Effect of Tactile Feedback for Button GUI on Mobile Touch Devices

Heesook Shin, Jeong-Mook Lim, Jong-Uk Lee, Geehyuk Lee, and Ki-Uk Kyung

This paper describes new tactile feedback patterns and the effect of their input performance for a button GUI activated by a tap gesture on mobile touch devices. Based on an analysis of touch interaction and informal user tests, several tactile feedback patterns were designed. Using these patterns, three user experiments were performed to investigate appropriate tactile feedback patterns and their input performance during interaction with a touch button. The results showed that a tactile pattern responding to each *touch* and *release* gesture with a rapid response time and short falling time provides the feeling of physically clicking a button. The suggested tactile feedback pattern has a significantly positive effect on the number of typing errors and typing task completion time compared to the performance when no feedback is provided.

Keywords: Tactile feedback, tactile pattern, button GUI, mobile touch device, user experiment.

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I. Introduction

As a touch interface is becoming more popular in various devices such as mobile phones, tablet PCs, and media players, there is a rising interest in the area of high-quality tactile feedback responding to users' touch gestures for enhancing the value of touch interaction.

Following this trend, various haptic application program interfaces (APIs) have appeared and are supporting developers based on the linear motor mainly working with mobile devices [1]. In contrast, some researchers have attempted to develop new tactile actuators to enlarge the scope of tactile expression [2]–[3]. In addition, new study findings were recently reported on the effect of tactile feedback on large interactive surfaces, as large interactive touch surfaces have begun to be used in various environments [4].

Particularly in the field of mobile devices, as the demand for high-quality tactile feedback is growing more rapidly compared with other touch devices, many related studies are being carried out, and new products with advanced technology are being launched.

Although there have been various works supporting high-quality tactile feedback, currently used tactile expressions are insufficient to simulate the feeling of physically clicking a button and improve the input performance of button GUI manipulation.

This study was therefore conducted to identify appropriate tactile feedback patterns of clicking gestures on a button GUI and to investigate their effect on typing performance based on interaction in hand-held mobile devices such as smartphones.

The remainder of this paper is organized as follows. In Section II, other works related to this topic are described. Next, the implementation of a hardware and software platform is introduced in Section III. The design of tactile feedback patterns, user experiments, and experimental results are then presented in Section IV. Finally, some concluding remarks, as well as our important findings and contributions, are provided in Section V.

II. Related Works

In an early related work on tactile touch feedback for a button GUI, the use of Active Click [5] was reported with brief evaluation results using voice coils. This study showed that tactile feedback is effective in improving the input speed of a number of entry tasks, especially under noisy conditions, as compared to without tactile or audio feedback. However, this study showed limited tactile feelings and patterns owing to the actuator characteristics.

Other studies regarding tactile interfaces coupled with GUI elements were introduced by Poupyrev and others [6]–[7]. User studies [6] have also demonstrated the effectiveness of tactile feedback in terms of task completion time for tilting interfaces with a list GUI element. They also reported that tactile feedback is most effective when the GUI elements need to be touched or dragged across the screen, such as a button or scroll bar [7].

In [8], Hoggan and others described that the addition of tactile feedback to a touch screen improves finger-based text entry. The authors tested this in both static and mobile environments using a physical keyboard, a standard touchscreen, and a touchscreen with tactile feedback added. Their study showed the clear effect of tactile feedback for mobile devices; however, there was limited tactile expression owing to the commercial actuator characteristics and the use of only one tactile pattern for a button-clicking event. The authors also mentioned that higher-specification tactile actuators can improve performance even further.

Lee and others [9] discussed virtual button performance; the impact of audio and vibrato-tactile feedback; the impact of different types of touch sensors on use, behavior, and performance; and a quantitative comparison of finger and stylus operation. They demonstrated that tactile or audio feedback improved the speed of finger-operated virtual buttons more so than without feedback. Because they were not concerned about tactile feedback patterns, they used only one vibrato-tactile pattern generated through the built-in actuator (force activated resistive sensor) for a button-clicking event.

SemFeel [10] introduced an advanced tactile expression to inform the user about the presence of an object and additional semantic information about that object using multiple vibration motors. In addition, haptic numbers [11] provide a tactile way to inform a user of the numbers on a mobile touch screen device instead of a visual or auditory representation. They defined three different tactile patterns for the numbers and compared the effect of the representation models in terms of user performance and satisfaction. That study, in common with Tacton [12]–[13], is a research branch of non-visual information presentation especially using tactile stimuli.

