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Ori-TENG： 3D Printed Origami Tessellations as Triboelectric Nanogenerators for Self-powered Sensing and Energy Harvesting

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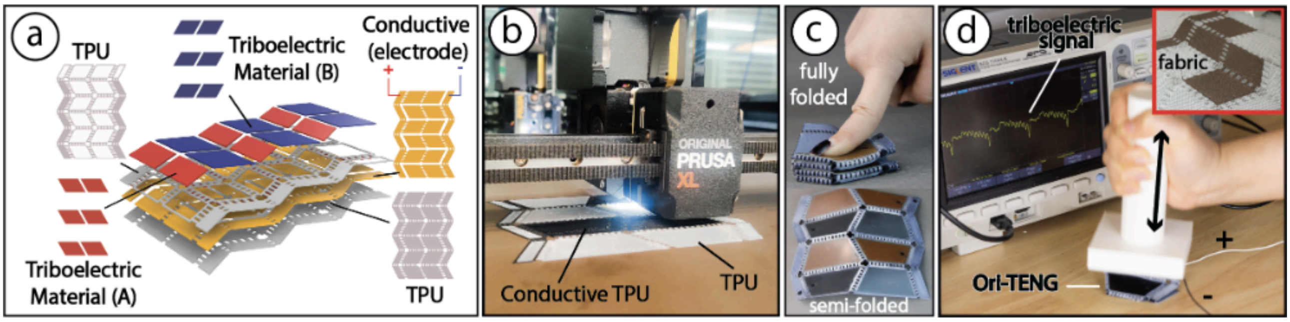

Abstract: We introduce Ori-TENG, a design and fabrication framework for 3D printed origami tessellations that function as triboelectric sensors and energy harvesters. Ori-TENG structures are 3D printed flat in a single step, then folded, with internal electrical routing optimized for both folding mechanics and triboelectric performance.

Tags: Printed Electronics, Energy Harvesting, Origami

1 Introduction

Multimaterial 3D printing has emerged as a powerful tool for the fabrication of interactive components within the HCI community. While traditionally this 3D printing method turns otherwise passive mechanical components into interactive elements, researchers have demonstrated how multimaterial printing with conductive filament seamlessly enables sensing capabilities in mechanically active components during printing *(Alalawi et al., 2023; Gong et al., 2021; Lee et al., 2024; Ozbek et al., 2025; Sakura et al., 2023)*.

With sensing being one facet for achieving interactivity, researchers have begun exploring more ways to make structures more interactively-rich; for example, by having a single geometry support multiple electrical functionalities simultaneously. One interaction principle that achieves this dual-function is called the triboelectric effect. Thus, by leveraging the triboelectric effect, the same geometric structure can serve both energy harvesting *(Arora et al., 2018; Arora & Abowd, 2018; Rui et al., 2020; Wan et al., 2020; Zheng et al., 2016)* and sensing *(Chen et al., 2020; Khan et al., 2017; Liu et al., 2022; Yu et al., 2023)* purposes.

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Triboelectric sensors or energy harvesters comprise a simple structure and a basic working principle. They rely on the material pairing and layering of conductive and non-conductive (triboelectric) materials, with the working principle based on contact electrification between the materials. This means that geometries exhibiting reciprocal motion (sliding or spring-like movement) and have large contact areas, like folded or spring-like structures, are most suited for this principle. In fact, origami tesselations, with their spring-like geometry and many folds, have emerged as promising candidates *(Chung, Song, Chung, Choi, Lee, Lin, & Hong, 2021; Chung, Song, Chung, Choi, Lee, Lin, Hong, & Lee, 2021; Pang et al., 2022; Tao et al., 2020; Yang et al., 2015)*.

However, scaling triboelectric systems within origami tessellations remains a challenge. Most prior work relies on external wiring, which becomes inefficient as tessellation complexity increases—especially since each origami pattern has unique folding requirements, and the triboelectric effect demands specific material assignments on contacting faces. Moreover, the design space of origami structures suited for triboelectric applications, along with the criteria for evaluating them, has yet to be systematically explored.

In this paper, we introduce Ori-TENG, a design and fabrication framework using conductive multi-material 3D printing for triboelectric origami tessellations. Ori-TENG contributes:

- A systematic exploration of origami tessellation design space and metrics that influence triboelectric effect performance
- An internal routing strategy that requires only two wires, regardless of tessellation scale
- A multi-material fabrication pipeline compatible with the triboelectric effect

2 ORI-TENG

Our work relates to research on the fabrication of multimaterial printing of interactive mechanical elements.

