Action-Origami Inspired Haptic Devices for Virtual Reality

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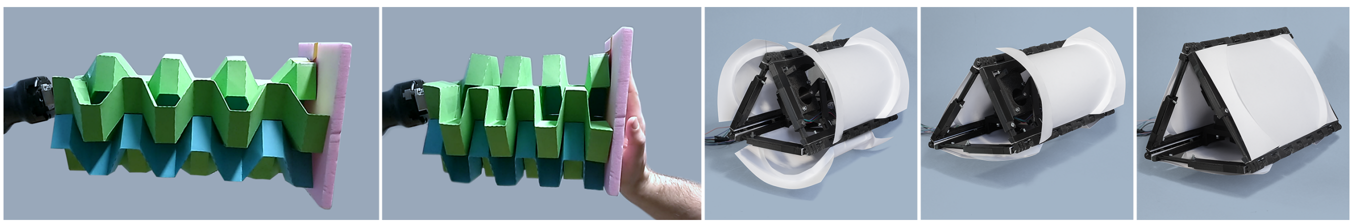

Figure 1: Origami-based haptic interfaces: (left) application of a zig-up-zag-up zipper flower tube for elastic response haptic simulation; (right) Shiftly - a mechanized shape-shifting haptic prop with a simple origami pattern.

ABSTRACT

Origami offers an innovative way to implement haptic interaction with minimum actuation, particularly in immersive encountered-type haptics and robotics. This paper presents two novel action-origami-inspired haptic devices for Virtual Reality (VR). The Zipper Flower Tube is a rigid-foldable origami structure that can provide different stiffness sensations to simulate the elastic response of a material. The Shiftly is a shape-shifting haptic display that employs origami to enable a real-time experience of different shapes and edges of virtual objects or the softness of materials. The modular approach of our action origami haptic devices provides a high-fidelity, energy-efficient and low-cost solution for interacting with virtual materials and objects in VR.

CCS CONCEPTS

• Computer systems organization → Robotics; **• Human-centered computing → Haptic devices**; **Virtual reality**.

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KEYWORDS

Origami, haptics, virtual reality, rigid-foldable tubes.

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1 INTRODUCTION

VR has revolutionized our approach to design by enabling users to explore new ideas in an immersive setup. Haptic feedback makes VR tangible, significantly enhancing users' experience and immersion [Kreimeier et al. 2019]. Supporting the perception of specific materials or shapes is then a fundamental requirement of immersive early-stage design. Yet, enabling different haptic representations and interactions in fast succession within a single scene remains a challenge. For instance, several virtual objects or material samples close together usually require a prop change that is often not time- and energy-efficient even with a robotic arm on mobile platform.

Origami is the art of folding to create various shapes and has inspired many engineering solutions. Origami-based haptic props offer more straightforward mechanical solutions and fewer actuators than pin displays or passive props. In particular, action-origami

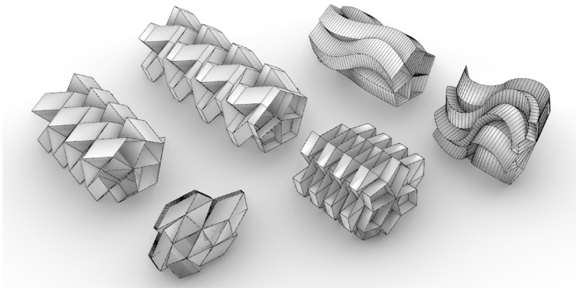

Figure 2: Zipper flower tubes design variations in expanded and collapsed states: (left) flat-foldable zig-zag tube, (center) zig-up-zag-up tube with modifiable length, and (right) semi-discrete flower with developable strips.

can be animated with an intelligent application of the force that will cause the action. By combining action-origami with minimal mechanical actuation, we created flexible and responsive props for high-fidelity, low-cost, and energy-sufficient haptic feedback.

In this work, we introduce two novel haptic devices for VR that emerged from a combination of action origami and mechanical solutions: (1) the Zipper Flower Tube can simulate different material elasticity and stiffness with a single actuator (robotic gripper); (2) the Shiftly can simulate different shapes and surfaces with only three small stepper motors. Their design enables the rendering of different haptic stimuli in quick succession with a single prop.

2 ZIPPER FLOWER TUBE

Rigid-foldable origami has many applications, as it can be materialized by flat panels and rotational hinges. Foldable tubes, in particular, can be coupled in a zipper fashion to increase the stiffness of the resulting structure while they expand [Filipov et al. 2015]. This connection is used in the tubular flower, which consists of rotational congruent tubes with a deltoid cross-section [Sharifmoghaddam et al. 2023]. Due to their inherent recomposition and out-of-plane stiffness, tubular flowers exhibit a more robust cantilevering effect during expansion than alternatives. Furthermore, their interlocking behavior in the expanded state distinguishes them from scissor structures and configurable springs. The tubes are robust enough to be utilized for dynamic haptic feedback. Some design variations are shown in Figure 2. We used the central model with five $180g/m^2$ paper tubes of 4.5 sections each and a custom mounting with ball bearing to accommodate the tubes' rotation. The total flower tube length ranges between $22.5 - 45$ cm with a cross-section of $17cm$. The cross-section is adjustable, and the number of petal tubes can be changed. The high-stiffness collapsed and expanded states allow us to retain the pressure applied by the user and simulate the stiffness of various materials. The pressure is measured by the F300 force-torque sensor mounted behind the HandE gripper as shown in Figure 1, which allows us to present stiffness in response to pressure by controlling the folding speed with the gripper's fingers.

3 SHIFTLY

Inspired by [Rabinovich et al. 2019], Shiftly uses a curved origami pattern to transition from zero to positive stiffness by activating

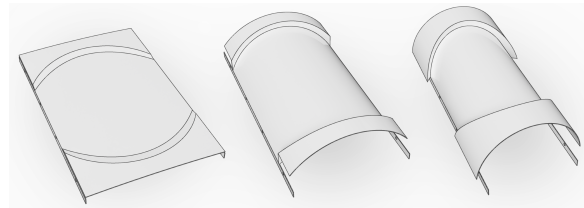

Figure 3: Depiction of Shiftly's origami pattern and folding that results in a stiff curved surface.

predefined creases. We lock or unlock the folding creases with a single mechanical motorized trigger applying the force along the shorter side of the sheet (see Figure 3), using three E Series Nema 17 stepper motors with 16 Ncm holding torque. Our shape display is based on a combination of three pieces of dense paper with curved creases mounted on a rectangular frame each that are arranged in a triangular prism. The device's frame length is 233mm, and its width depends on the contraction and extension of each folding element, ranging from 92mm to 148mm, making the touch area of the origami wide enough for a hand. The 360° touch surface is 97mm long and reaches up to 183mm between the creases at the center of the surface.

Shiftly can render different shapes variations, from a prism to a cylinder with partial side transitions thanks to the independent actuation. The depictions of possible transformations (full contraction, partial contraction, and fully extended state) are shown in Figure 1. The configuration of Shiftly allows the simulation of objects and materials familiar to real life: from cups, bottles, or pipes in full contraction to books, corners of the walls, or sharp edges of the furniture in full extended mode.

4 DEMONSTRATION

In the demonstration, the participants will explore a VR material palette and several differently shaped objects. The stiffness of different virtual material samples will be simulated with the zipper flower tube on a robotic gripper. Our Shiftly prototype will simulate three virtual objects of different shapes, e.g., a coffee mug in round contraction, a document folder in partial contraction, and a triangular box in the fully extended state.

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