Conductive, Ferromagnetic and Bendable 3D Printed Hair for Designing Interactive Objects

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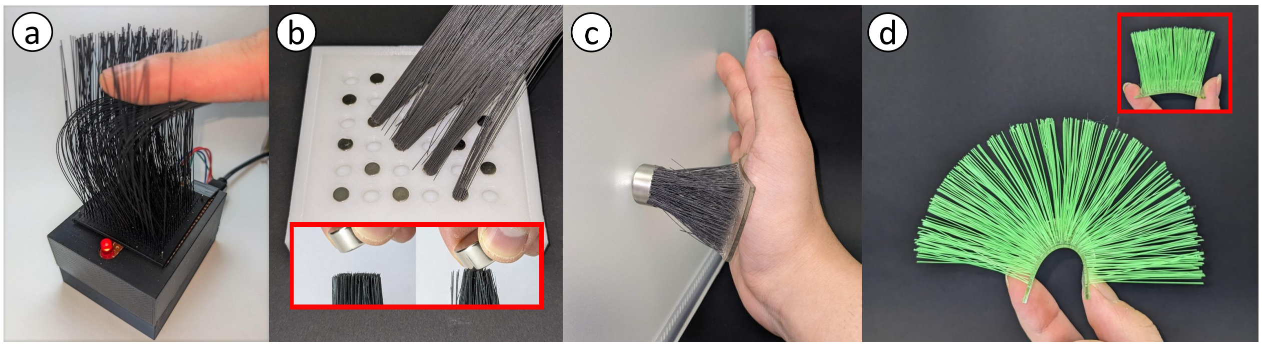

Figure 1: Conductive hair turn on an LED with touch detection (a). Ferromagnetic hair prototyped application capable of tactile representation of brushes (b). Ferromagnetic hairs with soft resin give the user's hand a visual and tactile sense of magnetism (c). The hair structure with a soft base can change the spread of the hair tip by deforming the flexible plate (d).

ABSTRACT

The hair structure, a characteristic object that can be formed using 3D printers, is used to enrich the expressivity and haptic sensation of a printed object. However, in conventional 3D printing techniques, the hair structure is printed using a uniform and general plastic such as Poly-Lactic Acid (PLA). In this study, we attempt to print the hair structure using conductive and magnetic iron filaments, commonly used to allow an Fused Deposition Modeling (FDM) printer to create a functional object, to extend the possibility of the 3D printed hair technique. Furthermore, we planted the printed hair in the soft resin used for resin crafts. We provide detailed material information and validate the printability of each filament. With these methods, we demonstrate applications, such as hairy devices that can detect when a human touches hair, brushes attracted by magnet arrays, and flexible attachment of hair structures to the human body.

CCS CONCEPTS

• **Human-centered computing → Haptic devices**.

KEYWORDS

digital fabrication, 3D printing, tactile presentation, hair structure

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1 INTRODUCTION

In recent years, the development of 3D printing technology has made it possible to create fine shapes and complex structures using inexpensive 3D printers. In particular, hair structures can be made with a diameter of 1 mm or less using a fused deposition modeling (FDM) 3D printer [2, 6]. Hairy objects, such as VR controllers [3] and texture expressions [1], are used to reproduce tactile sensations.

Although FDM 3D printers allow users to print objects using various types of materials, such as conductive and flexible filaments, only standard plastics (e.g., PLA and ABS) have been used for printing hair structures; this is because it is challenging print fine objects stably using special filaments consisting of powdered material (filler), and only models have been used with expensive 3D printers. However, with the development of the 3D printing environment (materials, 3D modeling and slicer software, and machine), the stability, accuracy, and speed of inexpensive 3D printers have dramatically improved over the years. Therefore, by choosing an appropriate material and designing appropriate 3D model data, challenging 3D printing deemed difficult can be possible. If 3D printed hair with various materials is available, we can design interactive objects that provide not only the tactile presentation but also functionality such as touch detection.

In this study, we validate the printability of several special filaments and present hair structures printed using conductive and magnetic iron filaments. In addition to the conventional tactile presentation, hair made of conductive filaments can be utilized as electrodes that enable touch detection (Figure 1a), and hair made of magnetic iron filaments can be used for haptic sensations by attracting them with magnets (Figure 1b). Furthermore, we attempted to plant one end of the printed hair in the soft resin used for resin crafts. Users can create conductive, magnetic, and bendable hair structures by combining these features.

2 MATERIAL SELECTION AND PRINTABILITY

We introduce the selection and performance of each material and describe how example applications are created. We used two FDM 3D printers (Creality Ender3 and Ender3 V2) to print the hair structure. Note that the 3D model of the hair structure was modeled using Rhinoceros and Grasshopper with reference to previous studies [6].

2.1 Conductive filament

Conductive filaments consisting of base plastic (PLA) and carbon powder can provide conductivity to objects. This material is often used in applications such as fabricating interactive objects and creating components for electronic circuits [4, 5]. It is possible to detect that a human touches or strokes the hair by a change in capacitance. In addition, it is possible to determine how much hair is bent by a change in resistance, similar to a flex sensor.

