Preliminary Investigation of Tapping Force on Pressure-Sensitive Touchscreen for Expanding Input Vocabulary on Smartphone

Ryo Ikeda, Yuta Urushiyama, and Buntarou Shizuki
University of Tsukuba
1-1-1 Tennodai, Tsukuba, Ibaraki, 305-8573, Japan
{ikeda,urushiyama,shizuki}@iplab.cs.tsukuba.ac.jp

ABSTRACT
We propose a method of expanding the input vocabulary of a smartphone by using tapping force on its pressure-sensitive touchscreen. In our method, the input mode is switched by users controlling multiple levels of tapping force. To design our method, we conducted a preliminary user study to investigate the maximum number of levels in which users can control their tapping force. We found the thresholds for distinguishing the tapping force that users exert. The results showed that the accuracy of the 3 and 4 levels of tapping force without feedback were 84.9% and 77.7%, respectively, and that the thresholds should be calibrated per user.

Author Keywords
one-handed; mobile devices; force input

CCS Concepts
•**Human-centered computing** → **Human computer interaction (HCI);** Interaction techniques; Gestural input;

INTRODUCTION
A touchscreen is the dominant input interface on a smartphone. However, unlike the functionality of a mouse, which has buttons and a wheel, or a physical keyboard, which has several keys and various shortcut commands, the input vocabulary on a smartphone is limited because only a time-series of touch locations is used for manipulation. Furthermore, a smartphone is often used with one hand, making it difficult for users to manipulate it with multiple fingers. Thus, the input vocabulary is more limited.

Touch pressure [14, 9] has been used to expand the input vocabulary on a smartphone. In relation to this, tapping force has also been used to expand the input vocabulary [7]. Since a touch is a continuous action, the user can control the pressure level while receiving feedback. On the other hand, a tap is a momentary action which is fast, making the use of tapping force attractive. However, since a tap is a momentary action, the accuracy in controlling the tapping force could be low. Heo and Lee [7] distinguished a strong tap from a gentle tap by using the data from the built-in accelerometer and a time-series of touch locations. They showed that users can control the tapping force in 2 levels at a success rate of 95%. However, investigation into whether users can control the tapping force in 3 or more levels has not been reported.

In our research, we are investigating a method of expanding the input vocabulary on smartphone by expanding the tapping with multi-levels of tapping force. Our method uses a maximum force value obtained from the pressure-sensitive touchscreen as the tapping force. Previously, we conducted a pilot user study to investigate how accurately users can control their tapping force when the system's detectable force range was linearly divided into 2–6 levels. The results showed that users could control 2–6 levels of tapping force with success rates of 98.1%, 82.5%, 74.1%, 67.8%, and 54.0%, respectively, and suggested that the accuracy could be improved by dividing the system's detectable force range nonlinearly.

In this paper, we show the results of another preliminary user study in which we investigated the maximum number of levels in which users can control their tapping force and found the thresholds for distinguishing the level of tapping force that users exert.

RELATED WORK
Many techniques that use various touch features to expand the input vocabulary of touchscreens have been proposed. These techniques are divided into two categories depending on whether a motion after touching the screen is required (e.g., moving the finger or pressing the screen): single-step or multi-step.

A *single-step technique* activates a command at the moment a finger comes into contact with the screen. Therefore, these techniques are fast and require minimal touchscreen area. These techniques utilize various touch features: different levels of tapping force (e.g., a strong and gentle tap [7]), different sizes of finger contact area [1]), differentiation between palm and finger touches [10], and different areas of finger pads [8]. These techniques can be used with one hand. However, tech-

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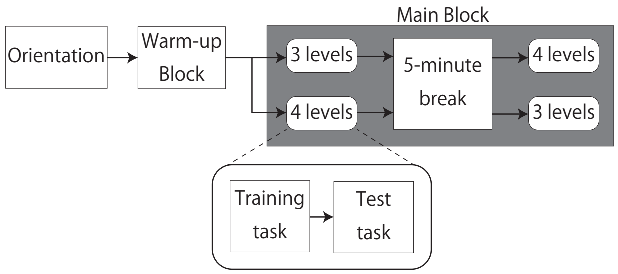

Figure 1. Procedure in the user study.

