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# A Study on Text Entry in XR: Case of Korean

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**Abstract:** In recent years, extended reality (XR) devices have been developed into see-through HMD (Head Mounted Display) with bare-hand interaction. Previous studies on inputting text based on bare-hands in XR were mainly conducted using virtual keyboards, but most of them focused on inputting alphabetic characters, so there is still insufficient research on inputting Korean characters. In addition, virtual keyboards in previous studies were mainly augmented in mid-air, thus various augmented positions were not considered. Therefore, this paper presents a study on augmented positions for inputting Korean text in the XR environment. For this purpose, we developed an experimental environment for three augmented positions (mid-air, physical planar surface, and inner surface of the palm) based on the international standard Korean keyboard layout and analyzed its effects on text entry through an experiment. From the analysis results, it was confirmed that the virtual keyboard performed the best overall when augmented in mid-air.

***Keywords:*** *augmented reality, bare-hand interaction, extended reality, virtual keyboard*

## 1. Introduction

Extended reality (XR) is defined as an umbrella term that encompasses many kinds of reality [1, 2], such as virtual reality (VR), augmented reality (AR), and mixed reality (MR). Representative commercial XR devices include Microsoft's HoloLens, Apple's Vison Pro, XReal's Nreal Light, and Meta's Quest. These XR devices are either optical see-through (OST) head-mounted displays (HMD) focused on AR or VR HMDs that have a video see-through (VST) mode to support AR.

Text entry is an essential task in human-computer interaction [3-5]. In XR, which is a new interactive environment, virtual keyboards are primarily used, leveraging existing input technologies for user-friendly text entry [5, 6]. Today's XR devices, with the advancement of hand-tracking technology, use bare-hand interaction as an exclusive or additional input method [6, 7]. Interacting with the virtual keyboard using bare-hands in XR is primarily performed through direct hand touch [5, 6, 8].

However, most virtual keyboard studies in XR have focused on standard alphabetic characters using the QWERTY keyboard layout [9], so there is still insufficient research considering the international standard (2014, ITU E.161) Korean keyboard layout, Chon-Ji-In (hereafter CJI). In addition, virtual keyboards in previous studies were usually augmented in mid-air [4, 7, 9-14], and various augmented positions were not considered.

Therefore, this paper deals with the effect of augmented position on text entry through a virtual keyboard based on the CJI layout in the XR environment. Three different augmented positions are used (mid-air, physical planar surface, and inner surface of the palm), and through an experiment, the performance of the virtual keyboard is evaluated in three aspects (accuracy, letters per minute, and interaction satisfaction).

This paper is organized as follows. In Section 2, we introduce previous studies on virtual keyboards. Section 3 presents the experiment conducted on three augmented positions, and analyzes the experimental results. Finally, followed by conclusions in Section 4.

## 2. Related works

Studies on virtual keyboards for Korean text entry in XR environments are limited, and most have focused on the international standard CJI layout. Kim et al. (2018) proposed an interactive virtual CJI keyboard through eye tracking on a VR HMD with blocked surroundings [15]. The proposed method used eye tracking to move a pointer and eye blinking as the input signals. In their study, comparative experiments were conducted with and without filters on the tracked signals. Yu et al. (2023) proposed a virtual CJI keyboard augmented over fingers on a VR HMD with blocked surroundings and compared it with a virtual Korean two-set keyboard augmented in mid-air [16]. In their study, the virtual Korean two-set keyboard was operated through controller-based interaction or bare-hand interaction. However, the study has issues that the number of subjects was too small (5 people) and the comparison results are unknown as the usability evaluation was performed only on

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the proposed method. These studies were all conducted in blocked VR environments, so see-through was not considered. They also did not quantitatively compare different augmented positions.

