RecyGlide: A Forearm-worn Multi-modal Haptic Display aimed to Improve User VR Immersion Submission

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ABSTRACT

Haptic devices have been employed to immerse users in VR environments. In particular, hand and finger haptic devices have been deeply developed. However, this type of devices occludes hand detection for some tracking systems, or, for some other tracking systems, it is uncomfortable for the users to wear two different devices (haptic and tracking device) on both hands. We introduce RecyGlide, a novel wearable multimodal display located at the forearm. The RecyGlide is composed of inverted five-bar linkages with 2 degrees of freedom (DoF) and vibration motors (see Fig. 1.(a)). The device provides multimodal tactile feedback such as slippage, force vector, pressure, and vibration. We tested the discrimination ability of monomodal and multimodal stimuli patterns on the forearm and confirmed that the multimodal patterns have higher recognition rate. This haptic device was used in VR applications, and we proved that it enhances VR experience and makes it more interactive.

CCS CONCEPTS

• Human-centered computing → Haptic devices.

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KEYWORDS

Multi-modal haptics, vibrotactile feedback, VR applications

1 INTRODUCTION

Recently, multiple VR applications have been proposed in many fields: medicine, design, marketing, etc., and to improve user immersion, new methods or instruments are needed. Haptic technologies provide a solution and enhance user experience using tactile stimuli [Han et al. 2018]. Most haptic devices are located on the palm or fingers. However, in some cases, the haptic device position is a problem because VR Hand Tracking Systems need visible fingers (Leap Motion) or a hand controller (HTC VIVE SYSTEM) to recognize the position of the hand. Therefore, we propose a novel multimodal haptic display located on the forearm.

Various forearm haptic devices with monomodal stimuli have been developed [Dobbelstein et al. 2018; Moriyama et al. 2018]. However, they have a persistent problem: users experience more difficulty perceiving a stimulus on the forearm. The forearm is not
an advantageous zone since it does not have as many nerves comparing with a palm or fingertips. Consequently, our device produces multimodal stimuli for improving user perception. Furthermore, multimodal stimuli experiments have been employed on the users’ hands, where the results show improvements in pattern recognition [Cabrera and Tsetserukou 2019].

2 USER STUDY
The objective of this study is to analyze the users’ perception and recognition of patterns when monomodal and multimodal stimuli are rendered on the forearm and to determine if the multimodal stimuli increase the users’ perception of the contact point position. Six volunteers completed the experiments. Before each section of the experiment, a training session was conducted, where all the patterns were delivered to the users five times. In the first phase of the experiment, the user only feels the sliding sensation on the skin generated by the device. In the next phase of the experiment, the user experiences stimuli through a combination of vibrating motors and the aforementioned sliding sensation. The results of the experiment will help to understand if the two tactile channel stimuli improve the perception of the position generated by RecyGlide device.

For the execution of this experiment, a pattern bank of 6 different combinations between displacement and vibratory signals on the right forearm was designed and is shown in Fig. 2. In the first group (patterns a, b, and c), monomodal stimuli are delivered; the second group (patterns d, e, and f) consists of multimodal stimuli. The vibration is delivered progressively according to the contact point.

Figure 2: Displacement patterns: (a) Small (SD): 25% (17.84 mm). (b) Medium (MD): 50% (35.67 mm). (c) Large (LD): 75% (53.51 mm). (d) Small with vibration (SDV): 25%. (e) Medium with vibration (MDV): 50%. (f) Large with vibration (LDV): 75%.

3 EXPERIMENTAL RESULTS
The results of the experiment revealed that the mean percentage of correct scores for each subject averaged over all six patterns ranged from 80 to 96.7 percent, with an overall group mean of 90.6 percent of correct answers. The confusion matrix shows that the distinctive patterns LDV and SDV have higher recognition percentage of 100 and 97, respectively. On the other hand, patterns MD and SD have lower recognition rates of 80 and 77 percent, respectively. For most participants, it was difficult to recognize pattern SD, which was usually confused with pattern MD. Therefore, it proves the requirement of more distinctive tactile stimuli (vibration) to improve the recognition rate. The results of the single factor analysis of variance (ANOVA) without replication showed a statistically significant difference in the recognition rate of different patterns (F(5, 30) = 3.2432, p = 0.018532 < 0.05). The paired t-tests showed statistically significant differences between the SD and SDV (P=0.041<0.05), and the statistical difference between MD and MDV (P=0.025<0.05). These results confirm our hypothesis that the multimodal stimuli improve the perception of the position for small displacements.

4 APPLICATIONS
For the demonstration of RecyGlide, some applications were developed using the Unity 3D game engine. The SubmergingHand application clearly illustrates how the device improves user immersion in a virtual reality environment. The device provides a sensation of the liquid level using the position of the contact point on the forearm. The viscosity of the liquid is represented by the normal force applied in the contact point. When the liquid is viscous, the applied force is high, and the vibration motors work with a higher frequency. The application is shown in Fig. 1.(c) (top).

The “Edgefeel” application is an example of how our device helps to perceive the VR environment. Usually, VR users do not distinguish object boundaries and do not feel the physical limits of static objects in scenes such as walls and tables. RecyGlide informs the boundary collision of the hand tracker by activating the vibration motors and moving the contact point to one of the two sides, which is called “collision side” (Fig. 1.(c) (bottom)).

5 CONCLUSIONS
We proposed a new forearm-worn haptic device and conducted several experiments with it. The results of the experiment demonstrated that multimodal patterns are easy to recognize. Therefore, we consider that the device is suitable for sending various VR messages to the user through the designed patterns.

Though the forearm is not an advantageous area, the device has excellent performance and improves VR realism and user immersion. The feeling of submersion in liquids can be used in numerous applications such as submersion and medical simulators, games, etc. Boundary collision detection is useful for all kinds of VR applications because it is a constant problem in VR environments.

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