

TriFlock: Selective Electrostatic Flocking via Multi-material 3D Printing

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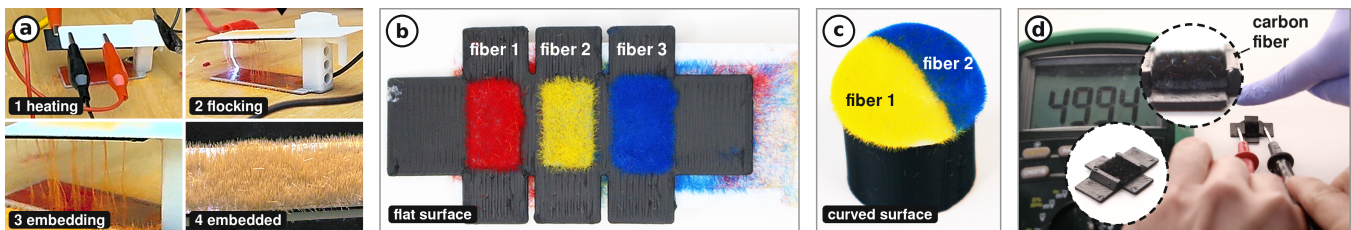


Figure 1: (a) The TriFlock process enables multi-fiber flocking on (b) flat, and (c) curved surfaces, as well as (d) flocking of functional conductive fibers (carbon-fiber) for sensing.

Abstract

We present *TriFlock*, a digital fabrication method that enables electrostatic flocking via multi-material 3D printing. Electrostatic flocking is a method that uses high-voltage electric fields to apply textures onto surfaces via short fibers and adhesives. While traditional flocking relies on bulky handheld tools and screen-printed glues, it struggles with non-planar geometries, fine features, high-voltage functional fibers, and selective multi-material patterning. TriFlock overcomes these limits by 3D printing localized adhesive layers alongside electrically isolated regional electrodes and customizable fiber beds. We demonstrate TriFlock across three key application spaces: a planar object selectively flocked with multiple colors, a doubly-curved dome, and a carbon-fiber touch sensor.

CCS Concepts

• Applied computing → Computer-aided manufacturing; • Human-centered computing → Interaction devices.

Keywords

electrostatic flocking, digital fabrication, multi-material 3D printing

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1 Introduction

Electrostatic flocking is the process by which a high-voltage electric field propels short, cut fibers onto a glue-coated substrate to form textured surfaces. Traditionally, electrostatic flocking has been used in textiles to add tactile finishes to fabrics and objects. However, in recent years, researchers have increasingly explored functional roles for electrostatic flocking to advance thermal management, soft sensing, friction properties, and triboelectric energy harvesting [Hu et al. 2025; McCarthy et al. 2021; Shen et al. 2025; Zhang et al. 2025].

Conventional electrostatic flocking relies on fixed-voltage handheld generators and screen-printed adhesives, introducing four key limitations: (1) bulky commercial tools cannot flock small or hard-to-reach features; (2) screen-printed glues cannot conform to 3D geometries, forcing makers into labor-intensive manual glue brushing and stenciling; (3) standard setups connect the entire substrate to a single ground electrode beneath the adhesive layer, charging the whole surface at once and preventing adjacent regions from being selectively flocked with different fibers; and (4) fixed-voltage devices cannot generate the higher field strengths required to propel thicker, longer, or functional fibers.

To address these limitations, we introduce *TriFlock*, a **digital fabrication** method that embeds flocking directly into a multi-material 3D print. While prior digital fabrication approaches have



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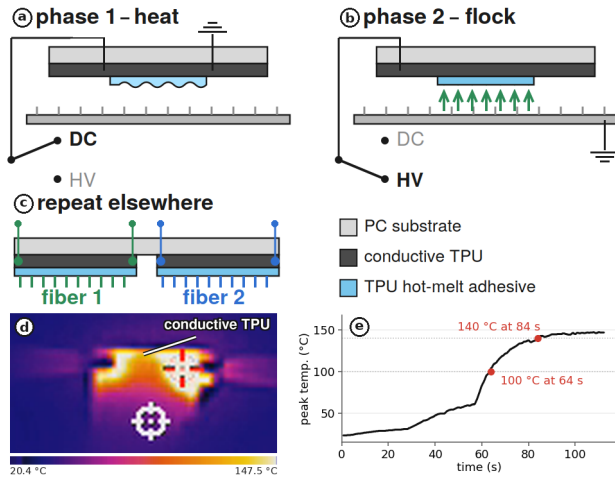


Figure 2: The Conductive TPU layer is used for both heating & flocking.

generated fibrous textures without flocking, by extruding FDM filament strands [Laput et al. 2015; Wang et al. 2024] or printing micro-pillars [Ou et al. 2016], they remain bottlenecked by nozzle resolution and printable filament choices. TriFlock instead decouples fiber selection from printability, enabling the use of unprintable functional fibers (e.g., cotton, carbon fiber) down to 10 μm in diameter.

In summary, TriFlock contributes a multi-material fabrication method that enables: (1) electrically isolated regions for selectively flocking multiple patterns or materials; (2) direct, screen-free adhesive deposition for flocking complex, non-planar geometries; and (3) customizable electrode fabrication that decouples electrostatic flocking from the voltage and geometry constraints of traditional hardware.

