Demonstration of ThermAirGlove: A Pneumatic Glove for Material Perception in Virtual Reality through Thermal and Force Feedback

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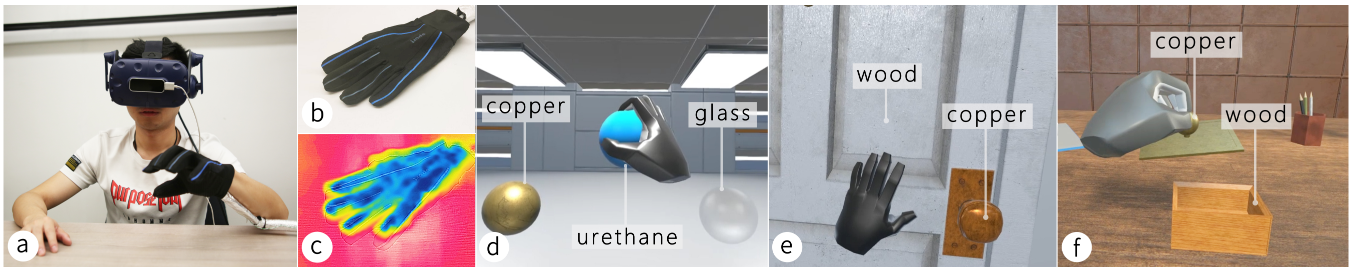

Figure 1: (a) a user wearing ThermAirGlove (*TAGlove*) and grasping the virtual object in VR, (b) the RGB image of *TAGlove*, (c) the thermal image of *TAGlove* filled with cold air, (d-f) Examples of *TAGlove* applications in virtual scenes, left to right: three virtual spheres with different materials, a wood door with a copper handle, a wood box with a copper lid.

CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**; **Haptic devices**.

KEYWORDS

Haptic glove, pneumatic, thermal, material identification, virtual reality

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1 INTRODUCTION

The main goal of haptics in VR is to improve the realness of the simulated scenario. One of the major real-world activities is to identify the size and the material of an object. Typically, when a real object is grasped in the hand, its size can be perceived through the kinesthetic force and constraint on the fingers, and its materials and surface temperature can be informed by the thermal cues. As the skin of human fingers is usually warmer than the objects under the room temperature (24 - 26 °C), the thermal perception mainly comes the responses of cold thermoreceptors in the skin. The decrease in skin temperature can infer the material composition of the object, such as metal, wood, plastic, etc.

While various solutions [Bouzit et al. 2002; Chen et al. 2018; Connelly et al. 2010; Zhu et al. 2019] have been proposed to provide the kinesthetic force feedback in VR, it is still challenging to use these devices to perceive the virtual objects with similar shape yet different materials. For example, two virtual cups with the same shape, one of which is made of steel and the other is plastic, will feel the same based on the force feedback. On the other hand, Ho's research [Ho 2018] showed that the subjects could identify different materials with significant different thermal properties, ranging from foam, glass, wood, to copper. In addition, the rigid peltier-based thermoelectric cooler (TEC) can provide thermal feedback in VR [Peiris et al. 2017], which can potentially simulate the perception of materials. However, directly attaching the rigid TEC modules on a VR user's hands may restrict the finger movement, and affect the user experience in VR.

We demonstrate ThermAirGlove (*TAGlove*), a pneumatic glove with embedded air bags which provide concurrent on-hand thermal and force feedback in VR. Besides simulating VR objects in different temperature, *TAGlove* could generate the thermal cues of different materials (e.g., copper, glass, urethane, etc.) by controlling the air temperature, and support users' material identification in VR. In addition, the force feedback by the inflated air bags could simulate the size of the virtual objects.

