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Handwritten Input Using a Palm as a Writing Medium in MR Environments

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Abstract— **This paper introduces a handwriting input method that uses the palm of the hand as a writing surface to address the limited input options currently available for MR devices. By providing users with an additional text entry method, this research aims to improve the overall input experience in mixed reality (MR) environments. We developed a prototype on the Microsoft HoloLens 2 and conducted a study comparing four input methods: aerial handwriting, palm-supported handwriting, whiteboard-supported handwriting, and the default virtual keyboard. The results demonstrated that having a physical writing surface significantly enhances input speed, accuracy, and usability compared to aerial handwriting. It also demonstrated the possibility of eyes-free input. This indicates that using body parts as writing surfaces is a promising approach for text entry on MR devices.**

I. Introduction

In recent years, head-mounted MR devices such as HoloLens 2 and Vision Pro have attracted considerable attention. Head-mounted MR devices have the capacity to superimpose digital content on a real-life scene on a display, thereby rendering the digital content to appear as if it were present in the scene, and capable of moving as if it were an actual object in the scene. This technology combines the immersive experience of virtual reality (VR) with the ability to interact with physical reality through augmented reality (AR). The provision of information from both the virtual and real worlds simultaneously enables users to have virtual experiences in the real world and to communicate with people in the real world through the virtual world from remote locations.

MR devices, in many cases, are equipped with a display and a camera that enables hand tracking to realize MR by itself. With hand tracking, HoloLens 2 does not require a controller for input and thus does not rely on external input devices such as a keyboard, and a less stressful, easy-to-type text input method is being sought. However, while proposals and evaluations have been made to improve virtual keyboards [1], there are still few types of character input methods available for head-mounted MR devices. As a result, it is not possible to choose the input method that best suits the situation and application.

Fig. 1: Conventional air handwriting input

Fig. 2: The proposed method in action

Flick input [2], [3] and gesture input methods [4], [5], which have been proposed as text input methods in MR and VR spaces, have been shown to improve the accuracy and speed of the input compared to the default HoloLens 2 input method when the input method is familiar and masterful by the user [2], [4]. However, these input methods are not widely used in society, and many people need to practice the input method, which is more of a burden. In this paper, we focus on handwritten text input, which is a familiar method for daily use. A method of inputting handwritten text on electronic devices that does not involve the use of an external input device is known as aerial handwritten text input [6], [7]. However, similar to a virtual keyboard, it necessitates raising the hand to write on an intangible object, lacking any tactile feedback, as illustrated in Fig. 1. This makes writing difficult and tiring [8]. It was hypothesised that this phenomenon could be attributed to a deficiency in support from the writing medium. As demonstrated in Fig. 2 and 3, we propose a novel input method that involves utilising the opposite palm of the hand as the writing medium. With this proposed method, the user can receive the benefit of not having to carry a device for input while obtaining the same assistance for input as when using an external input device.

II. Proposal Focus and Related Research

A. Flick input in transparent head-mounted displays

Ooka et al. [2] proposed a flick input method with a reconsidered operation method for MR devices using HoloLens. In the input method, the action of pointing at the target object with the index finger and bringing the index finger and thumb together is defined as a click, referred to as AirTap. The drag operation required for flick input is performed while in the AirTap state, and the subsequent action of releasing the index finger and thumb is defined as the end of the drag operation. In this way, tactile feedback is provided at the beginning and end of input to assist the input operation. In the evaluation of input speed and accuracy, subjects who were already using flick input with smartphones and other devices gave better evaluations than the virtual keyboard. However, the results

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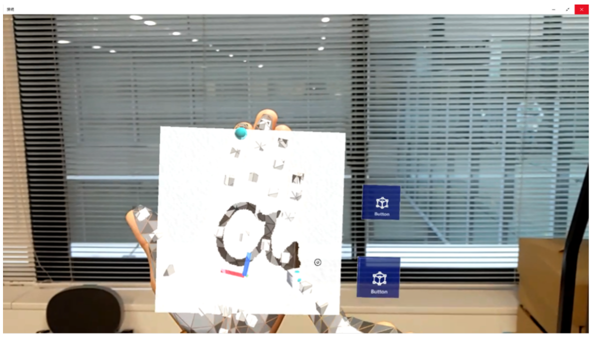

Fig. 3: View of the proposed method through HoloLens 2

for subjects who were not using flick input were poor, and the results varied depending on the degree of proficiency with flick input. This was also seen in the usability evaluation, where the SUS score [9] used as an indicator was better for subjects with higher proficiency in flick input.