Given these considerations, we further investigated virtual keyboard studies for inputting alphabetic characters through bare-hand interactions in XR environments. Speicher et al. (2018) implemented a virtual QWERTY keyboard augmented in mid-air on a VR HMD with blocked surroundings, and compared its performance of six input methods (head-pointing, controller-pointing, controller-tapping, hand, pad-based discrete cursor, and pad-based continuous cursor) [10]. The results of their study showed that the controller-pointing method performed the best. Xu et al. (2019) implemented a virtual QWERTY keyboard augmented in mid-air on an OST HMD, and compared its performance of eight combinations, which included four pointing methods (controller, head, hand, hybrid) and two input methods (tap and swipe) [4]. The results of their study showed that the best performance was achieved when the controller was used. Dudley et al. (2019) implemented virtual surroundings and then compared the performance of a virtual QWERTY keyboard on a VR HMD by combining two augmented positions (mid-air and desk surface) and two finger usage conditions (only index finger and all fingers) [5]. The results of their study showed that using only the index finger was generally superior. It was also confirmed that the presence of a physical desk surface resulted in lower error rates and increased comfort. Song et al. (2022) implemented a virtual QWERTY keyboard augmented in mid-air on a VR HMD with blocked surroundings, and proposed a method for inputting special characters using four hand gestures [9]. The proposed method enabled faster input than a typical virtual QWERTY keyboard without compromising the accuracy. Kem et al. (2023) implemented a virtual QWERTY keyboard on a VR HMD and compared its performance of four combination, which included two modes (VR and VST) and two input methods (tap and swipe) [6]. The results of their study showed that the VR mode outperformed the VST mode quantitatively; however, there was no difference in the subjective questionnaire results. It was also confirmed that the tap input method was superior to the swipe input method.

Most studies have implemented virtual keyboards using the standard QWERTY layout and augmented them primarily in mid-air. Although there have been studies that augmented positions other than the mid-air and compared them, there is insufficient research using the surface of the hand as an augmented position, such as [16]. Therefore, this paper aims to use mid-air and physical object surfaces as augmented positions, as in [5]. Inspired by [16], the inner surface of the palm is also considered as an augmented position.

## 3. Experiment and Discussion

### 3.1. Experimental environment

The experimental environment used Microsoft's HoloLens 2 as an XR HMD that supports bare-hand interactions (tracking both hands and fingers). The virtual keyboard was implemented using the Mixed Reality Tool Kit (MRTK), an XR content development library officially supported by Microsoft. The virtual keys for the interaction used the button object, which is one of the basic objects provided by MRTK. According to Dube and Arif (2020), the shape of the virtual key (e.g., square or circle) does not affect the input speed and error rate [17]; therefore, the implemented virtual keys are squares, which is the default button shape in MRTK. Previous studies [5, 6] showed that using only the index finger is faster and has fewer errors than using all fingers on a virtual keyboard, so the virtual keys were designed to support interaction with the index finger only.

The layout used for inputting Korean text on the virtual keyboard was the international standard CJI layout. The size (width × depth) of the virtual keys used in previous studies varied, such as (22.5 mm × 22.5 mm) in [6], (25 mm × 25 mm) in [5], (34 mm × 34 mm) in [18], and (45 mm × 45 mm) in [19]. Because most virtual keys had sizes ranging from approximately 2 cm to 4 cm, we used (30 mm × 30 mm) as the size of the virtual key (5 mm distance between each key was used). The implemented virtual keyboard is shown in Fig. 1 and includes special keys, as listed in Table 1, for operations such as inputting double consonants, combining vowels, and editing the input text.

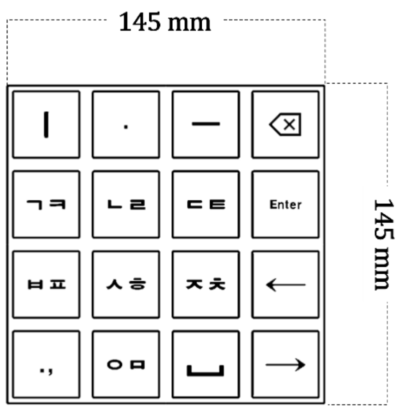



**Fig. 1.** Implemented virtual keyboard.

**Table 1.** Function keys of the implemented virtual keyboard.

| Function key | Description |
|---|---|
| Backspace | removes incorrectly an entered character. |
| Enter | submits an entered text. |
| Space | inserts a space character. |
| Next | moves a cursor to the next character position. |
| Previous | moves the cursor to the previous character position. |

The virtual keyboard was augmented in mid-air and two physical surface positions (physical planar surface and inner surface of the palm). The physical planar surface (hereafter plane-surface) refers to a flat surface, such as the top of a desk for virtual keyboard augmentation, as in [5], and the inner surface of the palm (hereafter hand-surface) literally refers to the palm surface of the hand.