We selected two PLA-based conductive filaments to print the conductive hair structure: MSNJ Conductive filament[1] and Protopasta Electrically Conductive Composite PLA[2]. MSNJ's conductive filament showed good forming results in the hair structure. In contrast, Protopasta's conductive filament is readily available. We used Protopasta filaments at the beginning of our 3D printing experiments. We succeeded in forming hair with this filament, but they were slightly brittle after 3D printing. The later modeling with the MSNJ conductive filament improved this situation. We were able to print the conductive hair structure using the same method as the modeling method described in [6]. Similar to the models in previous studies, the model can be formed by specifying parameters such as length, density, and thickness of the strand.

We show an application using the conductive hair structure in Figure 1a. Capacity measurement was implemented using Arduino Uno and CapacitiveSensor library. This example detects three states (non-touching, finger touching, and most of the hand approaching).

Currently, it is impossible to detect the direction of stroke. We are considering a solution by devising the mechanism of 3D printing. We think alternating conductive and non-conductive sections next to each other would allow for the possibility of detecting the direction of stroking. It is possible to apply to the interaction where the hair structure is placed on a trackpad by detecting in which the hair is stroked.

2.2 Iron-filled Filament

Ferromagnetic filaments that consists of iron powder material can impart ferromagnetism to objects. An object printed using this filament also exhibits ferromagnetism that responds to magnets and behaves similarly to iron. As an optional property, the surface of the object can be rusted with certain post-processing after 3D printing. To print ferromagnetic hair structures, we selected Protopasta Iron-filled Metal Composite PLA[3]. To 3D print this hair, it is necessary to raise the temperature by 20 °C and the flow by 10% from the environment described above. The number of strands of hair drawn by the magnet changed according to the magnetic force. The stronger the magnet, the more hair it can attract and the stronger the haptic sensation it can generate.

We show an application using a ferromagnetic hair structure and permanent magnets in Figure 1b. First, we attached the printed hair to a printed handle similar to a flat brush. Next, we printed a 2D board in which the permanent magnets could be placed at a certain interval. Strands of the printed hair are drawn to an array of permanent magnets in order by stroking the board using a brush. Therefore, a partially resistant haptic sensation can be represented when writing a symbol or the like using a brush. We can design an application that provides haptic presentations to users in response to specific characters or patterns because this configuration can be controlled by changing the power and layout of the magnets.

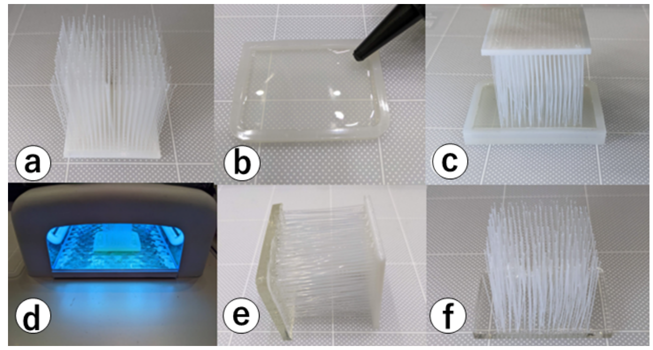

Figure 2: The Process of planting hair to soft resin.

2.3 Planting Hair Structure in soft resin

Both ends of the printed hair structure are fixed to a printed plate to be stably printed, and one side was cut off using a box cutter. Therefore, the bottom plate planted hair is a hard plate and cannot be bent. We believe that we can move and twist the hair structure more dynamically by making the bottom more flexible. Here, we present a technique that replaces the bottom plate with different materials by planting the tip of the hair in it. We select soft resin used for resin crafts as the bottom parts of the hair to provide flexibility to the hair structure.

In Figure 2, we show the procedure for planting the hair onto a soft resin in order. First, we printed a hair structure using an ordinary PLA material and cut it off between one side of the plate and the hair after 3D printing (Figure 2a). Next, we poured the soft resin into a small silicone mold (Figure 2b). Then, we placed the tip of the hair into the soft resin and cured the resin using UV light (Figure 2c, 2d). After curing, we obtained a hair structure sandwiched between a soft resin plate and a hard plastic wall (Figure 2e). Finally, we made the hair structure planted in the flexible bottom plate by cutting between the other side of the plastic wall and the

[1]https://www.amazon.com/dp/B08Z3NZCB7
[2]https://www.proto-pasta.com/collections/all/products/conductive-pla
[3]https://www.proto-pasta.com/collections/all/products/magnetic-iron-pla

hair (Figure 2f). As shown in Figure 1d, the spreading of the hair tips can vary according to the deformation of the flexible plate.

As an example, we introduce a haptic sensation method that combines hair printed using a ferromagnetic filament and a soft resin plate (Figure 1c). Because the bottom can be handled flexibly, it is possible to attach the hair structure not only to flat surfaces but also to curved parts such as the palm. The magnetic force can be felt with the haptic sensation of the palm when the user's hand is brought closer to a magnet.

3 DISCUSSION AND FUTURE WORK

In this study, the 3D printed hair structure can flexibly change its shape and has a sensing function. The hair structure can be used not only as a texture, but also as an electronically controllable interactive component that can be used to improve the immersive experience of VR by utilizing tactile changes. In future work, we plan to electronically control hair by combining electronic parts with the hair structure. It is considered that this can be controlled by embedding a BioMetal (linear shape memory alloy) to continuously curve the bottom. In addition, the direction and movement of the hair can be improved by designing the shape of the silicon mold used for the hair plantation.

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