There was also a study on identifying the most pleasant tactile feedback for a mobile touch screen button [14]. As satisfaction is an important element in human–computer interaction usability, the authors evaluated the pleasantness of various kinds of tactile stimuli and their effect on typing performance.

As previously mentioned, earlier studies have demonstrated the various aspects of the benefits of tactile feedback, such as an enhancement of usability, task performance, and user preference. Furthermore, some researches are concerned about methods of information representation using tactile stimuli.

With reference to the aforementioned studies, this research aims at finding tactile patterns simulating the feeling of physically clicking a button, as well as evaluating the performance of these feedback patterns in interaction with a button GUI on mobile touch devices. To generate various tactile feedback patterns, a new mobile device bumper case through a built-in film-type vibration actuator was designed and implemented. Based on mobile devices covered with this type of bumper case, several tactile feedback patterns were designed, and three user experiments were conducted. The findings of these user studies have contributed to an investigation into important elements used in designing tactile patterns for simulating the sensation of touching a physical button when interacting with mobile touch devices and the effect of using the suggested feedback pattern on the typing performance.

III. Implementation

1. Tactile Bumper Case

To enlarge the scope of tactile feedback expression, a new type of actuator and hardware platform was implemented [15]–[16].

The actuator uses an electro-active polymer (EAP) exhibiting a high deformation rate, low driving voltage, low weight, and thin thickness. Mechanical movement can be made using other characteristics of changing size or shape when an electric field is simulated. A new tactile bumper case built into an EAP film was implemented, and various types of tactile feedback were generated through the case covering mobile touch devices in response to the user's touch.

In this study, an EAP film measuring 34 mm × 38 mm ×

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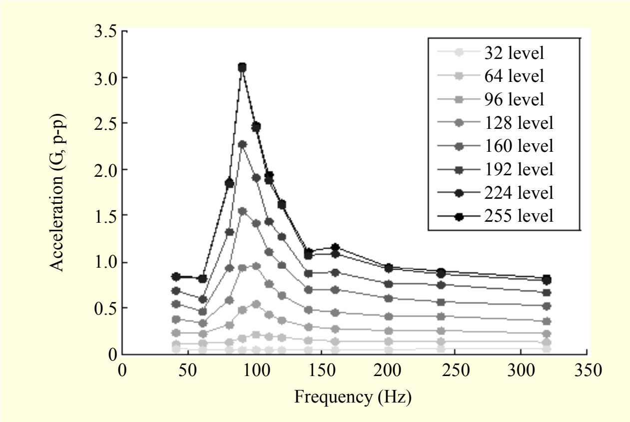

Fig. 1. Frequency response characteristics of EAP film–type actuator.

Fig. 2. Bumper case.

0.5 mm was used, and its response time was within 5 ms. The response time was measured from the occurrence time of a touch event to the generation time of tactile stimulation. Figure 1 illustrates the frequency response characteristics of the tactile actuator used in this study.

Elongation is proportional to the input voltage. The tactile actuator has a wide operating frequency range and resonant frequency of around 90 Hz. Here, a zero level indicates a zero input voltage, and a 255 level means a 3.3 voltage, as shown in Fig. 1.

The bumper case contains an EAP film actuator, a micro-controller unit, a communication (Bluetooth) module, an amplifier, and a battery. All electronic and mechanical parts are installed under a protective cover plate. Figure 2 shows the appearance of the case. Reference [15] describes in detail how this actuator can be used with a mobile touch device.

2. Control Flow

To design and evaluate various tactile patterns, we defined and implemented a tactile SDK in a haptic library module. This provides the overall APIs for controlling the bumper case; for example, the play, stop, resume, pause, add, and delete functions of the tactile patterns in pattern storage with several

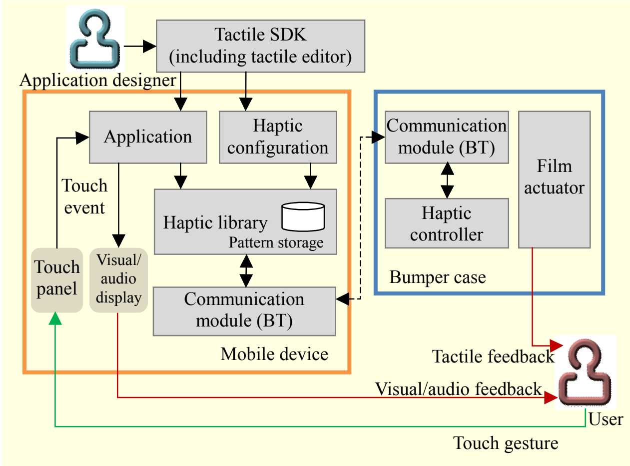

Fig. 3. Working structure of new hardware and software platform.

