Preliminary Investigation of Text Entry Method with Haptic Feedback from Real Object Surfaces Estimated Using Hand Tracking on HMD

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ABSTRACT

In virtual reality systems, users enter text by selecting virtual keys with the fingers. A virtual keyboard is displayed in mid-air and thus does not provide haptic feedback. To address this problem, we present a text entry method that uses the surfaces of real objects around the user to provide haptic feedback. A real object surface touched a hand is recognized using the position and posture of the hand acquired by a hand-tracking sensor on a head-mounted display; a virtual keyboard is placed on that surface to provide haptic feedback. We performed a pilot study to compare text entry performance when the virtual keyboard was placed in mid-air, on a wall, on a desk, and on the user's thighs. The result shows that each virtual keyboard placement and the presence/absence of haptic feedback did not affect input performance.

CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**; **Text input**.

KEYWORDS

virtual reality, touch interaction, soft keyboard, on-world interaction

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1 INTRODUCTION

One method to enter text in virtual reality (VR) systems is to touch a virtual keyboard displayed in mid-air with the user's fingers; this does not deliver haptic feedback. The lack of such feedback affects input performance. Previous methods used a physical keyboard [4], a touch panel [3], or the user's own hands and arms [10] to deliver feedback. However, these methods require additional devices. Other methods use real objects to provide haptic feedback (e.g., [9, 11]). MRTouch [9] employs the surface of a real flat object captured by a depth camera on a head-mounted display (HMD). Gripmarks [11] estimates the shape of a real object that a user is grasping based on the shape of the user's hand, then displays an appropriate model in VR. This allows the user to obtain haptic feedback from the real object grasped.

We present a text entry method that provides haptic feedback by estimating the shape of a real object that the user touches. When the user thus chooses an object, the virtual keyboard is placed on the surface of the object by reference to the position, posture, and shape of the user's hand. This provides haptic feedback without any need for an additional device or a dedicated model.

2 TEXT ENTRY METHOD

We designed a trigger for the placement of a virtual keyboard on a real surface (Fig. 1). The user first performs a pinch gesture with the index finger and thumb (Fig. 1 left). Next, the user places both palms on the real surface for 3 s, which causes the virtual keyboard to be displayed (Fig. 1 right). The keyboard is designed based on Half-QWERTY [5] (Fig. 2). If the user executes the trigger with the right (left) hand, the right (left) half of the keyboard will be displayed. Because the keyboard is thus divided into two parts, the user can employ the surfaces of different objects using either hand.

Each real object surface is estimated by reference to the position and orientation of the hand (as aquired by the tracking sensor) when the user places a palm on the surface of the object. First, the approximate position and orientation of the surface are estimated from the hand position and orientation. Next, the curvature of the surface is estimated through cubic spline interpolation of the coordinates of all fingertips. The surface along the curve is thus unique. Finally, the virtual keyboard is placed on the estimated surface.

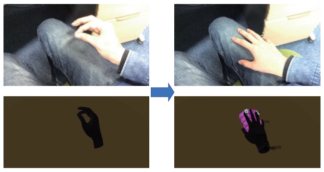

Figure 1: Trigger used to place the virtual keyboard.

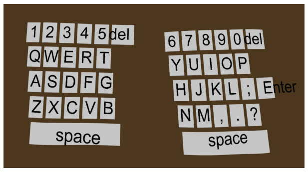

Figure 2: Virtual keyboard.

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3 PILOT STUDY

We conducted a pilot study with four participants (22–23 years, M = 22.5, SD = 0.5; all male; all right-handed; all from our laboratory) to evaluate our method's preliminary performance. We compared the performance of our method in four different placements of the virtual keyboard: mid-air (Fig. 3a), on a wall (Fig. 3b), on a desk (Fig. 3c), and on the user's thighs (Fig. 3d). We implemented the application using the Unity game engine running on a Hewlett-Packard laptop with an Intel Core i7-7700HQ CPU and an NVIDIA GeForce GTX 1070. We used an Oculus Quest HMD, which features a hand tracking sensor.

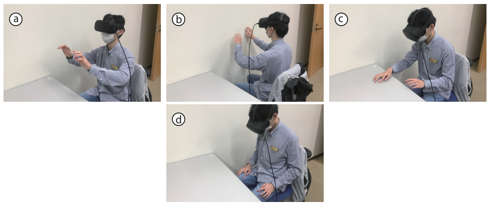

Figure 3: Four placements of the virtual keyboard with corresponding user postures for each placement.

