Haptic Finger Glove for the VR Keyboard Input

Yuya Hoshi[1], Chenghong Lu[2], and Lei Jing[2,3](✉)

[1] The Graduate School of Computer Science, Tohuku University, Sendai, Japan
[2] The Graduate School of Computer Science, The University of Aizu, Aizuwakamatsu, Japan
[3] Research Center for Advanced Information Science and Technology (CAIST), The University of Aizu, Aizuwakamatsu, Japan
leijing@u-aizu.ac.jp

Abstract. With regards to use Virtual Reality headsets, people have many opportunities of key entry. However, current methods for key entry are suffering from low input speed and high error rate. In this paper, we suggest a new key entry system, Air keyboard with haptic finger glove. By applying haptic illusions such as phantom sensation and apparent movement, the finger glove could simulate the tactile feedback such as typing and unevenness sensation with low cost. Several controlled experiments were conducted to evaluate the efficiency and the accuracy of the air keyboard together with haptic finger glove. The result shows that the haptic finger glove could help user to better interact with the virtual keyboard. Moreover, a short-term training could increase the input efficiency and reduce the error rate, which is comparable or better than traditional pointing method with handheld controllers.

Keywords: VR keyboard · Haptic · Phantom sensation

1 Introduction

Virtual Reality (VR) headsets are getting customer levels. However, there are very few intuitive methods of key entry. One of the most general methods is pointing and selecting character by using handheld controller. This method has many downsides, such as the speed and accuracy of typing are relatively low and it is stressful to use. By the way, obviously, the most common method of key entry is Qwerty keyboard. Current VR headsets, Oculus Quest has feature of hand tracking. But there is no key entry system by using their own hand in current VR headsets. Can we implement keyboard in the VR environment? The goal of this study is to suggest new key entry method for VR environment which can enter text with high accurate, high speed, and less stressful. We can implement mid-air keyboard method, but inexistence of physical feedback makes it difficult to use keyboard as same as physical one. To achieve these goals, we focus on the haptic sensations which the user would feel as if they are using the

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physical keyboard. The main issue of our research is how to simulate the haptic feedback from physical keyboard. The main feedback to simulate are typing the button and unevenness feedback when moving the finger across the buttons. We implement haptic finger glove by applying haptic illusions on finger to show those sensations. Haptic illusions enable user to show sensations by mistaking perceptions. Hence, we can give those sensations with more simple components with haptic illusion.

2 Related Works

T.M. Andualem, N. Atulya, R. David, and L.S. Emanuele searched about stiffness discrimination with visual only, tactile only, and both feedback [1]. They found visual feedback would compensate missed kinematic feedback in their experiment. We need to consider what feedback would be needed for our application use.

In terms of keyboard for VR environment, Facebook Reality lab searched about tactile feedback of mid-air keyboard [2]. In this study, they showed only touch and press sensations for fingers. They might be enough sensations to show for controlling keyboard, but we thought unevenness sensation across keys is also important information to show.

On the other hand, there are some key entry device researches which does not look Qwerty keyboard. C. Mehring, F. Kuester, K. Singh, and M. Chen have developed the glove type key entry system called Kitty [3]. User can input characters by pressing sensors on the glove with similar finger movements with Qwerty keyboard. However, it would need much training to improve input efficiency. In our system, we showed not only touch and type sensations, but also unevenness sensation across keys. Moreover, to reduce the learning cost, we used virtual Qwerty keyboard.

3 Method

3.1 Basic Theory

We used haptic illusions called phantom sensation and apparent movement. They enable user to show feedback points between actuators. Figure 1 shows the phenomena of phantom sensation. By changing amplitude of stimuli, the flexible sensation location can be achieved [4]. Figure 2 shows the phenomena of apparent haptic motion. Moving sensation is appeared when two stimulus amplitude were changed in time series. We applied these phenomenons on finger because it can reduce the number of actuators.