2.1 Origami Tesselation Design Space

Ori-TENG focuses on flat origami structures that can be folded post-printing and scaled by increasing base units—hence, we limit our design space to origami tessellations. We surveyed tessellations ranging from lower-dimensional patterns (primitives), like Miura-Ori, to higher-dimensional structures *(Meloni et al., 2021)*. To evaluate the suitability of these tessellations for the triboelectric effect, we used three main criteria: (1) whether the structure is reconfigurable (i.e., supports reciprocal motion), (2) whether contact area overlap exceeds 75%, (3) and whether internal wiring in a single layer is feasible. In total, we evaluated 19 structures. The results of this formative study are shown in Figure 1 and Figure 2.

2.2 Structure and Routing

Ori-TENG's structure consists of four material layers, illustrated with the Miura pattern in teaser figure-a. The first layer is TPU (0.2mm thick), providing elasticity and a spring-like form. The second layer uses conductive TPU (0.3mm thick) to enable both flexibility and conductivity. Layers three and four include discrete triboelectric material pairs (A and B) (0.2mm thick), electrically grouped by material, along with insulating TPU (0.2mm thick). The Small side cells, which we refer to as "power rails," route to either material A or B, representing positive and negative polarity. Only one unit per rail is exposed for wiring, reducing the system to two external wires. Material assignment is based on triboelectric principles, ensuring contact occurs between opposing materials during deformation.

The expanding routing strategy works for six structures (Figure 2). The remaining four require conductive routing on two separate layers, which increases overall thickness by at least 0.5mm (by adding conductive and insulative layers). This added bulk can hinder foldability, making those designs less practical. For this reason, we focus only on structures that use single-layer routing and maintain foldability.

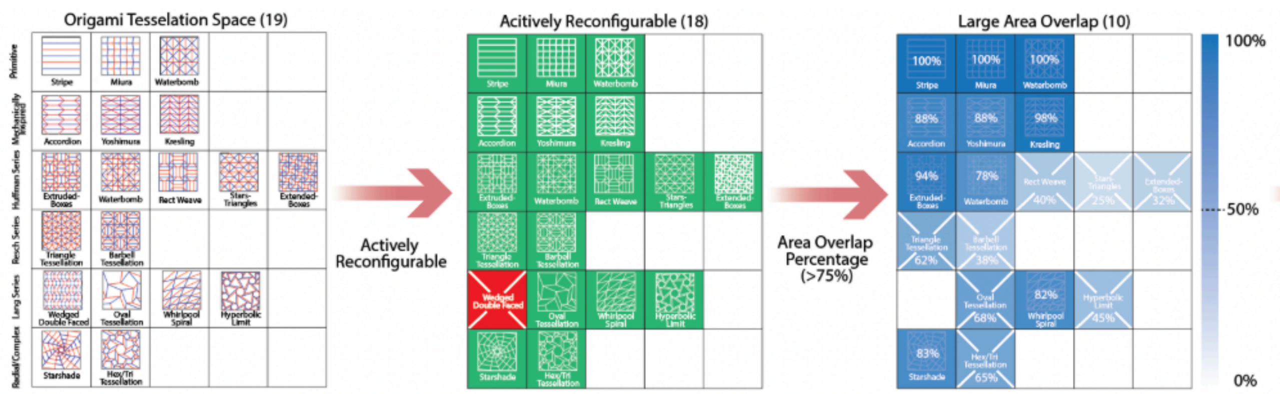

Figure 1: Systemic design space exploration of origami tessellations (19) that are compatible with the triboelectric effect (6). We evaluate the space through three main criteria: (1) active reconfiguration, (2) area overlap percentage (>75%) and (3) routing of electrical connections in a single layer.

2.3 Fabrication Pipeline

We use a Prusa XL 3D printer for multimaterial printing (teaser figure-b). TPU is used as the flexible insulating material, and Filaflex conductive TPU for the conductive layers. For the triboelectric pair, we selected PVDF and Nylon due to their printability. Other pairs are also viable *(Zou et al., 2019)*.