The hand-surface is limited in area and differs in size among users. Considering this, the virtual keyboard at this position was augmented relative to the size of the user's palm. The palm size was calculated using hand pose estimation from HoloLens 2, as shown in Fig. 2, by tracking $p_{origin}$, $p_{axis}$, and $p_{ref}$; where $p_{origin}$ is the metacarpal joint of the pinky, $p_{axis}$ is the tip joint of the pinky, and $p_{ref}$ is the knuckle of the index.

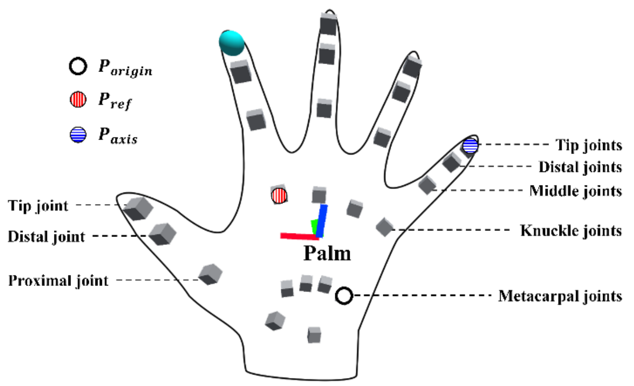



**Fig 2.** Hand pose estimation using HoloLens 2.

The detailed calculation process is as follows: 1) Create a vector $\vec{A}$ from $p_{origin}$ to $p_{axis}$ and a vector $\vec{B}$ orthogonal to $\vec{A}$ from $p_{ref}$. 2) The virtual keyboard is augmented in the position $p_{origin} + (\vec{A} - \vec{B}) / 2$. 3) The augmented virtual keyboard is configured using tracked rotation information of the palm. 4) The keyboard size is proportional to $\| \vec{A} \|$ and $\| \vec{B} \|$. The implemented virtual keyboard in the hand-surface is shown in Fig. 3.

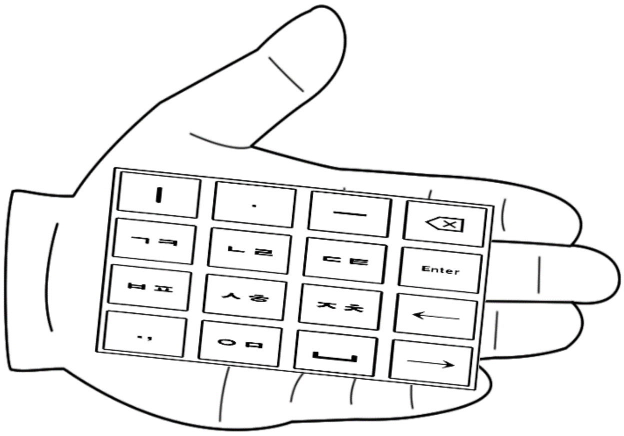



**Fig. 3.** Implemented virtual keyboard in the hand-surface.

Text entry is generally evaluated by inputting a predefined text phrase and comparing the measured performance of two or more input methods [6, 20]. The implemented virtual keyboard was also evaluated for text entry performance using this method. Fig. 4(a) shows the text entry via the virtual keyboard. The evaluation metrics for this virtual keyboard were accuracy and letters per minute (LPM), which are traditionally used. For alphabetic text entry, characters per minute is commonly used, but since Korean characters are typed letter by letter (e.g., consonants, vowels) and combined into a single character, the LPM was used. In addition, the interaction satisfaction was measured to confirm the impact of the virtual keyboard on user satisfaction. It was evaluated based on a 5-point Likert scale using the user interface shown in Fig. 4(b).


(a) (b)

**Fig. 4.** Example of performance evaluation: (a) Korean text entry; (b) interaction satisfaction.

### 3.2. Experimental procedure

The experiment was conducted following the procedure shown in Fig. 5, and the performance of the virtual keyboard was evaluated and compared in the three augmented positions (hereafter the mid-air position is referred to as $A_{air}$, the plan-surface position as $A_{plane}$, and the hand-surface position as $A_{hand}$). The augmented positions were presented in a randomized order to reduce the effect of participants adapting to the virtual keyboard.