3.2 How to Show Unevenness Sensation

When user move their fingers on the keyboard as shown in Fig. 3, facing point on key is changed as they move their finger. We focus on this, and achieved

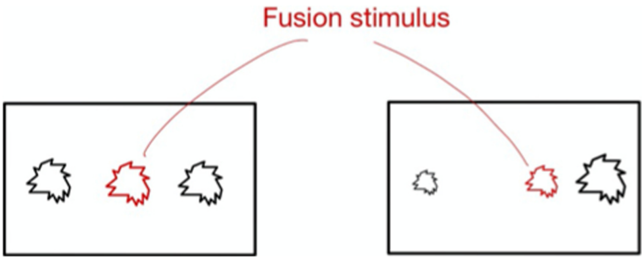


Fig. 1. Phantom sensation phenomena

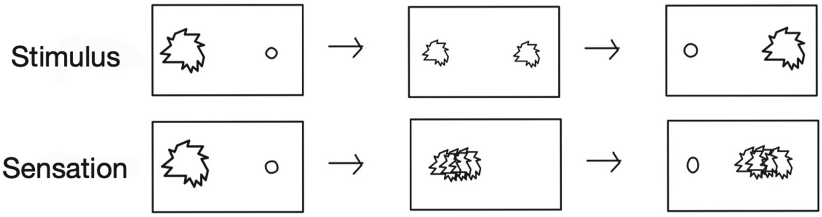


Fig. 2. Apparent haptic motion

this change by applying apparent haptic motion as shown in Fig. 3. User feels touching point as vibration. When they move their fingers on the keyboard, vibrating point is also moves based on their finger movement.

3.3 How to Show Type Sensation

When the user press a key, they get counter force from key in physical world, as shown in Fig. 4. We could not show the sensation of counter force with DC vibration motor, but we expressed this with vibration point and power change as shown in Fig. 4. We apply phantom sensation on finger to show stimuli on the point of finger where pressed the key.

4 System Design

4.1 Outline of System

Figure 5 shows the system outline. In our system, we use VR headset, Oculus Quest to show visual and audio feedback to user. Since Oculus Quest has a feature of hand tracking by image processing, we did not need any other additional tracking equipment. We use Oculus Link to connect PC and run software on Unity. For what at the PC side, we implement our virtual keyboard system. Based on the collision information on tracked finger in Unity, the virtual keyboard sends signals to finger glove controller via Bluetooth. Finger glove controller controls vibration motors to show real time haptic feedback.

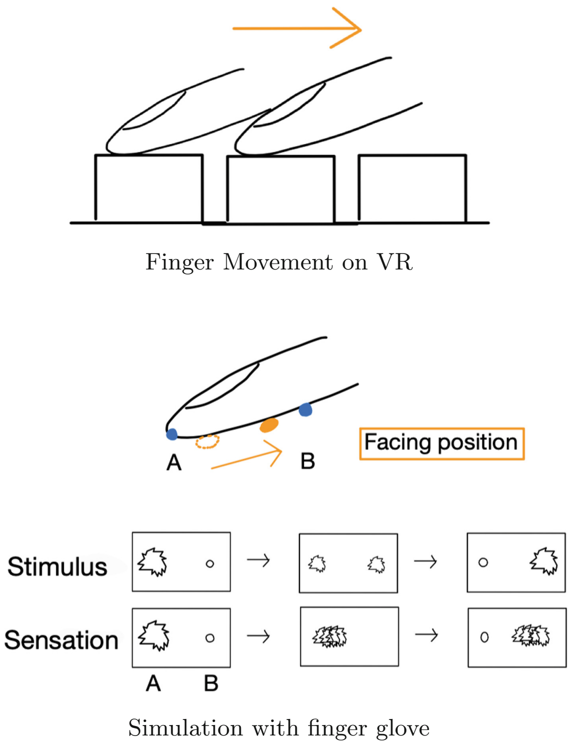


Fig. 3. Unevenness across keys

4.2 Implementation of Virtual Keyboard

We use an asset, Oculus integration, which is supported by Oculus to make use of Oculus Quest headset with hand tracking. Based on the information of finger position, we put spheres on the tip of fingers. In this system, user will use only thumb, index and middle fingers due to the accuracy of hand tracking. The user can type keyboard by colliding these spheres on the key. When finger touching on a key, user get haptic simulation of touch. If the user moves their finger with touching key, they get unevenness simulation. When user type key, they get type simulation. We made models of keyboard. Same as Qwerty keyboard, user can type capitalized character by holding shift key. When user type any keys, the keyboard output sound of type. In every several frames on Unity, this system sends signals to control haptic finger glove via Bluetooth.

