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A Novel Haptic Feedback Device Using Stick-Slip Actuators

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I. Introduction

Stick-slip actuators (SSAs), commonly used in high-precision positioning systems, provide precise linear motion through stick-slip motion induced by frictional and inertial forces. However, their potential for haptic feedback applications remains largely unexplored. In this paper, we propose a novel haptic feedback device that utilizes an SSA to enable dynamic grasping and generate various tactile sensations. Unlike conventional systems that require multiple actuators or complex mechanical structures to deliver both haptic expressions, our device achieves comparable effects using only a single actuator.

The advancement of virtual reality (VR) technologies has increasingly enabled immersive experiences, primarily through the use of audiovisual presentations. However, replicating realistic tactile interactions with virtual objects remains a significant challenge, limiting the improvement of the sense of presence and operability. Accordingly, numerous studies have explored the development of interfaces that deliver richer haptic experiences [1], [2].

Among various tactile modalities, this research focuses on the perception of object grasping, surface texture, and slippage within virtual environments. Previous studies have proposed a range of devices to address these aspects [3], [4]. For instance, Choi et al. combined a voice coil actuator (VCA) with a braking mechanism to develop a device capable of simulating the weight and grasping sensation of virtual objects using the thumb, index, and middle fingers [3]. Similarly, Lee et al. proposed a VR haptic device incorporating a force sensor, trackpad, and VCA without any movable components, demonstrating improved reliability while enabling tactile expression of surface textures and softness [4]. However, many existing methods require complex structures and multiple actuators to simultaneously provide force feedback and friction or slippage sensations, remaining miniaturization and simplification problems.

To address these issues, we propose a novel haptic feedback device employing a stick-slip actuator (SSA). An SSA consists of a piezoelectric element, a drive rod, and a slider (Fig. 1). By applying periodic electrical signals to the piezoelectric element attached to the drive rod, microscopic vibrations and displacements are generated. The resulting frictional and inertial forces between the drive rod and the slider produce linear motion [5].

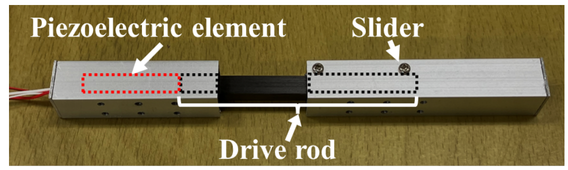

Fig. 1. **Structure of the stick-slip actuator.** The left end of the drive rod is fixed, with the piezoelectric element attached. A friction material is mounted inside the slider. When a periodic electrical signal is applied to the element, it induces microscopic vibrations in the drive rod. By varying the signal pattern, the slider moves left or right.

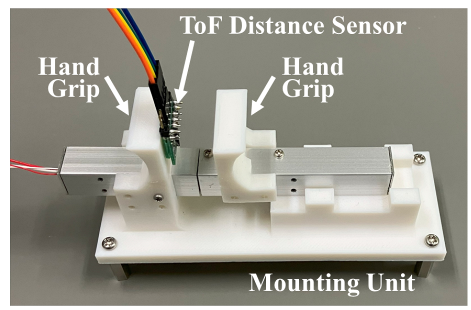

Fig. 2. **Prototype of the proposed haptic feedback device using SSA.** The device consists of SSA, two hand grips, and a ToF distance sensor, and all integrated via a mounting unit.

Although SSAs are typically utilized in high-precision positioning systems [5], such as nanopositioning stages and micro-manipulators, our study explores their novel application in user-interactive scenarios, specifically for haptic feedback in VR. This study focuses on their mobility and stick-slip-based actuation mechanism to generate diverse sensations and enable dynamic grasping within a single device. Additionally, the actuator can continue to generate tactile feedback even when moderate external forces are applied by the user. Such capabilities have been difficult to achieve with conventional devices.

Furthermore, by synchronizing the device with visual content, we aim to establish multimodal interaction systems where, for example, a CG character's biting motion is synchronized with the device, conveying sensations such as the feeling of chewing and the reactive force from an object to the user's fingers.