Therefore, we propose the use of handwritten text input because we believe that the use of an input method with low difficulty and no difference in proficiency level will lead to easier investigation of the effects of tactile feedback and the presence or absence of support.

B. *Changes in text input with and without tactile feedback*

The lack of tactile feedback is a factor in the difficulty of text input on MR devices. Wu et al. [10] have shown that providing external tactile feedback when inputting on a virtual keyboard in a VR space improves input speed and accuracy. In the case of a flat keyboard, the keyboard surface is actually touched to input, so there is an inherent tactile feedback from the physical contact. However, as shown in the study by Ma et al. [11], additional tactile feedback mapped to specific actions (such as key presses) improves typing speed and reduces errors compared to relying solely on the inherent physical contact feedback from touching the surface.

Therefore, this study will examine whether tactile feedback also affects input in handwritten text input by comparing three different writing media: the air, the palm of the hand, and the writing medium. Both the palm and the board provide tactile feedback when actually touched. But in the case of the palm, tactile feedback also exists on the writing medium side. The comparison will focus on the possibility of receiving tactile feedback that corresponds to actions by both the agent (writer) and the patient (writing surface).

III. IMPLEMENTATION OF A HANDWRITTEN TEXT INPUT SYSTEM USING MR DEVICES

HoloLens 2 is a head-mounted MR device, and is equipped with various sensors such as IMU and depth sensors. The device can project virtual objects and information overlaid on the real environment through a transparent display.

A. *Hand tracking with HoloLens 2*

When using a head-mounted MR device to input handwritten text in the MR space, it is necessary to recognize the fingers used to write the characters. In the HoloLens 2, hand detection and tracking are achieved through a combination of time-of-flight depth sensors and infrared cameras, which accurately capture hand gestures and movements in real-time. This sensor system can detect 25 joint points per hand, as well as the depth of the hand and the orientation of the palm. The hand tracking system in HoloLens 2 has an effective range of approximately 0.8 meters from the device, covering a field of view of about 70 degrees diagonally. However, HoloLens 2 hand tracking has been shown to have an error range of 2 cm on average, according to Soares et al [12]. Another problem with the hand tracking is that the writing hand overlaps the palm of the hand that serves as the writing medium in this study. In this scenario the hand tracking of the palm may not work properly because part of the hand on the writing medium side is hidden. Therefore, it is necessary to design the system to take these factors into account. This research proposes an effective approach to enable accurate handwriting input in mixed reality (MR) environments, even when the user's hands are overlapping. The method involves creating a virtual writing surface (canvas) within the MR space, which is initially positioned independently of the user's hand. The user then aligns their palm with this virtual writing surface. Once this alignment is achieved, the system focuses on tracking only the fingertip used for writing, which remains visible to the camera. By leveraging the known position of the virtual writing surface and selectively tracking the visible writing fingertip, this approach overcomes the challenges posed by partial hand occlusion and hand overlap, allowing for stable and precise handwriting input in the MR space.

B. *Creating an experimental application using Unity*

1) Mixed Reality Toolkit: In creating the application, we used the Mixed Reality Toolkit (MRTK), a set of components provided by Microsoft for developing HoloLens applications. MRTK is used to implement hand tracking and direct manipulation of objects by hand in this research.

2) Experimental Applications: The experimental application has the functions to write and erase letters on the canvas in MR space with the fingertips. In addition, the virtual writing surface can be moved and fixed within the MR space to align it with the user's palm. This allows the system to track the writing input in relation to the aligned virtual surface, rather than relying solely on the position of the user's hand.

IV. EVALUATION METHOD

A. *Experimental details*

The subjects were asked to input text using the experimental application, the input time and the number of mistakes were measured, and then a questionnaire for usability study was administered. This will allow us to evaluate both the usability and the ability to type characters when using a palm as a writing medium.