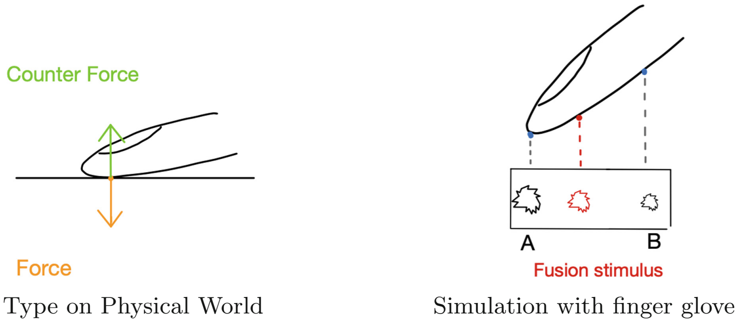


Fig. 4. Type a key

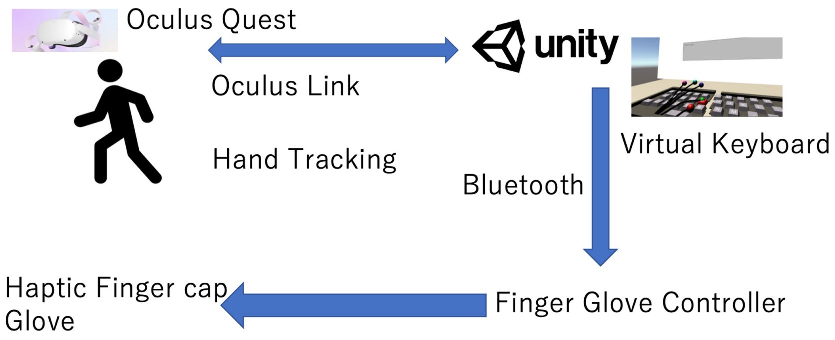


Fig. 5. System outline

4.3 Implementation of Haptic Finger Glove

Figure 6 is the prototype of finger glove. Haptic functions are showed by DC motors. Motors are controlled by ESP32 microcomputer. Figure 6 shows control circuit of DC motor. Each motor is controlled by NPN transistor (C1815), resistance (300Ω), diode (1N4007) and Pulse Width Modulation (PWM) signal. Due to the PWM pin number limits, we use the multiplexer to reduce the number of PWM pins (MUX, TC74HC153AP). MUX selects 4 PWM states by 2 bit digital signals. Figure 7 is our circuit image.

5 Experiment

5.1 Experiment Design

We conducted three experiments to evaluate the prototype system. First is about evaluating our new key entry method, Air keyboard with haptic finger glove perspectives from accuracy, speed, and mental workload of text entry. Second is about evaluating haptic functions of our Air Keyboard system. Third is about evaluating learnability of our system. Six subjects (age:20–24, 5M 1F) joined the

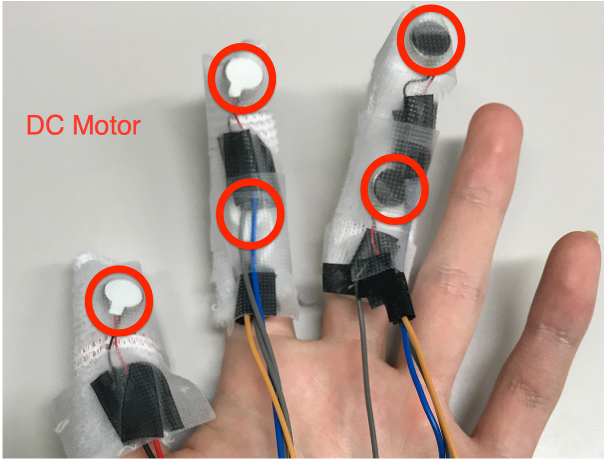


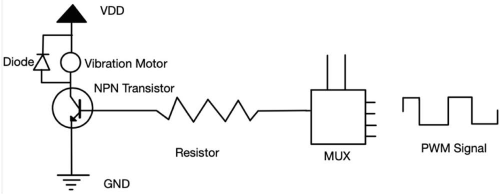
Fig. 6. Prototype of finger glove

first and second experiments. Three of them had much VR experiences, such as they have own VR headset. Other three did not have enough VR experiences. Third experiments participants were four student (age:20–26, 4M). All of their mother languages were not English, but they were familiar with English key entry with Qwerty keyboard.