The participants were recruited from among non-computer science students or first-year computer science students who were not expected to be familiar with XR. Recruitment was conducted through the intranet of the Korean National University of Technology and Education, and 20 participants were recruited (11 males and 9 females). Each participant was given an incentive to encourage participation.

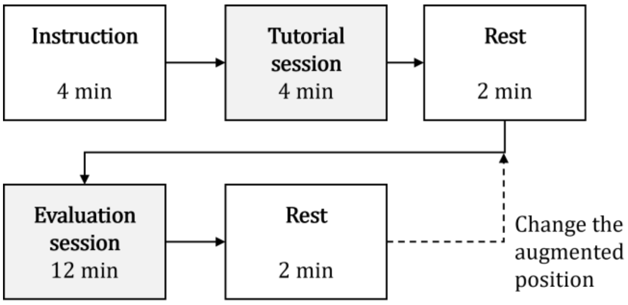



**Fig. 5.** Experimental procedure.

The experiment was conducted in an environment consisting of a desk and a chair, as shown in Fig. 6. A marker was used to provide a common environment for the participants (e.g., ensuring consistency in the plane-surface keyboard augmented position). Prior to the experiment, each participant was introduced to the experiment and asked to complete an informed consent form. After completing the consent form, the participants were equipped with the HoloLens 2.

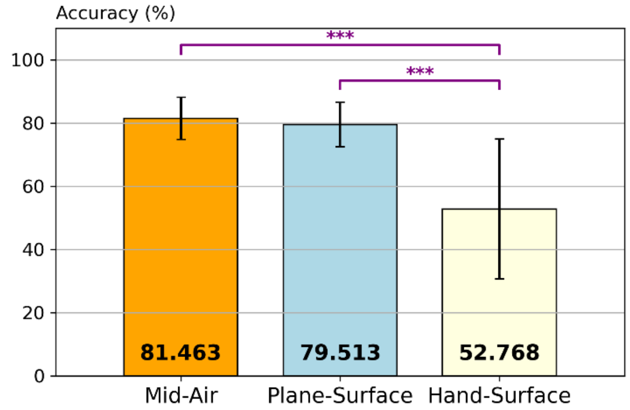
Participants were guided on how to use the virtual keyboard during the tutorial session. In this session, only $A_{air}$, a commonly utilized augmented position, was used. After guidance, three predefined words were randomly presented, and participants were asked to practice typing them using the virtual keyboard.

In the evaluation session, five predefined sentences were randomly presented, and participants entered them using the virtual keyboard. The typing time for each sentence was limited to 120 seconds. After completion, the accuracy and LPM were evaluated. The five sentences used in the evaluation were based on Korean proverbs, as in the short post practice in Hancom's Hancom-Taja, a well-known Korean text practice program. The types of proverbs used were as follows: 1) "나 먹자니 싫고, 남 주기 아깝다.", 2) "커도 한 그릇, 작아도 한 그릇", 3) "모기도 낯짝이 있지", 4) "땅 짚고 헤엄치기", and 5) "병 주고 약 준다."