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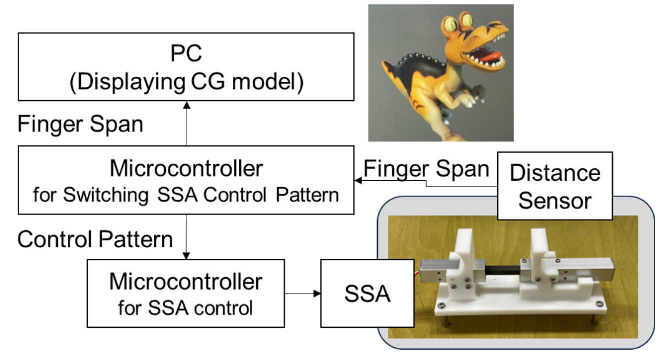

Fig. 3. **Process Flow.** The SSA is controlled based on the measured distance between hand grips, and its state is synchronized with a CG model on the PC to provide multimodal feedback.

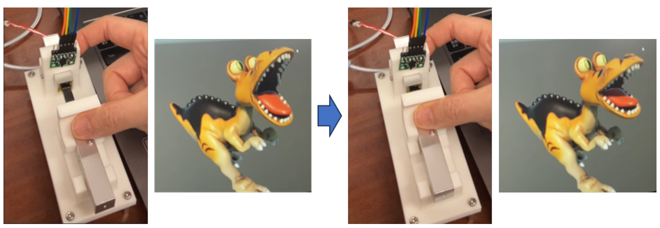

Fig. 4. **Example implementation of synchronized visual and haptic feedback.** The user operates the device by pinching and releasing it, which controls the mouth movement of a CG character. During the biting motion, the user feels varying tactile sensations, firmness, vibration, and softness, simulating the experience of biting through a hard object like a can.

II. Stick-Slip Actuator

In this study, we utilize a stick-slip actuator (SSA) manufactured by Microb Co., Ltd., Japan, as the actuator of the proposed device. The structure of the SSA used in our system is shown in Figure 1. The SSA consists of a piezoelectric element, a drive rod, and a slider. When a periodic electrical signal is applied to the piezoelectric element fixed to one end of the drive rod, the rod oscillates microscopically. By varying the input signal pattern, the slider moves left or right, enabling the actuator to expand and contract linearly.

The SSA operates through stick-slip motion based on friction and inertia forces. This mechanism allows the actuator to continue generating tactile feedback even when moderate external forces are applied by the user, making it well-suited for finger-controlled haptic devices.

III. System Configuration

Figure 2 illustrates the prototype of the haptic feedback device based on the SSA. It consists of the SSA, hand grips, and a mounting unit, both fabricated using a 3D printer and integrated with the SSA. A distance sensor is installed on one of the grips to measure the distance between the two grips. Based on this distance information, the system dynamically controls the SSA's movement direction and operation mode, enabling various tactile sensations in response to finger motions. Simultaneously, a CG model displayed on a PC (Unity) changes in coordination with the measured distance.

The overall system architecture is illustrated in Figure 3. The system comprises an SSA, a microcontroller for SSA control, a time-of-flight distance sensor (Pololu VL6180X), and a microcontroller for switching SSA control patterns (Raspberry Pi Pico) based on distance measurements. Distance data is transmitted to a PC via socket communication, allowing the visual content in Unity to change according to the distance between the user's fingers.

As an example implementation, we developed a content scenario where the opening and closing of the device corresponds to the mouth movement of a CG dinosaur character (Figure 4), aiming to present sensations such as the feeling of chewing and the reactive force from an object to the user's fingers by driving the SSA accordingly. While a virtual object (e.g., a can) being bitten by the character has not yet been implemented, the haptic feedback component is functional. In this scenario, the user can feel tactile sensations during the simulated biting motion. For instance, when imagining the character biting a hard object like a can, the user first perceives a firm resistance, followed by vibration, and then a softer sensation as if the can is being crushed.

Currently, we have designed four SSA operation patterns. By switching among these patterns depending on finger distance, the device can present various tactile sensations, such as softness and hardness sensations, as well as force sensations by switching vibration and expansion/contraction directions.

IV. Conclusion and Future Work

In this paper, we proposed a novel haptic feedback device utilizing a stick-slip actuator (SSA) and described its system architecture and key features. By controlling the actuator's movement direction and operational patterns, the device enables tactile sensations based on both slippage and friction, as well as dynamic grasping capabilities that have been difficult to achieve with conventional devices.

Future work includes expanding the range of tactile expressions achievable with SSAs and integrating audiovisual and haptic stimuli for synchronized multimodal interaction in VR environments. Building on insights from prior work [6], we also plan to conduct a user study to evaluate the system's effectiveness in delivering synchronized visual and tactile feedback.

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