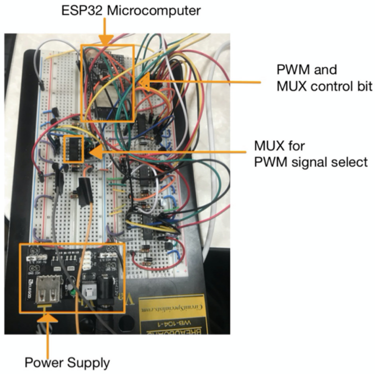
5.2 Key Entry Experiment

Experiment Setting. We conducted controlled comparative experiments between handheld controller(HC) and Air keyboard without finger glove(AK) and Haptic Air keyboard with finger glove(HAK). One is most general key entry method in VR environment, pointing with handheld controller. We use Oculus Quest handheld tracer, shown in Fig. 8. User can enter character by pointing key and press trigger on the handheld controller. User gets only visual feedback. Second is our new method, air keyboard without haptic finger glove(AK), shown in Fig. 8. User gets sound and visual feedback from this system. Third is air keyboard with haptic finger glove(HAK), shown in Fig. 8. User gets sound, visual and haptic feedback in this system. In this experiment, participants were asked to complete displayed English phrases as quickly and accurately as possible. We used English phrase which MacKenzie, I. S. and Soukoreff, R. W. suggest to evaluate key entry method [5]. In each experiment, random English phrases from this English phrase set are appeared in the panel in front of the participant.

Each participant evaluated each method in terms of accuracy, speed, and mental workload quantitatively. We evaluate accuracy of key entry on a scale of Characters per Minutes (CPM), (1) and Error Rate (ER), (2).



Circuit Diagram



Circuit Image

Fig. 7. Haptic finger glove (circuit diagram and circuit image)

$$CPM = \frac{C}{M} \tag{1}$$

- where C is number of correct character, M is minutes.

$$ER = \frac{E}{C+E} * 100\% \tag{2}$$

- where E is the number of errors.

To measure mental workload, we used NASA Task Load Index (NASA-TLX) sheet [6]. NASA-TLX is the mental workload quantities assessment technique. NASA-TLX is consisted by 6 subjects, mental demand (MD), physical demand (PD), temporal demand (TD), own performance (OP), effort (EF), and frustration (FR). Participants answered these subjects by putting circles on line, and we scored in terms of the position of circle. Participants skipped weight phrase because we used Adaptive Weight Workload (AWWL) which Mitake and Kumashiro suggest [7]. Moreover, since all of participants were Japanese students, they were given Japanese translated sheet of NASA-TLX which Mitake and Kumashiro published [7].

Experiment A Experiment B Experiment C

Experiment	A	B	C
Abbr. Name	HC	AK	HAK
Method	controller	finger without haptic	finger with haptic

Experiment 1 Table

Fig. 8. Comparative experiments

	A	B	C	D	E	F
1	HC	HC	AK	AK	HAK	HAK
2	AK	HAK	HC	HAK	AK	HC
3	HAK	AK	HAK	HC	HC	AK

Fig. 9. Experiment order table

Participants sat on the chair and adjusted the position of keyboard according to their preference. Participants were asked to test typing 5 English phrases (ex. I am a student) before each experiment for practice. To prevent having influences in the experiment order, each participant did experiment in different order. Figure 9 shows the order of experiments. Participants were asked to complete displayed English phrase. Each experiment continued two minutes. In these experiments, only correct characters were inputted. Incorrect characters were just counted as mistakes. After the three experiments, participants were asked to complete NASA-TLX sheet.

Experiment Result. Figure 10 shows the CPM, and Fig. 11 shows the ER in each experiment. Figure 12 shows mental workloads who had no VR experiences, and Fig. 13 shows mental workloads who had much VR experiences.

Analysis. For speed of input, we confirmed that there are only small differences between three methods. On the other hand, for accuracy of input, our methods scored four times worse point. This result suggested that user cannot use the