2 SYSTEM DESCRIPTION

The *TAGlove* system (Fig. 2) consists of a glove with five inflatable air bags attached on fingers and the palm, two peltier-driven temperature chambers (one at 68°C and one at 2°C), and the pneumatic control system. These system components are connected to

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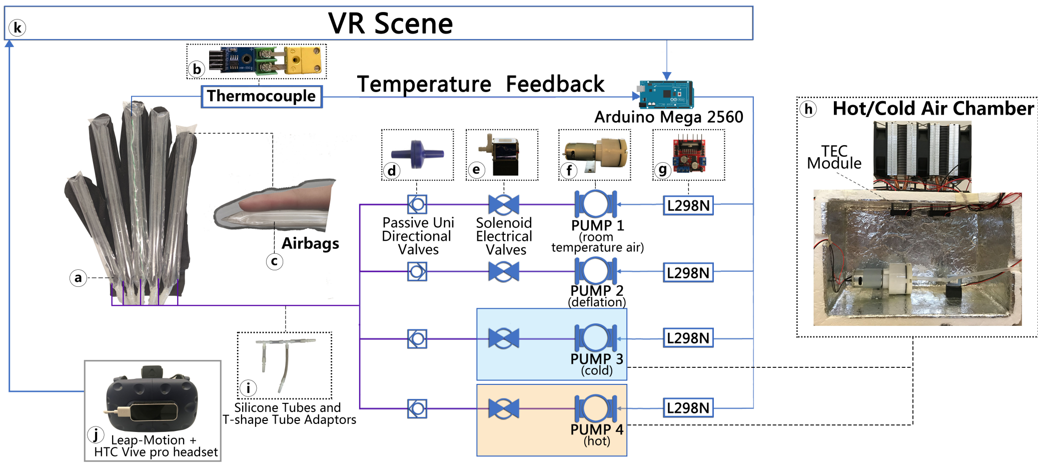

Figure 2: System Diagram of *TAGlove.*

each other through four solenoid electrical valves, four passive uni-directional valves, and four air pumps. Using Aruidno Mega, each pump was controlled by an external motor-driver circuit (L298N) with an external power supply of 24V5A. In the thermal and pneumatic control system, we used three air pumps to mix the hot, the cold, and the room-temperature air into the glove, and used one pump for deflation. To reduce the heat transfer during the air-pumping process, the cold and the hot pumps with solenoid valves were placed into the temperature chambers, and the silicone tubes were wrapped with thermal insulation materials. To generate the thermal cues of different materials, we implemented the PID algorithm, to fit the temperature of the air in the airbags with the values predicted by the semi-infinite body model of human skin contacting with a particular type of material [Ho 2018]. A type-K thermocouple was attached on the airbag on the middle finger to acquire the real-time temperature for the pump control.

We further technically validated the system by letting a user wear *TAGlove* and grasp three different balls in VR (Fig. 1a & d). The three virtual balls were made of three types of material (i.e., urethane, glass, copper) with significantly different thermal properties in VR. The system tracked the user's hand movement in VR using Leap-Motion, and triggered the pneumatic thermal system when the user's hand touched the virtual object. The results (Fig. 3) showed that when the user grasped virtual spheres, the temperature change of the airbag in contact with the finger could be consistent with the temperature trend from the theoretical model [Ho 2018]. With the PID control, the pneumatic thermal system could reach the thermal equilibrium within 2s. That is, right after the user's hand grasping the object, the system can rapidly decrease the airbag temperature, averagely 2.75°C/s for simulating copper and 1.87°C/s for glass, while there is no significant change of the temperature for urethane. Therefore, it could be feasible to use *TAGlove* to simulate the perception of touching virtual objects made of different materials and in different temperature, and further improve the realistic sensations in VR. Fig. 1e & f further illustrate two demonstrative scenario of using *TAGlove* in VR.

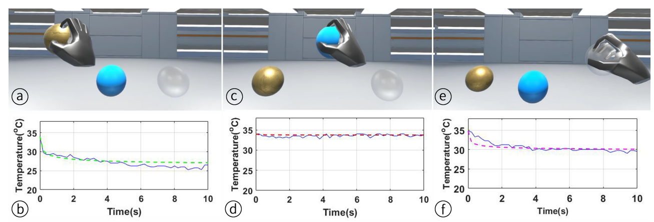

Figure 3: The temperature of the skin-contact airbag measured by the thermocouple (solid line) and the change of skin temperature predicted by the theoretical model (dotted line): (a & b) copper, (c & d) urethane, and (e & f) glass.

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