Demonstration of ElaStick: A Variable Stiffness Display for Rendering Handheld Flexible Object

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Figure 1: (a) ElaStick prototype and components, (b) user interaction with the ElaStick physical controllers, which is mapped to a flexible sword in virtual reality (c).

ABSTRACT

We present ElaStick, a handheld variable stiffness controller capable of simulating the kinesthetic sensation of deformable and flexible objects when swung or shaken. ElaStick is capable of rendering gradual changes of stiffness along two independent axes over a wide continuous range. Two trackers on the controller enable a closed-loop feedback that allows to accurately map the device's deformations to the visuals of a Virtual Reality application.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**.

KEYWORDS

haptics, dynamic force response, stiffness, virtual reality, controller

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1 INTRODUCTION

Virtual reality (VR) technology have come a long way, as various attempts have been made to improve the realism and immersion of the VR experience through haptic force-feedback. In fact, past research demonstrated that force feedback can greatly increase the realism of VR experiences. Examples include controllers that can simulate differently sized objects and their motion by rendering variation of inertia or rotational inertia [Shigeyama et al. 2019; Zenner and Krüger 2019], center of weight [Je et al. 2019], and damping oscillations of an object constrained by elastic strings mounted on the tip of a controller [Tsai et al. 2020]. However, existing approaches have not been able to create the haptic feedback of an object that flexibly deforms as users shake and swing it. By rendering various flexibility of an object, a user could, for example, perceive objects with different stiffness, as well as different shape, length and material.

To address this limitation we introduce ElaStick [Ryu et al. 2020], a novel controller capable of rendering variable and anisotropic stiffness in two independent axes. As a result, ElaStick is capable of simulating the sensation of holding deformable objects of different size or material composition. We demonstrate these capabilities with an application in which the user can experience holding and swinging swords of different lengths and material properties – the stiffness of the metal blade changes depending on the type of of sword the user holds, and depending on the material state of the blade, such as melted by fire or hardened by cold water.

2 SYSTEM IMPLEMENTATION

ElaStick (Figure 1) is a force-feedback controller compatible with the VIVE tracking system. It is composed of a movable and trackable tip, whose motion is constrained by two orthogonal pairs of variable stiffness tendons. Specifically, the tip was designed using a quaternion joint, which provides two-degree-of-freedom (2-DOF) bending motion without twisting. Four variable stiffness tendons around the joint connect both ends of the quaternion joint to adjust the device's stiffness. Each tendon is a series of two connected

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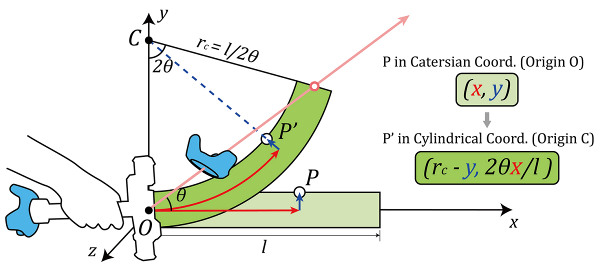


Figure 2: Estimation of deformation of virtual object using two VIVE trackers.

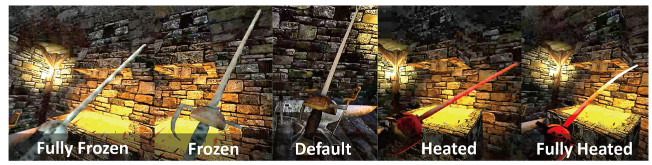
strings made by elastic rubber and inelastic fishing wire, whose stiffness is controlled by modulating the *effective length* of each string through winding and unwinding using spool motors. Using this setup, ElaStick can change its stiffness in a continuous range between 10.8 and $71.5 Nmm/°$ in two independent axes. A full description of the system and its mechanical characteristics was published at UIST 2020 [Ryu et al. 2020].

Unlike the system described in our prior work which does not allow exact tracking of the device deformation, in this SIGGRAPH Asia demonstration we have improved the ElaStick device by implementing a full feedback closed-loop controller. We achieved this by adding two VIVE trackers, one on each end of ElaStick (tip and handle, as seen in Figure 1). To correctly estimate the deformation of the virtual object, we assumed as in [Ryu et al. 2020] that the center line of the target virtual object has constant length and forms an arc whose endpoint is located along the direction where the ElaStick's tip is pointing. Then, the Cartesian coordinates of the object vertices are transformed to the corresponding cylindrical coordinates around the arc's center. For example, as shown in Figure 2, if ElaStick bends θ angle around the z axis from the initial state, the center line of a l long object draws an arc with a radius of $r_c = l/2\theta$ and a center angle of 2θ, and have the point C as its center. Then, the x and y coordinates of the vertex at P are transformed to the corresponding coordinates in cylindrical coordinates (P') in respect to the center C, with a radius of $r_c - y$ and an angle of $2\theta x/l$. The transformation of the mesh was implemented by building a custom shader in Unity Engine that directly maps the vertices of the mesh to the exact deformed shape of the physical controller.

3 APPLICATION

In previous work [Ryu et al. 2020], we suggested ideas for different form factors and application scenarios in VR games and training. In this demo, we present the Unity VR application "Magic Forge" which demonstrates ElaStick's capabilities of rendering continuous anisotropic stiffness in two axes, mapped to deformable virtual objects using a real-time closed-loop. In "Magic Forge", users choose, wield, and swing three types of swords (rapier, dagger, and saber) with different stiffness properties. Reflecting the characteristics of a rapier (thin and long), it has isotropic stiffness ($22.2 Nmm/°$) that flexes slightly when swung. The dagger expresses a knife with a short length (about half of a rapier) and has consequently higher stiffness ($44.5 Nmm/°$). Lastly, the saber has the same length as the rapier but with lower stiffness in the flat direction ($17.1 Nmm/°$) than in the edge direction ($51.3 Nmm/°$). As a consequence, users can feel a stiff blade when slashing the saber but fluttering oscillations when moving it along the flat direction.

(a) Three different swords in "Magic Forge"



(b) Heated/frozen swords due to user's interaction in "Magic Forge"

Figure 3: Rendered sword blades having different shape and state in "Magic Forge".

The user can further interact with the swords above by dynamically changing the material properties of the blades, further demonstrating the system's capability to render gradually varying stiffness in a wide range ($10.8 - 71.5 Nmm/°$). By holding the sword above a furnace, the stiffness gradually decreases, and this property change is visualized as using a glowing and flexible blade. Conversely, the opposite effect can be achieved by dipping the sword in a water basin, resulting in gradually stiffer blade and visualized as a freezing and stiff sword. The sword can assume any stiffness value within these two extremes.

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