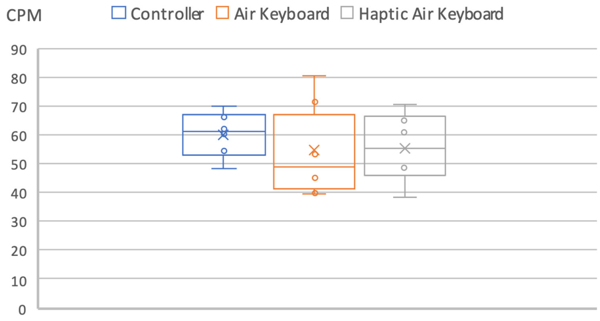


Fig. 10. Character per minutes

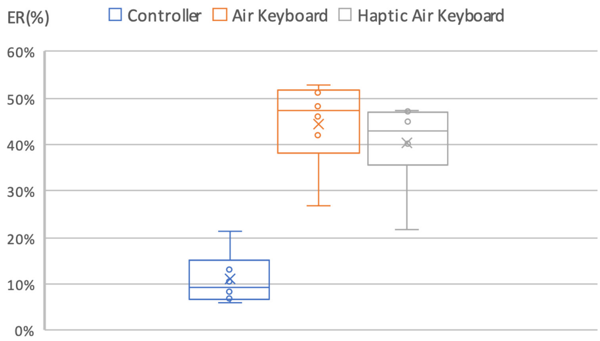


Fig. 11. Error rate

virtual keyboard system well without enough training. For mental workloads, we confirmed that there were big differences whether participants had much VR experience or not. Participants who did not have VR experiences got lower score in our system. On the other hand, participants who had much VR experiences answered higher score in our system. Particularly, participants who had much VR experiences answered the effort subject very low. It assumes that since they are already used to using handheld controller, they accept using it. However, participants who did not have much VR experiences prefer our system because our system is similar to usual Qwerty keyboard.

5.3 Haptic Function Evaluation

Experiment Setting. To evaluate our haptic function of finger glove, we asked participants about each sensations similarities compared to physical keyboard.

Experiment Sequence. Participants were asked to move their fingers. They were asked to type key, move finger from left to right, right to left, top to bottom, and bottom to top. After each movement, they were asked to score "How much

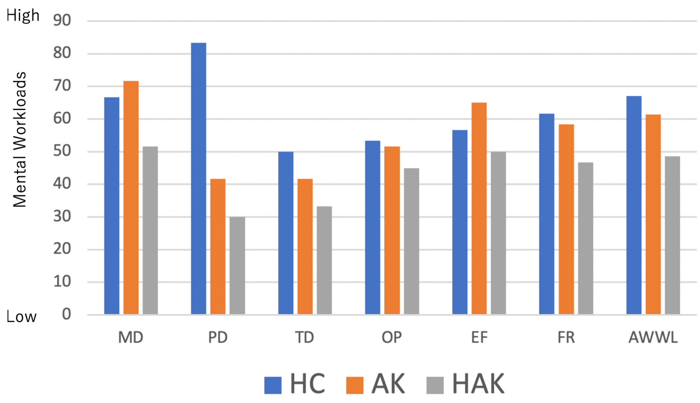


Fig. 12. Mental workloads who had no VR experiences

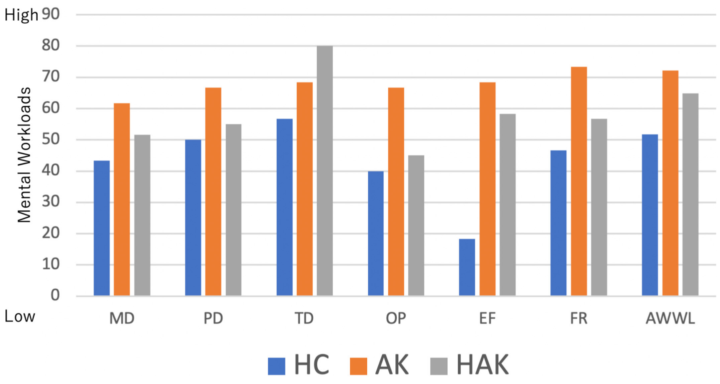


Fig. 13. Mental workloads who had much VR experiences

did you feel the sensation of them with comparing physical keyboard?" out of 7 points (1: completely different, 4: modestly same, 7: completely same).

Figure 14 shows the result of evaluations.

Experiment Result

Analysis. We confirmed that most of participants felt sensations that when they use keyboard. Five out of six participants felt the sensations of finger movement on keyboard. However, all of them did not notice before my asking. We assumed that those sensations could work unconsciously during using our system.