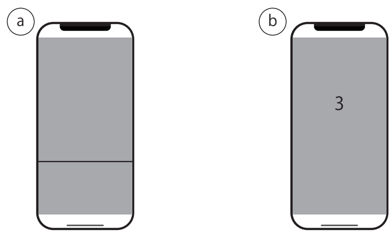

Figure 2. Screen configuration used in the warm-up block (a) and the test task (b).

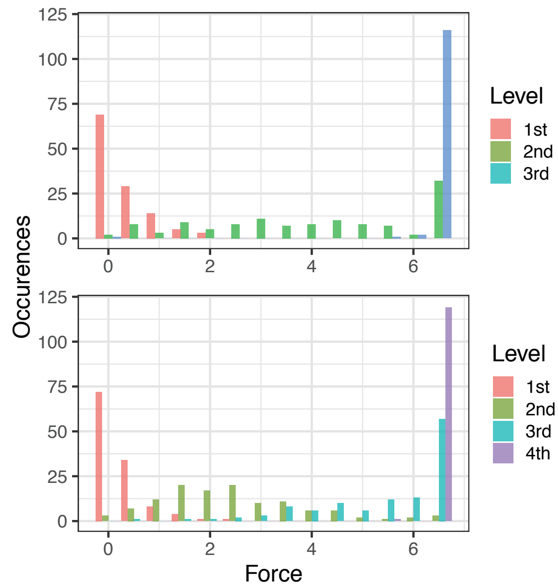

Figure 3. Histogram of the tapping force measured in the sessions of 3 (top) and 4 (bottom) levels.

niques that use different fingers (e.g., thumb, index, or middle finger [3]) or different parts of finger (e.g., fingertip, nail, or knuckle [5]) are difficult with one hand.

A *multi-step technique* requires users to perform additional motions after touching the screen such as rolling motion of thumb [12], exertion of pressure [14, 9] or shear force (e.g., [4]), swipe gestures from bezel [11], and consecutive distant taps [6]. Because many of these techniques [12, 4, 11] can also use the direction of finger movement, the expanded input vocabulary is larger than that of single-step techniques.

In this work, we develop a single-step technique that uses tapping force that is fast and only requires one hand.

PRELIMINARY USER STUDY

To investigate the maximum number of levels and the thresholds, we conducted a preliminary user study with 4 participants (22–23 years, $M = 22.5$, $SD = 0.5$; all male; all right-handed; all from our laboratory). They were all smartphone users. Since we already found that there was no prospect of improving the accuracy of 5 or more levels in our pilot study, we excluded these levels from this study and tested only 3 and 4 levels. In this study, we used an iPhone XS (5.8", iOS 13.1.3) to present the task and capture data. To capture the tapping force, we used the force property of the UITouch class, which delivers the unit-less force value between 0 and $\frac{400}{60} \approx 6.67$ in steps of $\frac{1}{60}$ with force sensitivity set to the "medium" (i.e., default) [2].

Procedure and Task

Figure 1 shows the procedure in the study. There was a warm-up block and a main block in this study. In the warm-up block, participants used the application shown in Figure 2a to get used to controlling the tapping force and perceive the system's detectable force range. In this application, the horizontal line moves vertically depending on the tapping force. The system's detectable force range is mapped onto the screen height. If participants tapped the screen at a tapping force equal to or greater than the maximum force that the system can detect, the horizontal line moved to the top of the screen. Participants tapped the screen freely for 3 minutes. After this, they proceeded to the main block. The main block had 2 sessions (3 and 4 levels). Each session consisted of a training task and a test task. In the training task, participants controlled the tapping force in 3 or 4 levels. After they felt they could control the tapping force, they started the test task. In the test task, they tapped the screen at the level of the tapping force that correspond to the number randomly displayed on the screen (Figure 2b). The higher the number, the stronger the level of tapping force. Each level was displayed 30 times. In total, we collected 4 participants $\times$ $(3+4)$ levels $\times$ 30 taps $=$ 840 taps in this study.

