ICAST2019: 30th International Conference on Adaptive Structures and Technologies
October 7-11, 2019, Montreal, QC, Canada

Incorporating Sensing Capability in an Electrorheological Haptic Module

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Abstract
We present embedding a sensing capability to a slim haptic actuator based on electrorheological (ER) fluids, designed for conveying vivid kinesthetic and tactile sensations at small scale. Haptic feedback is produced through electrorheological fluid's controllable resistive force and varies with the actuator's deformation. To demonstrate the proposed actuator's feedback in realistic applications, a method for measuring the actuator's deformation must be implemented for feedback control. To this end, in this study, we incorporate a sensor design based on stress-sensitive resistive film in bending to the ER haptic actuator. The combined actuator and sensor module was tested for its ability to simultaneously actuate and sense the actuator's state under indentation. The results show that the deflection sensor can accurately track the actuator's displacement over its small stroke range. Thus, the proposed sensor may enable control of the output resistive force according to displacement.

Introduction
Haptic technology has become essential in electronic devices today to bridge the gap between our physical world and virtual information through the sense of touch. Haptic feedback consists of two sensations: kinesthetic and tactile. Kinesthetic feedback is acquired by receptors in joints, muscles and ligaments, and provides information about force and displacement. Tactile feedback is observed by cutaneous receptors and provides information about vibration, texture and friction (Srinivasan and Basdogan, 1997). For the greatest immersion when designing for haptic feedback, both modes of feedback must be present.

The authors developed a haptic actuator based on electrorheological fluid that can convey both kinesthetic and vibrotactile sensations in a compact form (Mazursky et al., 2018, 2019). To demonstrate this actuator in real-world applications, such as haptic rendering of compliant objects, a method of sensing the actuator's state is necessary to incorporate control. Thus, the primary goal of this study is to embed a displacement sensor within a haptic button actuator based on mixed modes (squeeze and flow) of ER fluid, where sensations are generated from fluid flow through charged electrodes due to the user's interaction. Hence, to control the actuator's force output with respect to the user's finger position, this study investigates the addition of a stress-sensitive sensor to measure the displacement of the actuator's contact surface.

Methods
The mixed mode ER haptic actuator with the proposed sensor are presented in Fig. 1. When a user presses down on the contact surface, ER fluid beneath it is driven through squeeze and valve electrodes. Therefore, the resistive force felt in the user's finger directly corresponds to the fluid's yield stress under applied field. For a range of applied voltage magnitudes and frequencies, a range of haptic sensations may be felt by the user. The deflection sensor consists of a stress-sensitive film with resistance sensitive to bending. The sensor is adhered to the surface of the haptic actuator and spans halfway across the contact surface. Thus,

when the user interacts with the device, they press directly on the bending sensor and contact surface. By measuring the change in voltage across the sensor, the indentation depth may be approximated in real time.

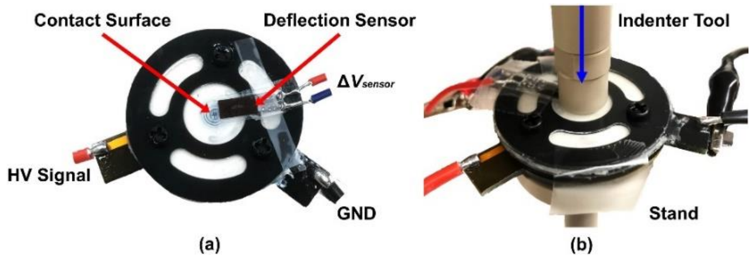

Figure 1. **(a)** Top-down view of the combined haptic actuator-sensor system and **(b)** the experimental setup.

To test the simultaneous performance of the actuator and sensor, mechanical analysis was conducted with a dynamic mechanical analyzer. As shown in Fig. 1b, this experimentation measured the total resistive force with respect to indentation depth over the actuator's 1 mm stroke. Two cycles of loading/unloading were performed at a rate of 1 mm/s. A function generator and voltage amplifier were used to supply the high voltage (HV) to the actuator's electrodes. A microcontroller was used to record the voltage across the sensor over time.

Results and Discussion

Figure 2 presents the combined actuator (force vs. time) and processed sensor (indented depth vs. time) data from the described experiment. Figure 2a and b show the response when 0 kV and a 4 kV 3 Hz sine wave are applied, respectively.

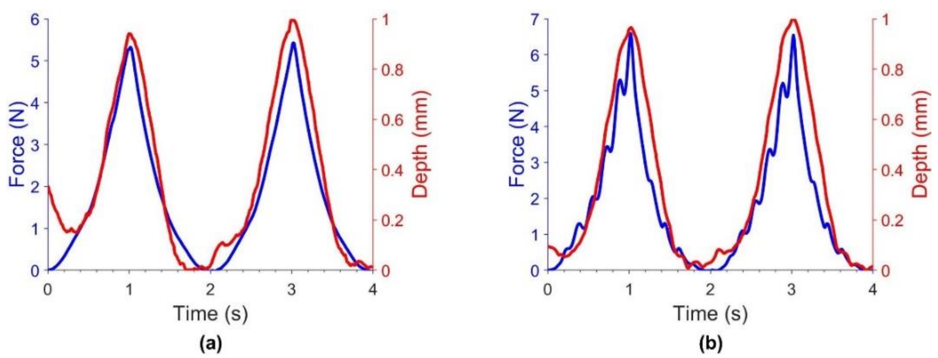

Figure 2. Actuator and sensor response subjected to **(a)** 0 kV and **(b)** 4 kV sine wave at 3 Hz.

As shown, the deflection sensor sufficiently tracks the actuator's displacement (1 mm over 1 second) and corresponding force output for both the off-state and high voltage. Therefore, the proposed sensor can enable control of the output resistive force according to displacement to demonstrate realistic applications of the ER fluid-based haptic module. Furthermore, the sensor does not impede upon the tactile and kinesthetic sensations (observed as oscillations in force in Fig. 2b) and the actuated forces do not influence the sensor's response.

References

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