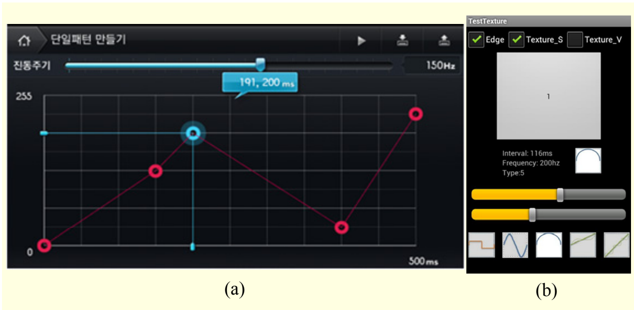

Fig. 4. Tactile pattern editors: (a) drawing a new pattern and (b) modifying a predefined pattern.

options, such as the repetition time, interval time, duration, and play type.

The pattern storage maintains predefined patterns pre-designed by users or application providers. Some APIs support the creation and playing of new patterns defined by parameter values of frequency, amplitude, and duration.

From a user touch action or an application command, a control message of a specific tactile pattern is sent to the bumper case, the actuator in the case is moved according to the control message, and tactile feedback is generated to the user.

Figure 3 shows the working structure of the new hardware and software platform. Owing to the fast response time (less than 5 ms) of the actuator, tactile feedback can be generated with little time delay in the visual and auditory display from the perspective of human perception [17]. In our experimental studies, we used only basic visual and controlled tactile feedback.

Tactile pattern editors were also implemented for the easy design and evaluation of various patterns, as shown in Fig. 4. These editors support the editing of tactile patterns that have several parameters, such as frequency, amplitude, duration, and interval, allowing a modification of the predefined tactile patterns. Arbitrary tactile patterns can be easily generated, tested, and modified using such editors on mobile touch devices.

3. Touch Gesture

As indicated in Table 1, four popular touch gestures were selected, and the combinations of their unit actions analyzed [18].

Among the four touch gestures, the tactile stimulation of the bumper case was applied to button GUI manipulation feedback with a tapping gesture, which is the most frequently used touch gesture and usage case for a mobile touch device.

Tactile patterns can be designed and applied to the unit actions of each touch gesture with consideration of usage and meaning. A tapping gesture consists of *touch* and *release* unit actions and is mainly used for manipulation of the button GUI element.

Table 1. Analysis of touch gestures.

Touch gesture	Combination of unit action	Usage case (representative GUI)
Tap	Touch + release	Button
Drag	Touch + move + release	SeekBar
Flick	Touch + quickly move + release	List
Press	Touch + hold + release	Text

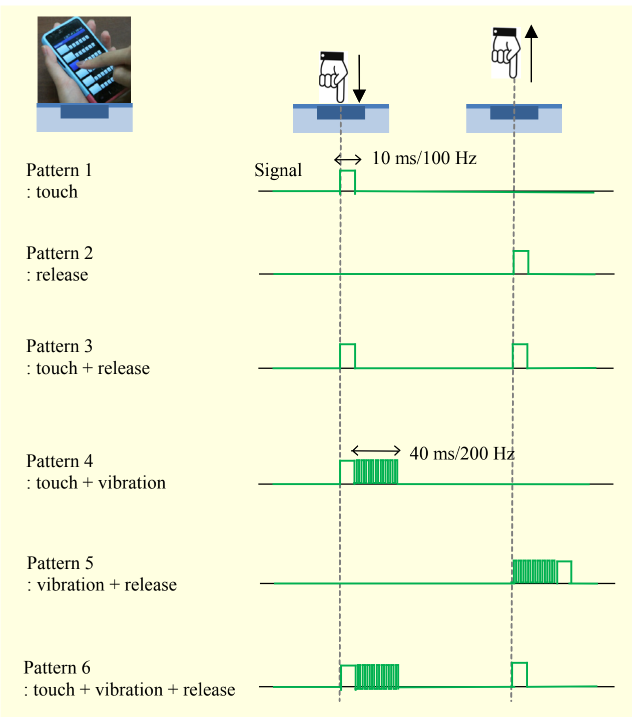

Fig. 5. Design of tactile patterns for simulating the sensation of physical button tapping.