The experiment involved nine subjects, all of whom had never used HoloLens 2 before and were between 20 and 24 years old.

(a) Handwritten text input using a whiteboard as support

(b) Aerial handwriting input and virtual keyboard

Fig. 4: Handwritten text input

The study compared four different text input methods using HoloLens 2. First, handwritten text input was tested using three different writing media: in air (without support), on palm (using the subject's own body as support), and on a whiteboard (using an external support). The whiteboard served as a reference condition in the comparison, representing a writing surface that is flat and fixed. Additionally, a virtual keyboard was also included since it is HoloLens 2's typical input method. To focus on the fundamental text input performance, the evaluation included character entry and text correction (deletion and re-entry of characters) but excluded Japanese language conversion processes (kana-to-kanji conversion). This approach allowed for measuring the basic usability of each input method without the additional complexity of language-specific conversion operations. In addition, since it is not realistic to write multiple letters in a row on the palm of the hand due to the limited size of the writing area, each letter was entered one at a time with the previous letter being cleared before entering the next one.

We evaluated the proposed method using three metrics: input speed, error rate, and usability. The details of each metric are described in the following sections. For input speed and error rate, statistical analysis was conducted with the null hypothesis of equal means, and two-sided multiple comparisons were performed with p values adjusted by Tukey's method.

The input method using the whiteboard is shown in Fig. 4a, where input is performed against a surface perpendicular to the ground, and the posture is not different from that used for aerial handwritten text input, as shown in Fig. 4b. The following 17 words and 71 letters were used in the experiment.

- the quick brown fox jumps over the lazy dog
- jinxed wizards pluck ivy from the big quilt

In order to familiarize the subjects with how to input text on HoloLens 2, we asked them to practice inputting the following two words using each input method.

- apple
- water

To prevent arm fatigue from carrying over between different input methods, a 5-minute break was provided each time the input method was changed during the experiment.

B. Input speed evaluation

The measurement included the total time from when participants began typing until they completed the 17 words. The typing process encompassed both the writing of characters and any button presses required for erasing letters.

C. Error rate evaluation

The error rate is measured using the Total Error Rate (TER) formula proposed by Soukoreff et al. [13]. They state that there are four types of character input.

- Correct(C): Correctly entered characters
- Incorrect-not-fixed(INF): Incorrectly entered character
- Incorrect-fixed(IF): Incorrectly entered character corrected with backspace
- Fix(F): Backspace key input

The total error rate (TER) is expressed by

$$TER = \frac{INF + IF}{C + INF + IF} \times 100. \tag{1}$$

In this experiment, INF is 0 because the subject must confirm that the character they typed matches the corresponding character before proceeding to the next character. IF includes characters that are rewritten after a mistake is noticed during the writing process.

D. Usability Evaluation

Usability evaluation is based on a questionnaire survey after having the user enter the data using four input methods. The questionnaire questions included the SUS (System Usability Scale) [9], which is used for usability surveys, and a free-text questionnaire in which respondents were asked to answer about their feelings and opinions when inputting text. SUS is an index to evaluate the perception of usability by preparing 10 questions to be selected from a 5-point scale of 1 (strongly disagree) to 5 (strongly agree). It is common to place positive questions at odd-numbered answers and negative questions at even-numbered answers. The SUS can obtain a score from the answers to the questions.

The System Usability Scale (SUS) is calculated using the formula:

$$SUS = 2.5\left\{\sum_{k=1}^{5}(a_{2k-1} - 1) + \sum_{k=1}^{5}(5 - a_{2k})\right\}, \tag{2}$$

where a_n is the response to the n-th question. This formula converts the responses to a 0-100 scale, with 100 being the maximum score. The conversion is necessary because odd-numbered questions are phrased positively (higher scores indicate better usability), while even-numbered questions are phrased negatively (lower scores indicate better usability). The score of 68 is generally considered the average for SUS, indicating about average ease of use. Usability can be further evaluated using the criteria tabulated in Table I.

The questionnaire used to calculate the SUS score is shown below.