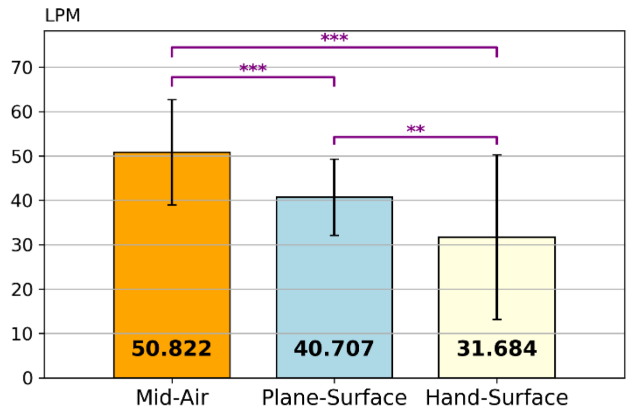

**Fig. 6.** Experimental environment.

### 3.3. Experimental results

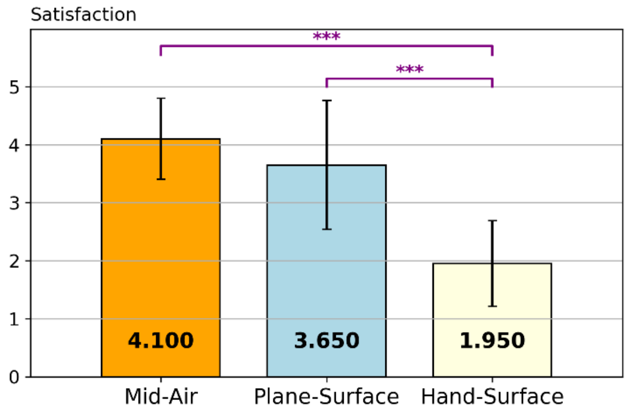
In this section, we aimed to confirm whether there were statistically significant performance differences among the evaluated data for $A_{air}$, $A_{plane}$, and $A_{hand}$. Since the sample size was less than 30, a normality test (Shapiro Wilk test) was conducted for each data. If the evaluated data followed a normal distribution, the parametric t-test was used; otherwise, the non-parametric Wilcoxon Signed-Rank test was used (with 95% confidence interval). The overall set of evaluated data is shown in Fig. 7.




(a)




(b)




(c)

**Fig. 7.** Mean evaluated data for all augmented position. Error bars indicate standard errors. *, **, and *** represent that p-value is less than 0.05, 0.01, and 0.001, respectively: (a) accuracy; (b) LPM; (c) interaction satisfaction.

### 3.3.1. Accuracy

In this paper, accuracy is defined as the degree of similarity between the presented sentence and the entered sentence, ranging from 0 (mismatch) to 1 (match). The difflib-SequenceMatcher library of Python 3 was used to calculate this degree. The evaluated accuracy data is shown in Fig. 7(a) (M( $A_{air}$ )=81.463, STD( $A_{air}$ )=6.688, M( $A_{plane}$ )=79.513, STD( $A_{plane}$ )=7.027, M($A_{hand}$)=52.768, and STD($A_{hand}$)=22.156). Except for $A_{hand}$ , the other positions did not follow a normal distribution (p( $A_{air}$ )=0.006, p( $A_{plane}$ )=2.756e-5, and p($A_{hand}$)=0.071); therefore non-parametric tests were used for comparison. These tests confirmed that there was no significant difference between $A_{air}$ and $A_{plane}$ (difference(△)=1.950, W= 51.0, p=0.227). It was also confirmed that $A_{air}$ was significantly higher between $A_{air}$ and $A_{hand}$ (△=28.695, W= 2.0, p=5.722e-6); and $A_{plane}$ was significantly higher between $A_{plane}$ and $A_{hand}$ (△=26.746, W=11.0, p=1.049e-4).

### 3.3.2. LPM

The LPM in this paper is an indicator that represents the number of keys typed in one minute and was calculated based on the number of consonant keys, vowel keys, and special keys typed during the typing time. The evaluated LPM data is shown in Fig. 7(b) (M( $A_{air}$ )=50.822, STD( $A_{air}$ )=11.877, M( $A_{plane}$ )=40.707, STD( $A_{plane}$ )=8.599, M( $A_{hand}$ )=31.684, and STD($A_{hand}$)=18.564). Only $A_{hand}$ did not follow a normal distribution (p( $A_{air}$ )=0.765, p( $A_{plane}$ )=0.897, and p($A_{hand}$)=1.369e-5); therefore a parametric test was used to compare $A_{air}$ and $A_{plane}$, and non-parametric tests were used otherwise. These tests confirmed that $A_{air}$ was significantly higher between $A_{air}$ and $A_{plane}$ (△=10.116, t=4.344, p=3.492e-4). It was also confirmed that $A_{air}$ was significantly higher between $A_{air}$ and $A_{hand}$ (△=19.139, W= 21.0, p=8.507e-4); and $A_{plane}$ was significantly higher between $A_{plane}$ and $A_{hand}$ (△=9.023, W=34.0, p=0.006).

