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Bottle of Water: Demonstrating Stiffness, Mass, and Inertia by Controlling Fingertip Contact Plane Tilt

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***Abstract*—Humans perceive various tactile sensations of objects through Exploratory Procedures (EPs). For instance, depending on different EPs such as enclosure, pressure, and shaking, users can perceive shape, stiffness, or the weight of contents within a container. Therefore, to present virtual objects with a high sense of reality, a device capable of rendering multiple physical properties corresponding to the user's interaction is required. However, it is challenging to mechanically implement and integrate multiple property rendering functions into a single device, especially for handheld haptic devices, due to constraints on weight, size, and rendering range. To address this issue, we have developed a haptic presentation system that focuses on human tactile perception characteristics and complementarily utilizes limited mechanical tactile stimuli and visuo-haptic interaction. The proposed system integrally controls and presents tactile cues regarding the tilt of the contact plane at each fingertip, which plays a dominant role in curvature perception, along with visual cues, based on the user's grasping and manipulation interactions. In this demonstration, we use a water-filled plastic bottle as an example to present its shape, stiffness, and the dynamic behavior of the water inside.**

***Index Terms*—Shape presentation, Stiffness presentation, Inertia presentation, Exploratory Procedures**

I. Demonstration Description

In this demonstration, participants will wear our developed handheld haptic device and a Meta Quest 3 to engage in the experience. Figure 1 shows an overview of the experience system. The participant will wear the microcontroller and battery unit on their wrist and hold the main body of the haptic device with their thumb, index finger, and middle finger. A pressure sensor is placed on the thumb part. This pressure sensor measures the user's grasping force and controls the haptic and visual stimuli.

Figure 2 illustrates a scene from the experience. In the virtual environment, a virtual desk, which is a virtual object, is placed at the same position as a real desk arranged in the physical space. Additionally, a virtual plastic bottle filled with water is placed on the virtual desk. The participant will grasp and manipulate this virtual bottle. In this demonstration,

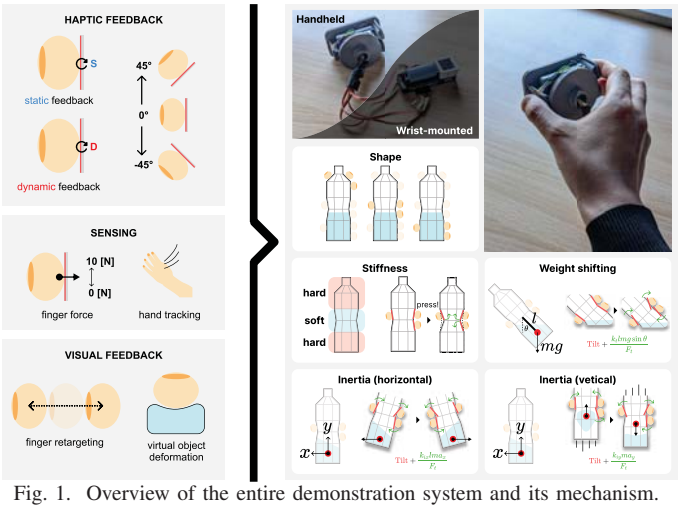

Fig. 1. Overview of the entire demonstration system and its mechanism.

the interactions available to the user and the presented tactile properties are as follows:

- Grasping the virtual bottle (Shape)
- Squeezing the virtual bottle (Stiffness)
- Tilting the virtual bottle (Center of gravity shift)
- Shaking the virtual bottle (Inertia)

The experience will be conducted while seated. The minimum duration for the experience is 5 minutes in total, consisting of 2 minutes for instruction on proper operation and 3 minutes for the experience itself.

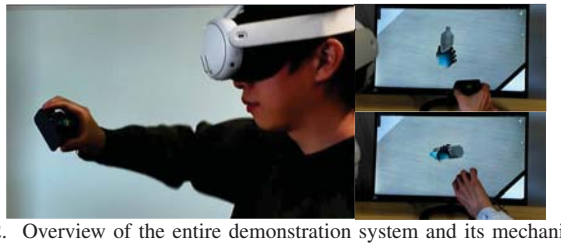

Fig. 2. Overview of the entire demonstration system and its mechanism.