1) Would you like to use this system frequently?

TABLE I: Criteria for Judgment by SUS Score

SUS Score	Grade	Adjectives
>80.3	A	Excellent
68 – 80.3	B	Good
68	C	Okay
51 – 68	D	Poor
<51	E	Awful

2) Did you find the system unnecessarily complex?
3) Did you think the system was easy to use?
4) Did you feel stressed by the effort of entering text?
5) Do you think this method of text input will make it easier to enter text in MR?
6) Do you think that only a few people would be able to use this system?
7) Do you think most people would learn to use this system very quickly?
8) Did you find the system very cumbersome to use?
9) Did you feel very confident using the system?
10) Did you need to learn a lot of things before you could use the system?

V. ASSESSMENT RESULTS

A. *Input speed evaluation results*

The results of the nine participants' input speed ratings are shown in Table II, and the results of the tests are shown in Table III and Fig. 5. The input speed ranking, based on average time taken, follows this order (from fastest to slowest): the virtual keyboard, handwritten text input using the whiteboard as support, handwritten text input using the palm as support, and aerial handwriting input.

In Fig. 5, * and ** are shown as symbols indicating significant differences at the 5% and 1% levels, respectively. The results of the tests in Table III show that there are significant differences between aerial handwriting input and both the virtual keyboard and the whiteboard as support. Therefore, it can be concluded that the presence of support improves the speed of handwriting input. In addition, there is a significant difference between handwritten text input using the palm of the hand as a support and using a virtual keyboard. However, considering that keyboards are primarily designed for fast text entry, it may not be surprising that handwriting input performs less favorably in terms of speed.

TABLE II: Time Taken for Input (seconds)

Subjects	Palm	Aerial	Whiteboard	Virtual Keyboard
A	201.0	175.4	109.0	119.2
B	574.2	395.5	238.3	154.5
C	475.1	484.8	450.6	118.6
D	384.2	444.7	291.1	167.9
E	371.0	505.3	323.3	212.7
F	180.7	232.6	221.1	142.5
G	193.6	295.5	155.7	112.9
H	161.0	434.0	159.0	136.9
I	179.6	533.6	190.8	165.6
Average	302.3	389.1	237.7	147.9

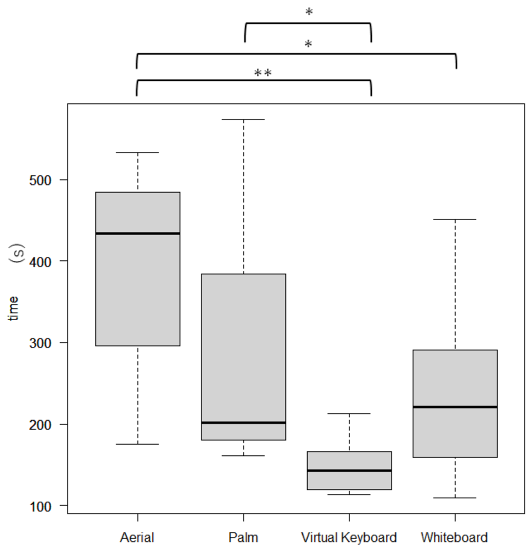

Fig. 5: Box and whisker plot of time taken

B. *Input Accuracy Evaluation Results*

Table IV shows the results of the evaluation of the input accuracy of the nine respondents. Table V also shows multiple comparisons of the TER results using p-values adjusted by Tukey's method. The evaluation results showed significant differences between the aerial and whiteboard combinations, as well as between the aerial and virtual keyboard combinations.

C. *Usability Evaluation Results*

The highest SUS score was obtained with the whiteboard method. Notably, the SUS score for the virtual keyboard was lower than expected, given its superior performance in other evaluation criteria. It scored lower than both the whiteboard and palm methods.