3.1 Task and Procedure

Participants entered 10 sentences at each keyboard placement. The sentences were randomly selected from a list of sentences with at least four words and fewer than 40 characters in the Enron mobile message dataset [8]. Each test commenced with a 5-min tutorial. After a short break, the experiment proceeded. The keyboard placement order was counterbalanced using a Latin square. Before each placement, the participants took 5-min breaks. The participants were instructed to transcribe sentences as rapidly and accurately as possible. After each placement, the participants were asked to remove the HMDs and complete questionnaires exploring their preferences. Each experiment required approximately 60 min.

3.2 Results

We measured text input speed and accuracy by calculating the words per minute (WPM) [1] and total error rate (TER) [6] across the 10 sentences for each participant. In addition, we used the NASA Task Load Index (NASA-TLX) [2] to assess user experience and workload. Figure 4 shows the results. Because the normality assumptions were satisfied (Shapiro–Wilk test, WPM: $p = 0.8801 > 0.05$; TER: $p = 0.2709 > 0.05$; NASA-TLX: $p = 0.5141 > 0.05$), we used repeated-measures analysis of variance to compare the values. As the results, we found no significant difference between the placements (WPM: $F_{3,9} = 0.4460$, $p > 0.05$; TER: $F_{3,9} = 0.6235$, $p > 0.05$; NASA-TLX: $F_{3,9} = 1.9060$, $p > 0.05$) (Fig. 4a–c). However, a significant difference in NASA-TLX physical demand ($F_{3,9} = 4.2446$, $p < 0.05$) (a measure of physical work difficulty) was detected (Fig. 4d), although the Tukey honestly significant difference post hoc comparison did not confirm significance (all $p > 0.05$).

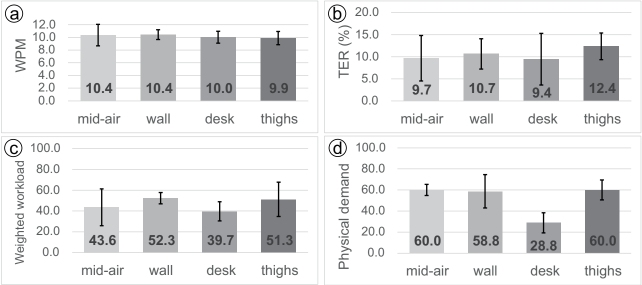

Figure 4: Input performances of the four placements: WPM (a), TER (b), NASA-TLX score (c), and physical demand (d). Error bars are ±1 standard deviation.

3.3 Discussion

The typing speed ranged from 9.9–10.4 WPM, consistent with the speed of typing on a QWERTY virtual keyboard in mid-air (9.77 WPM), reported by Speicher et al. [7] Therefore, all participants moved their index fingers at the same speed, regardless of keyboard placement. The mean TER of thigh placement tended to be higher than the mean TERs of other placements. This would be because the virtual keyboard placed on the thigh was smaller due to the narrower thigh as an input surface compared to the other placements.

The mean NASA-TLX score for wall placement tended to be higher than the mean NASA-TLX scores for other placements. The free-text questionnaire responses suggested that the virtual keyboard was not accurately placed on real surfaces; instead, it floated above the objects, causing discrepancies between visual and haptic feedback. Possible solutions include using the use of an increased number of points (e.g., > 5) for position estimation, non-uniform rational basis spline interpolation, or multiple measurements of fingertip coordinates followed by averaging. Non-uniform rational basis spline interpolation can increase the number of points, allowing the system to estimate more complex surface shapes than is currently possible.

4 CONCLUSION AND FUTURE WORK

We developed a VR text entry method that provides haptic feedback from a real object surface estimated using the position, posture, and shape of the hand acquired by a hand tracking sensor on a HMD. We conducted a pilot study to investigate our method's performance. We found no significant difference in mean WPM, TER, and NASA-TLX among the four placements (including mid-air placement). In the future, we will improve keyboard placement accuracy and evaluate the effect of improved accuracy and keyboard size on input performance. In addition, because our method can also be used in mixed reality, we will port it to the mixed reality environment and investigate input performance.

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