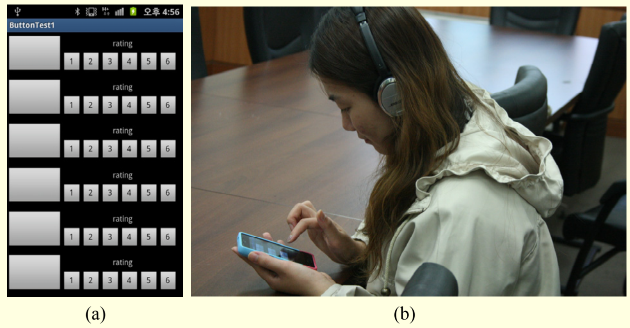

Fig. 6. User experiment application and environment: (a) application for measuring the reality aspect of tactile feedback patterns and (b) participant with noise cancellation headset.

Many different feedback patterns for a button GUI can be designed by mapping different patterns to the each touch and release unit action. Through a pilot test, we selected six such patterns, as shown in Fig. 5, according to the feeling of realistic button clicking and the suitability of button touch feedback. Each of the six selected patterns was made based on a simple impact or a combination of simple and vibration impacts. A simple impact has a 100 Hz square wave, whereas a vibration impact has a 200 Hz square wave with a 40 ms duration and can be sequentially displayed only before or after a simple impact. All patterns were simulated using 3.3 V (255 level) input voltages.

IV. User Experiments

1. Tactile Pattern User Test I

Six patterns for button touch feedback were designed, as shown in the previous section. To investigate the important elements of tactile patterns for simulating the sensation of touching a physical button in interaction with mobile touch devices, a user experiment was first conducted [19].

Four females and four males in their 20s and 30s (average age of 30.4) participated in this first evaluation. After a free button tapping trial and a comparison of the six different tactile feedback patterns, the participants were then requested to rank the feedback patterns based on their resemblance to the feedback felt from touching a physical button (see Fig. 6).

Ten trials were performed for each task, and a total of 120 trials were carried out. The experimental results are shown in Fig. 7. The rank scores of the six patterns differed significantly (based on a Kruskal–Wallis test, $p = 0.007$). Pattern 3 received the highest rank at a score of around 1.5, and patterns 2, 4, and 5 ranked much lower than pattern 3 (based on a Tukey HSD

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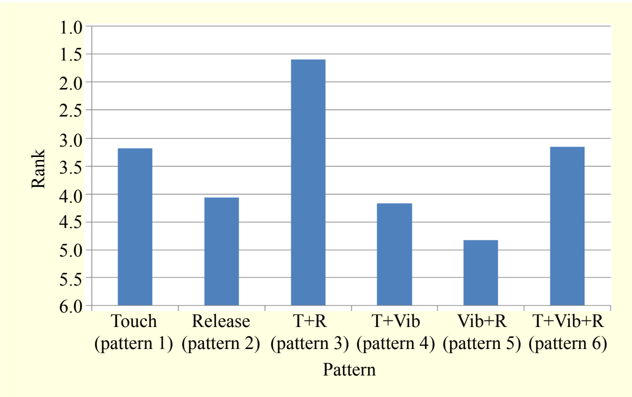

Fig. 7. Average rank of tactile patterns with a realistic description of physical button clicking by an EAP film–type actuator.

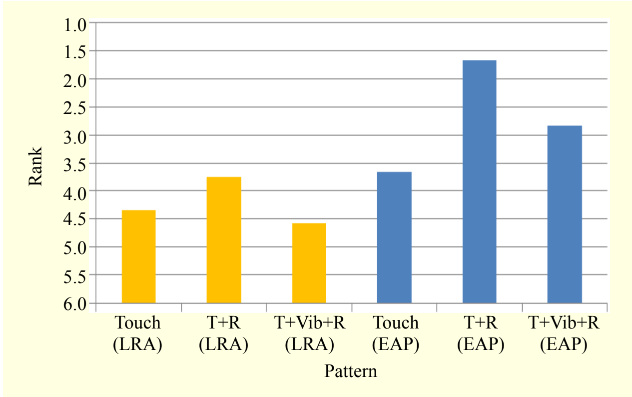

Fig. 8. Average rank of tactile patterns with a realistic description of physical button clicking by LRA and EAP film–type actuators.

post-hoc test).