2 Implementation

Structure. TriFlock structures comprise three stacked layers of 3D-printed materials (Fig 2-c): a polycarbonate (PC) substrate, a conductive TPU layer, and a non-conductive TPU adhesive layer. The 3D model is printed entirely in PC, which forms the solid body of the structure. Since TriFlock supports *selective* electrostatic flocking, we print the conductive TPU layer onto the regions designated for flocking, followed by a thin non-conductive TPU adhesive layer on top. The non-conductive TPU filament replaces the glue used to fix the fibers in traditional electrostatic flocking. We selected TPU as the adhesive material for its high viscosity and interlayer tackiness, which ensure reliable fiber adhesion. We chose conductive TPU (Conductive Filaflex) for its relatively low resistivity (3.9 $\Omega\cdot\text{cm}$) and flexibility, which allows for soft sensor applications. Finally, we used PC for the remainder of the structure for its stiffness and its higher thermal resistance relative to TPU. Heating is confined to the printed interlayer and the adhesive directly above it, and across our samples the base structure held its geometry through flocking.

Fabrication. We print TriFlock objects in a single pass using a multi-material 3D printer (Prusa XL). Once printed, the object is

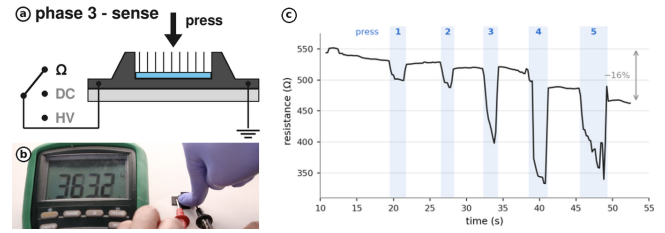


Figure 3: The Conductive TPU layer can also be used as a sensor.

ready for selective fiber patterning. Our flocking setup comprises two components: (1) the 3D-printed object and (2) a fiber bed (a conductive surface holding the unattached fibers). As shown in Fig 1-a, we use a PC plate lined with copper tape as the fiber bed. Using copper tape allows us to resize the conductive flocking region and reuse the base substrate. However, the fiber bed can also be 3D-printed with conductive TPU or any other conductive materials. We apply a high voltage between the conductive TPU layer and the copper tape electrode on the fiber bed, which creates the electric field needed for heating and flocking.

Flocking Mechanism. To drive both heating (activation of the adhesive) and flocking (driving of the fibers towards the adhesive), we use a single DC power supply in two stages: it powers the conductive layer directly for heating, and drives a high-voltage electrostatic generator for flocking. When connected to DC, the conductive TPU layer functions as a resistive heater that activates the adhesive TPU layer above it, turning it tacky (Figure 2a). In our experiments, we deliver power matched to the patch size: a 25×10 mm patch 0.4 mm thick reaches a surface temperature of 140 °C in 84 seconds, its activation temperature, and levels off at 147.5 °C (Figure 2d, e). We then rewire within a few seconds so that the supply powers the electrostatic generator, whose high-voltage output is connected to the same contacts (Figure 2b). In this configuration, the conductive TPU acts as the high-side electrode while the copper bed serves as the grounded counter-electrode. The resulting electric field propels fibers upward to embed them into the tacky TPU. As the adhesive TPU cools, flocking is constrained to a window of about 10 s, within which the fibers must permanently anchor into the TPU. We clear any loose fibers from the unactivated regions with compressed air or a light brush.

3 Demonstration

Next, we demonstrate the versatility of our method via three applications.

Multi-material Flocking. Multi-material 3D printing enables electrically isolated regional electrodes on TriFlock objects. By driving each electrode independently, we selectively flock multiple fiber materials or colors on a single part in successive passes, as shown in Fig 1-b.

Non-planar Patterning. Traditional non-planar flocking relies on manual stenciling and brushed glues; our computational pipeline, however, prints conformable adhesive patterns directly onto complex geometries. Furthermore, because the fiber bed itself can be

3D-printed, we can conformally match its shape to the curved custom geometries of the flocking regions. Fig 1-c illustrates two distinct fibers flocked onto a doubly-curved dome.

Functional Conductive Sensing. By integrating an adjustable power supply and custom electrodes, our method flocks non-standard fibers, like carbon fiber, beyond commercial voltage limits, enabling functional sensing applications. For example, a single carbon-fiber sample (Fig 1-d) yielded a base resistance of 551 Ω under finger pressure (Fig 3). Over five compression cycles, the baseline resistance drifted to 463 Ω , which we attribute to progressive fiber compaction.

4 Conclusion & Future Work

We presented TriFlock, a digital fabrication pipeline for integrating electrostatic flocking into single-pass, multi-material 3D printing. By printing electrically-isolated conformable regional electrodes and customizable fiber beds, TriFlock enables selective multi-material flocking, non-planar patterning, and high-voltage driving of functional fibers. In future work, we plan to develop an end-to-end computational design tool to generate TriFlock objects, and apply flocking to our prior work, Ori-TENG [AlAlawi et al. 2025], to enhance the performance of our 3D-printed origami energy harvesters, and to explore printed conductive-fiber arrays as conformal tactile skins; sensing surfaces that wrap around curved objects, with each addressable region acting as an independent touch sensor (taxel).

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