We had participants sit in a chair and hold the smartphone with their right hand. We asked them to tap with the thumb of the hand they held the smartphone in and perform the task as accurately as possible. To eliminate the order effect of the number of levels, we divided the participants into two groups. One group started with the session of 3 levels; the other started with the session of 4 levels. There was a 5-minute break between the 2 sessions. After all the sessions were completed, we interviewed participants about how many levels they felt they could control.

Results

Figure 3 shows histograms of the tapping force of all the participants measured in the sessions of 3 and 4 levels, respectively. With the data, we defined thresholds so that it is possible to classify two adjacent levels of the measured tapping force with maximum accuracy. For example, in the 3 levels of tapping

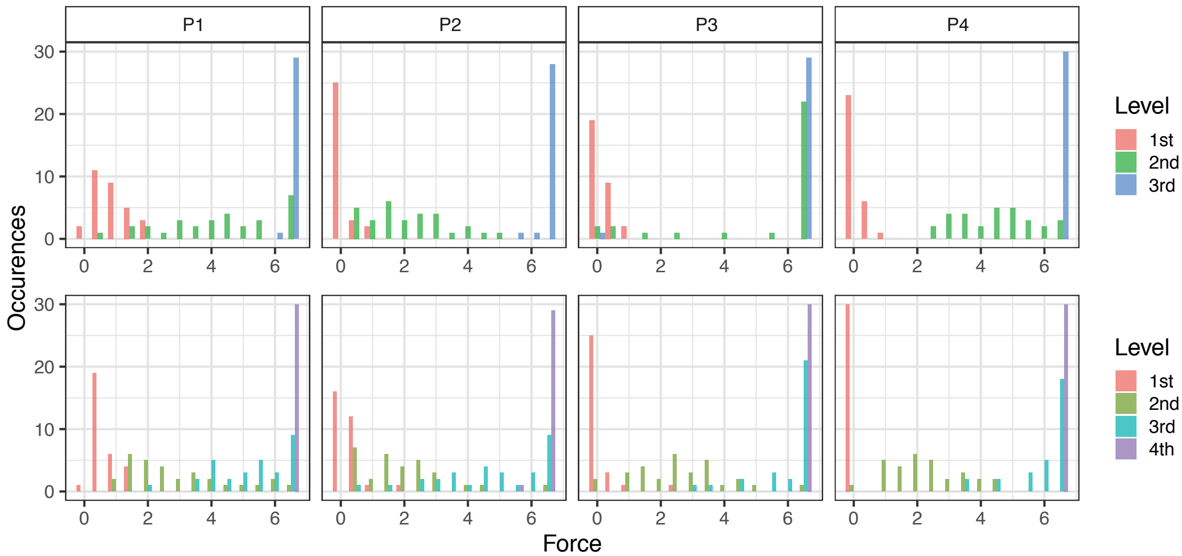

Figure 4. Histograms of the tapping force of each participant.

force, we defined two thresholds: the one between the first and second levels, and the one between the second and third levels.

In the 3 levels, the accuracy was 84.9%. More specifically, the threshold between the first and second levels was 1.27, and the accuracy of the first and second levels of tapping force were 94.1% and 89.1%, respectively. The threshold between the second and third levels was 6.59, and the accuracy of the second and third levels of tapping force were 76.6% and 95.0%, respectively.

In the 4 levels, the accuracy was 77.7%. In this case, the threshold between the first and second levels was 0.79, and the accuracy of the first and second levels of tapping force were 89.1% and 91.6%, respectively. The threshold between the second and third levels was 3.92, and the accuracy of the second and third levels of tapping force were 86.6% and 84.1%, respectively. The threshold between the third and fourth levels was 6.66, and the accuracy of the third and fourth levels of tapping force were 60.0% and 99.1%, respectively.

