Toward Designing a New Virtual Keyboard When All Finger Movements Are Known

**Abstract**
Compared with the physical QWERTY keyboards, the virtual keyboards are slow, inaccurate, and inconvenient because they simply imitate the traditional QWERTY keyboard. To improve the virtual keyboards, we focus on two observations. First, all alphabetic keys are already allocated to each finger of skilled typists. Second, non-touching fingers move in correlation with a touching finger because of the intrinsic structure of the human hand. Based on the first observation, we suggested a new virtual keyboard that restricts each finger to enter the pre-allocated keys only. Then, we statistically proved the second observation in our experiment. Through this experiment, we found the significant correlations between a touching and some of the other non-touching fingers. Finally, we discussed how these correlations can help to improve the performance of the virtual keyboards.

**Author Keywords**
Virtual keyboard; typing; multi-touch input; touchscreen

**ACM Classification Keywords**
H.5.2 [Information interfaces and presentation]: User interfaces – input devices and strategies.

**Introduction**
The software-based virtual keyboards have potential to expand beyond the physical keyboards since they can be
applied to any sized touch screen and also implemented using emerging technologies, e.g., computer vision technologies. Despite their advantages, the virtual keyboards that simply imitate the traditional QWERTY keyboard have intrinsic restriction, e.g., no tactile feedback, which decreases their typing speed and efficiency, in contrast to the physical keyboards [3].

Findlater et al. [1] had observed the natural typing patterns of skilled typists with the virtual keyboard on an interactive tabletop. They showed that typing with the two-handed virtual keyboard is possibly as quick as typing with the physical keyboard. One reason that slowed down the current virtual keyboards was that users sometimes tended to hit the adjacent keys in the same row or column. The most frequent cases, for example, were B-V, U-I, U-J, J-K, and I-K. Based on their results, we propose two ideas to decrease the typing errors for the virtual keyboards.

First, to alleviate the horizontal typing errors, which are unintended mistakes of hitting the adjacent keys in the same row, we focus on the behavior of the skilled typists. As shown in Figure 1, several online typing tutorial sites, such as [8], have unanimously taught how to type with the physical keyboard. Based on this, we assume that after learning, the skilled typists know all key locations and which finger to use to enter each letter. Therefore, we propose that each key column is allocated to the corresponding finger such as Figure 1, which implies that each finger is permitted to enter the pre-allocated keys only. For example, the Q, A, Z and P keys must be entered with the little fingers and the W, S, X, O, and L keys must be entered with the ring fingers. With these pre-allocations, we can eliminate most of the horizontal typing errors because, for example, the middle fingers are not permitted to enter their horizontally adjacent letters.

Second, we observed that when a finger touches a key on keyboards for typing, some non-touching fingers move in correlation with the touching finger. If the patterns of correlations are unveiled when a touching event occurs, then we can use not only a touched location but also the movements of some correlated fingers to know which key is targeted. Therefore, these correlations may help mitigate the vertical typing errors, which are unintended mistakes of hitting the adjacent keys in the same column. For example, although the location of L key is actually touched, the O key could be entered by considering the correlated non-touching finger locations.

In this paper, we propose a new virtual keyboard prototype based on the first idea. Then, we statistically see if there are correlations between a touching and the non-touching fingers to verify our second idea. Furthermore, we discuss how these correlations can help
to correct the vertical typing errors. We believe that these findings will contribute to improving the performance of the virtual keyboards in our future work.

**Related work**
To improve the virtual keyboards, several keyboard designs have been proposed. Findlater et al. [2] showed an automatic adaptation method based on the underlying key-press classification models for the personalized input. Kuno et al. [3] proposed a software keyboard based on the touch points of all fingers and their surroundings. However, when a key is entered, they focused only on the touch point of a touching finger.

On the other hand, some virtual keyboards have been designed with computer vision technologies. Taichi et al. [6] proposed a text input interface which had been designed using a gesture recognition technique with a single camera for keyboard-less devices such as tablet PCs. Also, Huan et al. [4] suggested a virtual keyboard matching hand postures with a 3D hand skeleton model.

**Experiment**
The objective of the experiment was to verify the new virtual keyboard designed based on our two ideas. Especially, we conducted an experiment to find the significant correlations between a touching and the non-touching fingers.

**Participants**
Five people, including 3 males and 2 females, who were regularly typing with physical and virtual keyboards were recruited. Before the main experiment, we ran a typing test with a physical keyboard for calculating typing speed. Their mean typing speed was 74.5 wpm (SD = 12.3).

![Figure 2: An experiment environment with a RGB camera, an infrared camera, and an infrared plane generator.](image)

**Experimental Setup**
Figure 2 shows our experiment environment under the restriction of light. To make a touch surface on top of the transparent box, we used the LLP (Laser Light Plane) method with an infrared plane generator and an infrared camera [7]. Then, several color markers were placed on all fingertips and wrists and were tracked by a RGB camera.