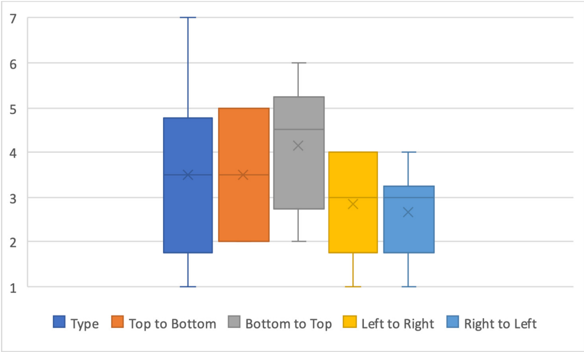


Fig. 14. Haptic function evaluation

5.4 Learnability Experiment

Experiment Setting. Judging by Experiment1, we thought that our system needs more pre-training to use well. Hence, we conducted 1 h experiment on four participants (age: 20–26, 4M) to measure the learning curve of our system.

Experiment Sequence. Participants did one minute experiment, same settings with experiment1. After 30 min training and 1 h training, participants did same experiment. In training session, We advised participants to practice the usage of Air keyboard. Participants choose to use their prefer fingers from one to three of each hand. Finger gloves were attached to only selected fingers, and user can type by only selected fingers.

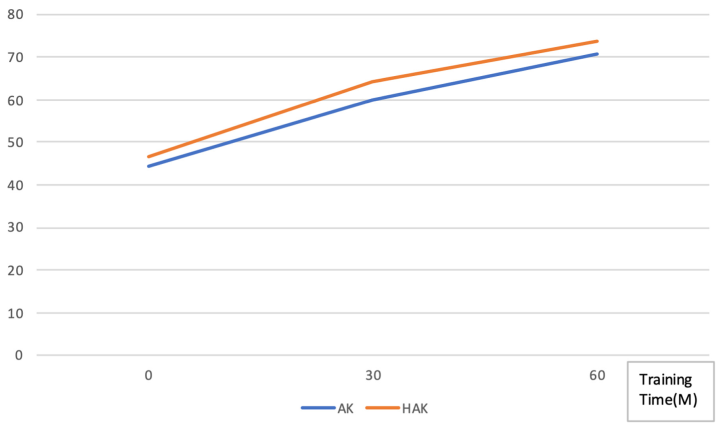


Fig. 15. CPM transition

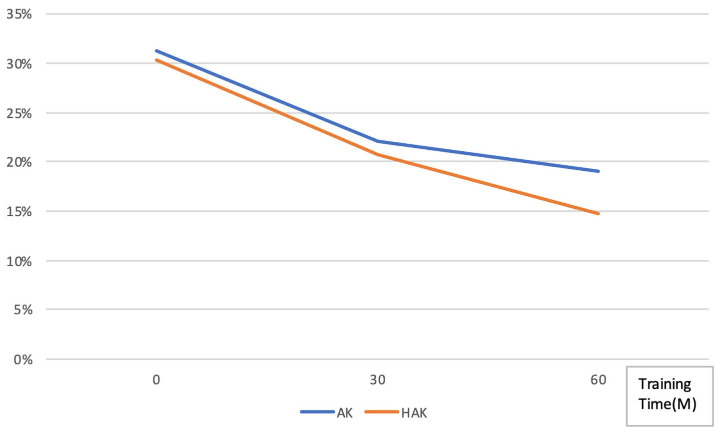


Fig. 16. ER transition

Figure 15 and Fig. 16 shows the transition of CPM and ER. One hour training resulted in improvement of typing speed and accuracy.

Analysis. We observed that one hour training increased input efficiency about 1.5 times, and reduce the error rate about one half. Compared to AK and HAK, HAK resulted better in CPM and ER after training session. Hence, our data suggested that the haptic finger glove could help user to better interact with the virtual keyboard. Compared to handheld controller in experiment1, our method resulted higher CPM after training. On the other hand, ER of our method was little bit higher than handheld controller.

6 Conclusion

6.1 Achievement

We implemented Air keyboard with haptic finger glove. Compared to general key entry method in VR, our system scored more speed of key input and comparable accuracy after 1 h training. Haptic feedback help users to control more accurately know their type and finger movement. After all, we conclude that our method can be replaceable with traditional method.

6.2 Future Work

The low accuracy of input in our keyboard is strongly related to the type recognition system in software and accuracy of hand tracking. There were some differences compared to our experiment settings, but this study [2] resulted lower than 3% error rate in mid-air keyboard. We estimate that improvement of typing software would improve the accuracy. Moreover, we will try to show haptic feedback with other methods.

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