### 3.3.3. Interaction satisfaction

Interaction satisfaction is an evaluation of the satisfaction with the interaction that users feel with the virtual keyboard augmented in a specific position. The satisfaction data was evaluated using a 5-point Likert scale as in [21], and the evaluated data is shown in Fig. 7(c) (M( $A_{air}$ )=4.100, STD($A_{air}$)=0.700, M($A_{plane}$)=3.650, STD($A_{plane}$)=1.108, M($A_{hand}$)=1.950, and STD($A_{hand}$)=0.740)). Since none of the cases followed a normal distribution (p($A_{air}$)=1.320e-4, p($A_{plane}$)=0.008, p($A_{hand}$)=7.472e-4), non-parametric tests were used for comparison. These tests confirmed that there was no significant difference between $A_{air}$ and $A_{plane}$ (△=0.450, W=20.0, p=0.063). It was also confirmed that $A_{air}$ was significantly higher between $A_{air}$ and $A_{hand}$ (△=2.150, W=0.0, p=1.083e-4); and $A_{plane}$ was significantly higher between $A_{plane}$ and $A_{hand}$ (△=1.700, W=0.0, p=3.650e-4).

## 3.4. Discussion

Our goal was to investigate the impact of different augmented positions (mid-air, plane-surface, and hand-surface) on Korean text entry through a virtual keyboard. In all analysis results, the performance of the mid-air was significantly superior. This may be because the CJI layout has been primarily provided through smartphones, and this input environment is similar to mid-air.

Among the text entry performance metrics, the LPM was significantly higher in the following order: mid-air > plane-surface > hand-surface. Since the LPM was calculated in letters per minute, it indicates the fast touch speed of the user. This order may be due to the fact that mid-air is always visible to the user. The hand-surface is also always in sight; however, unlike other augmented positions, it had the lowest LPM because one hand cannot be used for input.

Since all the data showed similar trends, a correlation analysis was performed to confirm the relationship between the data. As each of the overall data did not follow a normal distribution (accuracy: 1.693e-8, LPM: 0.010, and interaction satisfaction: 3.933e-5), a non-parametric Spearman correlation test was used for the analysis (with 95% confidence interval). The analysis results are listed in Table 2, and it was confirmed that accuracy and LPM were almost not correlated (r=0.338, p=0.002). It was also confirmed that both accuracy and LPM were significantly correlated with interaction satisfaction, and accuracy had a stronger correlation with interaction satisfaction.

**Table 2.** Correlation analysis results.

| | | Accuracy | LPM | Interaction satisfaction |
|---|---|---|---|---|
| **Accuracy** | r | | | |
| | p | | | |
| **LPM** | r | 0.388 | | |
| | p | 0.002 | | |
| **Interaction satisfaction** | r | 0.667 | 0.518 | |
| | p | 6.100e-9 | 2.256e-5 | |

## 4. Conclusion

This paper empirically investigated the effect of augmented position on Korean text entry using an XR device. CJI, an international standard Korean keyboard layout, was used as the keyboard layout, and mid-air, plane-surface, and hand-surface were used as the augmented positions. The experiment was conducted by comparing virtual keyboards based on augmented positions, and three performance data (accuracy, LPM, and interaction satisfaction) were evaluated. The analysis results indicated that mid-air performed the best overall ($Accuracy_{plane}{}^{air}$: △=1.950, p=0.227, $Accuracy_{hand}{}^{air}$ : △=28.695, p=5.722e-6, $LPM_{plane}{}^{air}$ : △=10.116, p=3.492e-4, $LPM_{hand}{}^{air}$ : △=19.139, p=8.507e-4, InteractionSatisfaction $_{plane}{}^{air}$ : △=0.450, p=0.063, and InteractionSatisfaction $_{hand}{}^{air}$ : △=2.150, p=1.083e-4). Furthermore, accuracy and LPM were correlated with interaction satisfaction (accuracy: r=0.667, p=6.100e-9 and LPM: r=0.518, p=2.256e-5). These results may explain why many commercialized XR devices use mid-air as the default augmented position for virtual keyboards. Future research is planned to further consider the Korean two-sets layout, which is widely used in Korean text entry studies.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### Conflicts of interest

The authors declare no conflicts of interest.

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