From user interviews and surveys, seven of eight participant users answered that short and clear patterns, such as a simple pulse with impact, are suitable for a button GUI simulation because they felt that the impact was similar to the sensations felt while typing on a physical keyboard. Moreover, they reported that a vibration feeling, such as a buzzing, is uncomfortable for a button click feedback because it seems like an alert or warning. The experimental results also showed that tactile patterns responding to each touch and release gesture provide the feeling of physically clicking a button, as shown in the experimental results of Fig. 7.

2. Tactile Pattern User Test II

From the previous user experiment, three patterns (patterns 1, 3, and 6) according to their ranking were selected and compared on two different HW platforms. The first was a bumper case using an EAP film–type actuator, and the second was a commonly used touch device using a linear resonant actuator (LRA). On commercial devices, a sharp single click (click effect, narrow pulse, and 100% power) pattern [1] was used against a simple impact pattern, and a 40 ms vibration pattern [1] was used against a vibration impact pattern. The resonant frequency of the LRA was around 200 Hz, and the rising and falling times were 50 ms and 80 ms, respectively.

The second user experiment was carried out under the same conditions and for the same task as the first user experiment with two different types of actuators.

The tasks were performed by twelve participants (eight females and four males, with an average age of 26.7 years), the results of which are shown in Fig. 8. All six patterns showed meaningful differences (Kruskal-Wallis, p = 0.003), and the T + R (EAP) pattern ranked highest (Tukey HSD post-hoc test).

The T + R pattern of the EAP-film type and LRA actuators ranked highest in both groups, although only the rank of the T + R pattern of the EAP type was statistically meaningful. Most participants determined the ranking of the tactile patterns according to the value of the rapid response time, the short and clear pulse pattern, and the activated pattern on both touch and release gestures, similar to the previous experiment.

Some reasons for these experimental results may be inferred from the actuator's characteristics. The EAP-type actuator has both a rapid response time and a short falling time; thus, it can generate a shorter tactile simulation more quickly than the LRA.

In addition, it was found that the tactile stimulation at the time of the touch and release gestures can produce a sensation similar to that of clicking a real physical button. Users seem to experience the feeling of pushing a physical button when the first tactile feedback, such as a simple impulse is generated for a touch gesture, and the feeling of a physical button rising when the second feedback is generated for the release gesture.

As in the preceding user interviews, most participants answered that a vibration feeling seems like an alert or a warning rather than a click. Because the feeling of depth and an after-image of the vibration feedback disturbed the feeling of short and sharp falling tactile patterns, the vibration pattern was found to be unsuitable for the tactile feedback of clicking a button GUI on a mobile touch device.

3. Text Input Performance User Test

In this user test, the effect of selected feedback patterns on typing performance was evaluated in comparison with a case without feedback. From the previous experiment, two patterns (patterns 1 and 3) were selected according to the rank of physical button resemblance and user surveys.

The T + R pattern ranked highest, and all users selected it as an appropriate tactile pattern for touch feedback for typing tasks on mobile touch devices. The Touch pattern and T + Vib + R pattern showed a similar rank as in previous tests, but the Touch pattern was preferred to the tactile feedback in the user surveys because users favored simpler tactile feedback for fast and accurate typing during interaction with button touches. This may be because they have experience using the Touch pattern provided by many commercial mobile touch devices.

These two feedback patterns generated by the EAP-type actuator and the case without feedback were compared in this user experiment. For this evaluation, virtual keypads with assigned digits and characters were implemented for a mobile touch device. Four different types of keypads were designed with different levels of layout complexity and different button sizes to measure the effect of feedback patterns on the typing performance according to the level of keypad layout difficulty.

Figure 9 shows the controlled experimental environment with twelve task conditions. Six females and eight males in their 20s and 30s (average age of 26.4) participated in this evaluation. They were required to enter a given expression comprising two four-digit numbers and one character as quickly and correctly as possible under the conditions of various keypad layouts and various types of tactile feedback. An example expression is "1234 + 5678." All of the fifteen trials were conducted under each of the twelve task conditions, and a minimum 10 trials of free typing was allowed for each keypad layout, allowing the participants to become familiar with each one.