We further analyzed the data of each participant. Figure 4 shows histograms of the 3 and 4 levels of the tapping force of each participant. We defined thresholds for each participant by using their data. We found that the accuracy were 88.0% in the 3 levels and 81.0% in the 4 levels. More specifically, in the 3 levels, there was a threshold for each participant that could classify the first and second levels of the tapping force with an accuracy of more than 90% (P1: 1.52, P2: 0.27, P3: 0.95, P4: 1.09). In contrast, there was a threshold that could classify second and third levels of tapping force with an accuracy of more than 90%, except P3. However, the threshold of P3 was 6.42, and the accuracy of the second and third levels were 33.3% and 96.6% (on average 65.0%). In the 4 levels, no threshold could classify the third and fourth levels of the tapping force with an accuracy of more than 90%.

In the interview, all participants said they could control up to 3 levels.

DISCUSSION AND FUTURE WORK

Many issues need to be resolved before applying our method to a real application.

We need to investigate the conflict between our method and conventional tapping. In the 4 levels, the threshold between the first and second levels was 0.79. However, according to Apple's documentation on force property, the average force of conventional touches is 1.0. This implies that a tap of the second level would be frequently recognized unintentionally if a 0.79 threshold is adopted. Therefore, we must define the threshold between the first and second levels higher than 1.0. In contrast, the threshold between the first and second levels in the 3 levels (1.27) satisfies this requirement. In addition, all our participants said they could control up to 3 levels in the interview. Therefore, 3 could be the maximum number of levels in which users can control their tapping force. Therefore, the first thing we will focus on in our future work will be investigating whether users can control their tapping force using these thresholds.

In this study, the thresholds and the distribution of tapping force varied between participants, suggesting that each user's thresholds must be calibrated individually to determine their optimal threshold instead of using fixed thresholds.

We also need to investigate the effects of feedback. Generally, if the system provides feedback, users can adjust their tapping force on the basis of the force relative to their previous tapping force. However, in the test session, we did not give the participants feedback on tapping force. Thus, the users may not have been able to control tapping force well in this study. Therefore, we will conduct another user study in which feedback is given to the users.

We need to investigate how various situations affect smartphones. In this user study, we had participants sit in a chair. However, smartphones are used in various situations, such as walking or lying in bed. Therefore, we need to investigate how these situations affect tapping force.

In our preliminary user study, users tapped the screen at the position where it was easy for them to tap. In real-world use cases, users tap the screen at various locations, and the ease of adjusting their tapping force can vary depending on the location they touch. Moreover, the user may not be able to control the touch location accurately because the device moves when tapped hard. Therefore, we need to investigate the performance of our method with various sizes and locations of targets.

EXAMPLE APPLICATIONS

Software Keyboard

Our method can be used to switch multiple inputs with a single tap, which can be adapted to text entry. Currently, in a software keyboard with the QWERTY layout, users can type an uppercase character by tapping the character after tapping a shift key. In addition, users need to switch to other keyboards to type a number or a symbol. With our method, it is possible to assign a lower-case character, an upper-case character, and a number and a symbol to different levels of tapping force on one key. Users can type text that contain a variety of characters without combining other keys or switching to other keyboards. However, there is a software keyboard users can type uppercase characters with by swiping a finger on a key. However, this method conflicts with gesture input (e.g., [13]). In contrast, our method could coexist with the gesture input.

Shortcut of Text Selection

Currently, text selection on a smartphone is usually performed in three steps. First, users press the text for a few moments to select a single word. Then, they move adjusters to determine the selection range. Finally, their finger breaks contact with the screen. In our method, users can select a single word, a line, and all of the text by tapping with different levels of tapping force, which could make text selection faster.

CONCLUSION

We proposed a method of expanding the input vocabulary on a smartphone by using the tapping force on its pressure-sensitive touchscreen. We conducted a preliminary user study to investigate the maximum number of levels in which users can control their tapping force. We also found the thresholds for distinguishing the tapping force that users exert. The results showed that the accuracy of the 3 and 4 levels of tapping force without feedback were 84.9% and 77.7%, respectively, and that the thresholds should be calibrated per user.

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