsakuasGiken Co., Ltd.) to allow controlling the rotation speed and heat from a computer, which is controlled by Arduino.

At the original use case for cotton candy making, crystal sugar (usually sucrose) is melted and extracted to generate a fluffy bunch of fiber sugar. The fusing point of crystal sugar is around 160–190 °C. When considering plastic materials, we paid attention to the fusing point. Therefore, we initially chose to use PP (polypropylene). The fusing point of PP is around 165–175 °C. PP was appropriate because they are non-toxic, odorless/recyclable, and are typically used for recyclable containers, fibers, stationary and so on. In our work, we mainly focused on usage of PP, however, we also tested PE (polyethylene), PLA (polylactide), and ABS (Acrylonitrile butadiene styrene).

Flufy [5] that used a cotton candy machine for fabrication, developed a system that automatizes the collecting procedure, with a DC motor and a delta structure. Referring to this approach, we developed a prototype to address the issue of automatic fiber collection. In our case, we expanded the approach, and the system was developed by attaching a geared motor driven at 6 V to the end of a robot arm (Dobot Magician, Shenzhen Yuejiang Technology Co. Ltd) controlled through a computer via serial communication from Arduino and Unity3D, which also has a user interface to simulate the generated fibers. A 3D model is attached to the end of the motor, which gets spun and the robot arm moves the 3D model back and forth to collect the fibers around the model.

Design Procedure

Figure 3 shows the work flow that the user will follow. The system can be used with or without a 3D printed model made by an external 3D printer. The user can simulate the fibers on our software to consider the design of their model. The system then generates the fibers controlled by desired parameters, followed by a post-processing procedure by the user (e.g., methods introduced in 3D Printed Hair [7]). The fibers can be collected either manually or automatically, depending on the usage. The materials are reusable, thus recyclable, and the user may retry the fabrication process multiple times.

GENERAL PERFORMANCE

We tested five speed variations, which include the minimum and maximum speed that the system can produce (which was 3800, 4800, 5100, 5800, 6700 rpm). We then tested variations of the materials at 5100 rpm. At last, we tested variations of the hole size of the wire net at 5100 rpm. For each study, we inserted about 10 g of the pellets into the pot. Before inserting the pellets, we ran the system to be heated up for at least 20 seconds. The pellets started to be extracted after about 10 seconds, and took about 1 minute to have all of the pellets to be extracted. We used a non-contact thermometer to observe the temperature of the system, which was 140 °C at the beginning and ended up at 240 °C after the extrusion.

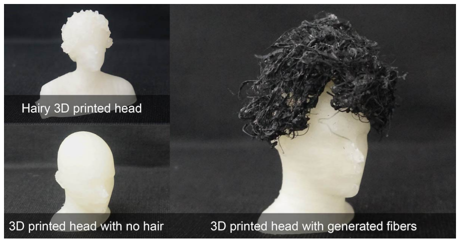

Figure 5: An example of a person with curly hair. A 3D printed head (made by Ultimaker 3, approx. 2.5 hours) with generated fibers with our system, dyed in black. The height of the head is approx. 55 mm.

Figure 6: An example of a tree. A 3D printed tree (made by Stratasys F170, approx. 3 hours) with generated fibers with our system, which is dyed in green. The height of the tree is approximately 100 mm.

Figure 4 shows example fibers observed from a microscope. Overall, the system successfully extracted thin fibers with PP, PET, and ABS. PE did have fibers extracted, however, each was thicker and short in length, compared with fibers extracted with other materials. In addition, although ABS performed well to extract fibers, due to the chemical characteristics of the material, it is not recommended to be used since it produces gases that are considered harmful to human health. In all cases except PE, fibers with diameters around 1 μm–100 μm were observed. The increase of the rotation speed helped increase the number of thin fibers. In addition, we observed that the exit hole size of the wire net influences the extracted fibers as well. Using smaller hole sized limited thick fibers to be extracted; thus the overall fibers tended to be thinner and softer. In contrast, in cases when we used hole sizes at 1.0 mm, the diameters of the fibers tended to have a larger dispersion.

EXAMPLE OF USE

Curly Hair and Diorama

When considering the generation of a hairstyle in a 3D model, curly hair could be thought to be difficult to create with 3D printers because hairs irregularly overlaps each other. A hairy bunch of the fibers from our system can be used as the part of a 3D model as shown in Figure 5. The methodology may give an advantage by allowing to give the unique texture of the curly hair.

Due to the unique textures where the fibers consist of fluffy and hard lumps, we consider use cases for designing plant dioramas. Figure 6 presents a tree with the leaves generated by our approach. For this example, instead of using the thinnest fibers that are extracted, we used fibers slightly thicker to give emboldened texture.

Other Applications

Due to the light weight of the fibers, the fibers can be actuated with an external force. Figure 7 (a) and (b) shows an example by using external force to actuate the fibers. These techniques can be used to represent dynamic textures of hairy parts of objects, such as animal's tails or for hairy characters (Figure 7 (c)). Our fibers help these creatures to express the unique textures of their body.

By using the automatic fiber collection approach, we can consider the technique as a method for covering the surface of wired 3D models that are created with methods introduced in WirePrint [8]. Combinations with such 3D printing techniques can be considered to be a great area to fasten fabricating activities (Figure 7 (d)).

Furthermore, the fiber hardness differs depending on the thickness. This characteristic can be used for changing the stiffness of cushions or stuffed toys, by inserting and stuffing them with different fibers extracted in different parameters.

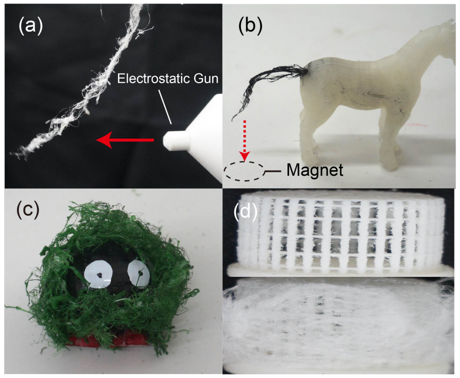

Figure 7: Other examples. (a) Electrostatic force is used to actuate the fibers. (b) Fibers dyed with ferrofluid. Magnetic force is used to actuate the fibers. (c) A hairy character. (d) Covering wireframes. Top: A wireframe printed 3D model. Bottom: The surface covered by our fibers.

CONCLUSION

This paper introduced a technique based on heat-aided rotary jet-spinning for personal and rapid fabrication. We explored rotation speed, material type and the size of the exit hole, and its effect on the fiber generation. The results show that thin fibers can be generated rapidly with machines available at personal levels. We presented example applications with our fibers, where our approach is combined with traditional 3D printing. This allows us to design soft and hairy parts of a 3D model. We aimed to introduce this approach for fabrication in HCI context, which we think that our work may encourage enriching rapid and personal fabrication by extracting detailed fibers for rich textures.

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