A total of over 2,520 trials were carried out because the input time was measured and counted as a valid trial for a trial without typing errors. The test application recorded the input time and error count of each typing trial. This experimental design selected a Latin-square order and balance between subjects.

The experimental results for input speed without error are shown in Fig. 10. Pattern 0 indicates no tactile feedback, and patterns 1 and 2 are a Touch pattern and T + R pattern, respectively. As the level of button layout complexity increased, the mean input time increased with significant differences (repeated measure ANOVA, $p = 0.000$, $\alpha = 0.05$). In addition, the input speed was fastest with a 3 × 3 keypad layout. The input speed with a 4 × 4 layout was faster than with a 5 × 5 or 6 × 6 keypad layout (Scheffe's post-hoc test, $p = 0.000$).

In relation to the type of tactile feedback pattern, the mean input time showed some differences. The T + R tactile pattern led to a rapid input time compared to without a feedback pattern, especially in a complex layout such as a 5 × 5 or 6 × 6 keypad layout, but the increase was not statistically significant. There was no two-way interaction between the feedback pattern type and keypad layout type ($p = 0.951$). From the

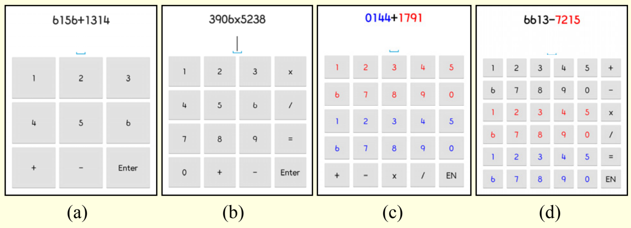

Fig. 9. Applications for text input performance test: (a) 3 × 3 button layout (16 mm × 16 mm button size), (b) 4 × 4 button layout (12 mm × 12 mm button size), (c) 5 × 5 button layout (9 mm × 9 mm button size), and (d) 6 × 6 button layout (7 mm × 7 mm button size).

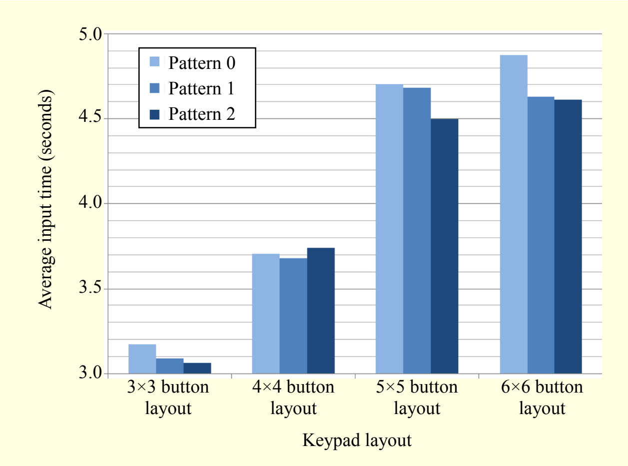

Fig. 10. Average input times for four types of keypad layouts and three types of tactile feedback patterns.

above result, we found that tactile feedback patterns do not have a positive effect on typing speed, assuming that the input tasks are conducted with no typing errors.

The effect on the error count was also evaluated during the typing tasks. The error count, which included any type of error that occurred, was measured during all fifteen trials. As the complexity of the keypad layout continued to increase, the mean error count increased with a significant difference (repeated measure ANOVA, $p = 0.026$, $\alpha = 0.05$). The different tactile feedback patterns also showed different error counts with statistical meaning (repeated measure ANOVA, $p = 0.010$, $\alpha = 0.05$), as indicated in Fig. 11.