**Keyboard Design**
As shown in Figure 1, a virtual keyboard with the pre-allocation of keys was designed where each finger is permitted to enter the pre-allocated keys only. This method fundamentally hinders most of the horizontal typing errors. In addition, since a personalization is also known as an important factor for the improved virtual keyboards [1], we asked participants touch their all fingers for preparation before they started typing, which we call the initialization phase. Based on these 10 finger touch points in the initialization, we generated the keyboard layout, as shown in Figure 3. After these touch
Figure 3: A keyboard layout generated for the experiment on the computer screen. It is arch shaped based on 10 finger touch points (white) and 2 wrist points (green).

locations were saved and a participant lifted off all fingers, the actual typing began.

Whenever a character was entered with a right finger, we saved two dimensional world coordinates of all fingers. In contrast, to mitigate the effect of the participant mistake, we did not save the finger locations when a wrong finger touched to enter a given character, e.g., using the left index finger to enter D. At that time, a red rectangle was shown for a short time as a visual feedback of the wrong touch on the screen.

Procedure
The experiment took about 40 minutes. Participants completed 20 practice phrases to understand our keyboard design, followed by the physical keyboard typing test. Then, they completed 40 test phrases. To consider all letters in alphabet, test phrase sets were deliberately selected from the MacKenzie phrases set [5]. We requested the participants to type comfortably and accurately just like they did on a physical keyboard.

Data and Analysis
Through the experiment, we obtained 9,250 labeled locations of a touching finger and the non-touching fingers. Then, the locations were transformed to the distance with regard to the initial touch positions determined in the initialization phase. From these finger movements, we analyzed the correlation coefficients and movements of all fingers except two thumbs. Two thumbs were excluded because they were used only for a space bar. The second-order partial correlation, One-Way ANOVA and two-sample t-tests were used for analysis. One-Way ANOVA was followed by Scheffe or Tamhane post-hoc analysis. We report significant findings at p<.05.

Result
The correlation between two fingers on the hand will be denoted as hand direction (the first finger-the second finger) for convenience. For example, the correlation between the index and middle fingers on the left hand is denoted as left hand (index-middle).

First of all, we checked the significant correlations between all fingers on each hand with the second-order partial correlation. Figure 4 and 5 show the second-order partial correlation coefficients and p-values of all fingers of the left and right hands respectively. Most of fingers had significant positive correlations (p < .01), excluding left hand (middle-little) and right hand (index-little, middle-little). However, the correlation coefficients of left hand (index-ring, index-little) were very weak, so these fingers were seen to act independently of each other (the partial correlation coefficients : -0.07 and -0.045 respectively with n = 5126). In summary, we showed that all fingers correlate positively with their adjacent fingers in addition to right hand (index-ring).
Figure 4: The second-order partial correlation coefficients and p-values between all fingers on the left hand. The highlighted cell in yellow indicates that they correlate each other (under partial correlation coefficient > 0.1, p < 0.01).

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Figure 5: The second-order partial correlation coefficients and p-values between all fingers on the right hand. The highlighted cell in yellow indicates that they correlate with each other (under partial correlation coefficient > 0.1, p < 0.01).

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Figure 6: The movements of the correlated fingers of the left hand. Each correlated finger moves uniquely depending on the key touched by a correct finger (p < .05).

The target of each index finger is relatively hard to guess since it enters one out of six keys. Our analysis showed that each key, which is entered by the index fingers, in the same column was also distinguishable with their correlated fingers (p < .05), excluding the F and V keys (p = .058) as shown in figure 6(a). Therefore, these findings indicate that when the index finger enters a key in a given column, the key can be deduced based on the correlated finger movements except the ambiguity between the F and V keys. It was also found that it is difficult to distinguish two keys in the same row only with the correlated finger movement when each index finger enters a key.

**Discussion**

In the traditional virtual keyboards, the target key is identified depending on which allocated space of a key is touched. For an extreme example, when a skilled typist touches a border between the adjacent keys in the same column, the vertical typing error may occur. Note that the horizontal typing errors were already mitigated in our design by the pre-allocation of keys to fingers. We also believe that the vertical typing errors can be reduced by considering the correlated finger movements as shown in our experimental analysis. In other words, if all finger movements are known, then the user intention of typing could be understood more accurately by using the mixed information of a touching finger location and allocated keys (Index: F(2,1624) = 340.443, p < .05, Ring: F(2,1624) = 332.133, p < .05). It implies that the left index and ring fingers moved significantly differently depending on which key the left middle finger touched. In other words, when the middle finger enters a key, the key can be deduced based on the correlated finger movements.
its correlated finger movements. We strongly expect the preliminary finding to improve the performance of the virtual keyboards in near future.

Future work
The experiment of this paper verified the correlation between all fingers which may eventually help to correct the vertical typing errors of virtual keyboards. Based on this, we will design and implement a new virtual keyboard equipped with the horizontal and vertical typing errors correction algorithms. Then, we will compare our prototype with the traditional virtual keyboards from the perspective of text entry speed and error frequencies. Finally, we will see if our findings are significant in practice.

Conclusion
As we aimed to reduce the typing errors of virtual keyboards, we focused on two ideas. We first proposed to pre-allocate a set of keys to each finger. It fundamentally prevents the most of horizontal typing errors from happening. Second, we statistically verified the correlations between a touching finger and some of the remaining fingers. It implied that the touched key could be deduced by considering its correlated finger movements. Then, we discussed about a new virtual keyboard design that may outperform the current virtual keyboards. Our following work in future was also introduced.

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References