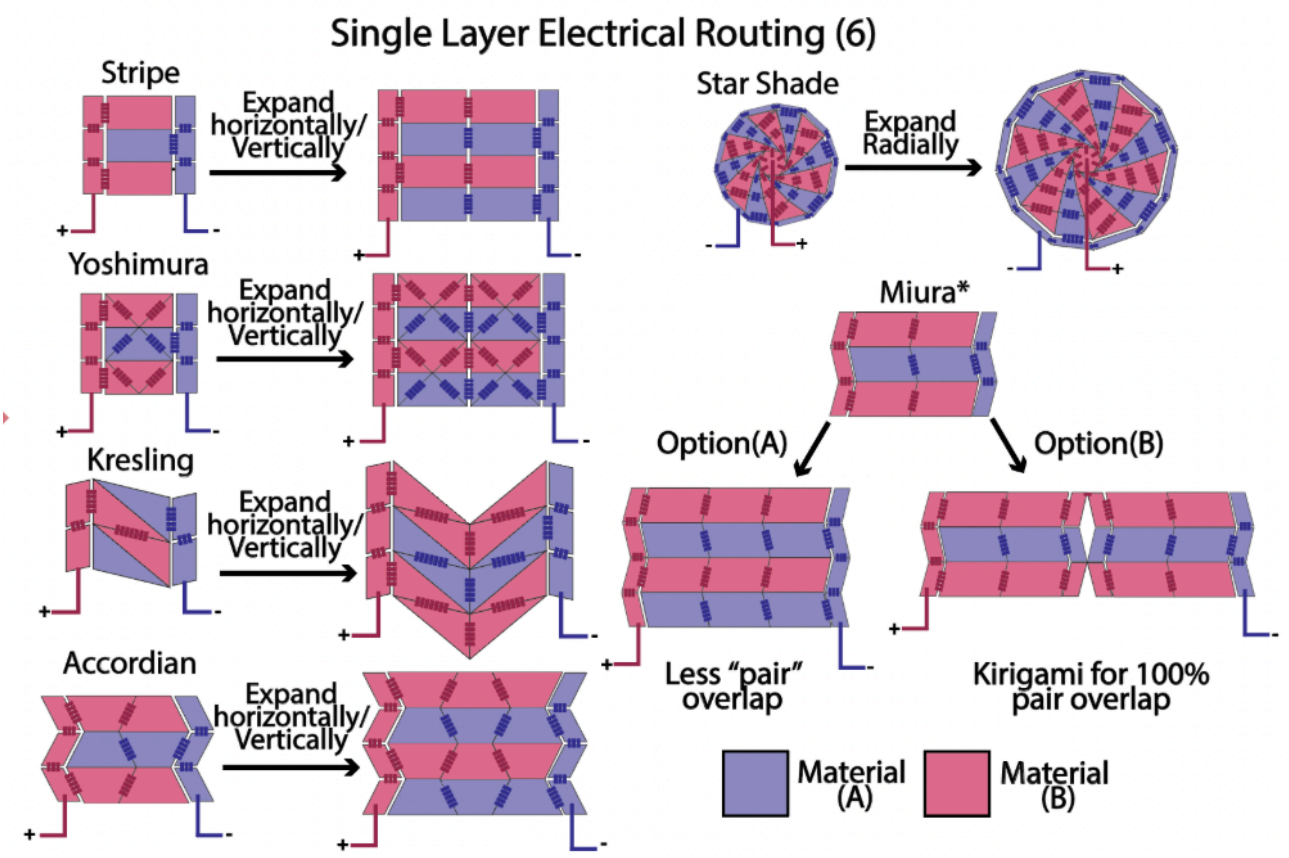

Figure 2: Of the origami tessellations examined, six can be electrically routed on a single layer, regardless of scale.

3 Conclusion and Future Work

With Ori-TENG, we demonstrated how fully 3D printed structures can satisfy both origami folding and triboelectric effect requirements—offering a flexible, scalable approach while limiting external wiring to only two. While origami folds typically involve face-to-face contact on both their inner and outer surfaces, our prints were only on one side to keep the structures thin for better folding. This design decision also limited our exploration to six key patterns rather than ten. In future work, we aim to leverage both sides to potentially double the contact area while ensuring small thickness, electrical isolation, and minimal external wiring. Leveraging 3D printing for Ori-TENG also opens opportunities for direct integration with fabric substrates, which we plan to further explore in future work (teaser_figure-d).

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