TABLE III: Results of Multiple Comparisons for Input Time

Variable 1	Variable 2	Adjusted p-value
Aerial	Palm	3.8×10^{-1}
Aerial	Whiteboard	3.7×10^{-2}
Aerial	Virtual Keyboard	4.4×10^{-4}
Palm	Whiteboard	6.2×10^{-1}
Palm	Virtual Keyboard	3.3×10^{-2}
Whiteboard	Virtual Keyboard	3.5×10^{-1}

TABLE IV: TER Results (%)

Subjects	Palm	Aerial	Whiteboard	Virtual Keyboard
A	5.3	0.0	0.0	0.0
B	38.8	16.5	2.7	0.0
C	11.2	6.6	6.6	0.0
D	16.5	14.5	2.7	5.3
E	18.4	39.8	9.0	4.1
F	0.0	9.0	0.0	2.7
G	4.1	24.5	2.7	1.4
H	1.4	14.5	5.3	0.0
I	2.7	6.6	1.4	1.4
Average	10.9	14.7	3.4	1.7

TABLE V: Results of Multiple Comparisons for TER Results

Variable 1	Variable 2	Adjusted p-value
Aerial	Palm	8.0×10^{-1}
Aerial	Whiteboard	4.6×10^{-2}
Aerial	Virtual Keyboard	1.7×10^{-2}
Palm	Whiteboard	2.7×10^{-1}
Palm	Virtual Keyboard	1.3×10^{-1}
Whiteboard	Virtual Keyboard	9.7×10^{-1}

TABLE VI: Average SUS Score and Grade per Input Method

Input method	SUS score (grade)
Palm	73.61 (B)
Aerial	53.61 (D)
Whiteboard	83.06 (A)
Virtual Keyboard	63.33 (D)

D. *Free-text Responses*

The free-text responses yielded the following observations:

- With aerial handwriting input, participants unintentionally moved their wrists while writing, causing the depth of their fingertips to shift and resulting in their fingers lifting off the virtual canvas, which led to interrupted character strokes.
- Having a supporting surface allowed participants to write characters without worrying about finger depth, reducing cognitive load and enabling more natural input.
- The whiteboard as a supporting surface provided noticeably better stability and ease of writing compared to other methods.
- Participants suggested that increasing the freedom of palm positioning could reduce fatigue and improve usability.

Additionally, during the experiment, participants commented that the presence or absence of a supporting surface altered their arm and hand movements. They also noted that the current system made it difficult to input text without visual confirmation, as they could not be certain their writing was being registered correctly.

VI. DISCUSSION

Looking at the results for typing speed between participants, the variation in results was largest for the aerial handwriting input, possibly due to differences in individual motor skills and familiarity with the technique. On the other hand, the differences among participants were smaller for the virtual keyboard.

Based on the results of input speed and accuracy, handwritten input appeared less efficient than the virtual keyboard. However, the two input methods using a support surface showed improvements. Both speed and accuracy increased compared to aerial handwritten character input. When comparing the two support surfaces, the whiteboard method often outperformed the palm method. This difference could be attributed to a specific issue with the palm method. Users tended to press their fingers against their palm during input. This caused the fingertip to sink below the input area, resulting in broken lines. In contrast, the whiteboard remained fixed.

TABLE VII: SUS Scores in the Presence and Absence of a Support Surface

Type	Average
With support surface	78.33
Without support surface	58.47

The SUS responses revealed interesting findings, as shown in Table VII. A notable difference emerged when recalculating the SUS scores based on the presence or absence of a support surface. This indicated that support surfaces significantly affected usability in character input with MR devices. Moreover, methods with support surfaces received higher SUS scores. This suggested that providing a support surface was desirable in character input systems for MR devices.

VII. CONCLUSION

In this study, we proposed a handwritten character input method using the palm as a support surface. Our study confirmed that, as in previous research on other input methods, the presence of a support surface also contributes to improving the handwriting input experience in MR devices. Furthermore, our findings suggest that using the palm as a support method may be able to fulfill the role of a support surface without relying on external supports. We believe that using the body as a support surface could enable new possibilities, such as writing characters without visual guidance, as the tactile feedback from the body part helps locate the writing position. This could contribute to the widespread adoption of MR devices.

For future work, we will focus on improving palm tracking technology to enable more precise tracking of the writing area on the palm. We are committed to addressing issues such as palm movement during character input. This advancement should lead to a higher evaluation of the palm as a support input method.

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