The lowest error count was found when pattern 2 (T + R) was used. Moreover, the tactile feedback showed fewer errors than the case without tactile feedback (based on a Turkey HSD test and Scheffe's post-hoc test, $p < 0.038$). There was no two-way interaction between the feedback pattern type and keypad layout type ($p = 0.757$). These results showed that tactile feedback patterns had a significant positive effect on the number of typing errors compared to the number of errors

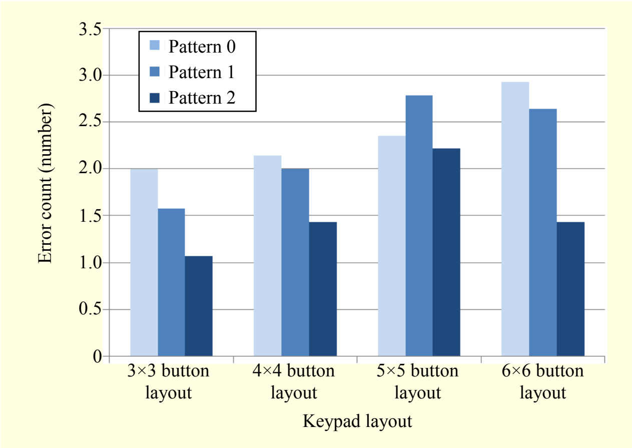

Fig. 11. Error counts for four types of keypad layouts and three types of tactile feedback patterns.

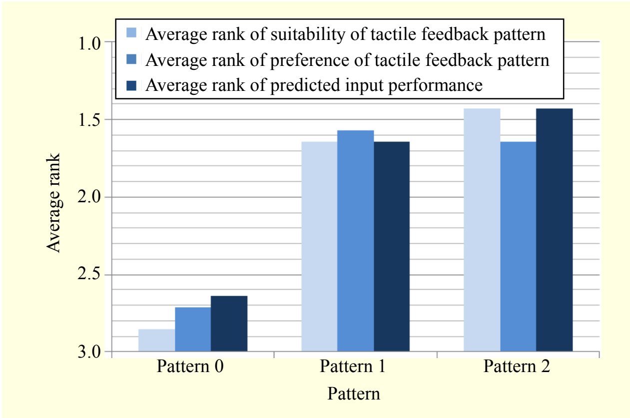

Fig. 13. Average rank of suitability pattern, preference pattern, and predicted input performance depending on the tactile feedback pattern.

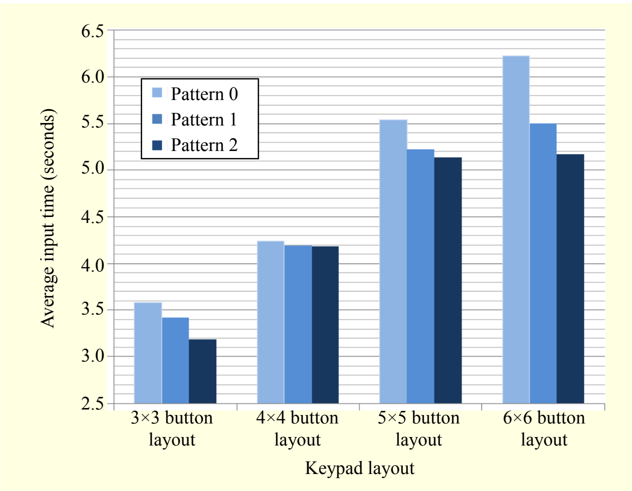

Fig. 12. Average typing task completion time for four keypad layouts and three tactile feedback patterns.

when no feedback was provided. In addition, the T + R pattern led to the lowest error count among the three patterns. Therefore, if the input time is measured to include the error correction time, then tactile feedback pattern 2 can be expected to stand out with regard to both the input speed and error count.

Figure 12 shows the average typing task completion times, which includes the error correction time. As the experimental results show, the different tactile feedback patterns have different typing completion times with statistical significance (repeated measure ANOVA, $p = 0.013$, $\alpha = 0.05$). In addition, tactile feedback pattern 2 showed a faster time than the case without tactile feedback (based on a Turkey HSD test and Scheffe's post-hoc test, $p < 0.021$). This means that tactile feedback pattern 2 is more effective in terms of input speed for general typing tasks including the error correcting time compared to the input speed performance without tactile feedback. This input task performance of the tactile pattern shows the remarkable effectiveness of a complex keypad layout such as the 5 × 5 and 6 × 6 button layouts. It should also be noted that the T + R tactile pattern was ranked highest, and in previous tests, all users selected it as an appropriate tactile pattern with touch feedback for typing tasks on mobile touch devices. The results from user interviews and surveys are summarized in Fig. 13.

The rank scores regarding the suitability of the tactile feedback patterns differed significantly (Friedman test, $p = 0.000$). Most users answered that it was comfortable to be provided tactile feedback on a mobile touch device, and the two proposed patterns were more acceptable than the currently used tactile feedback for commercial devices. The rankings of preference of the tactile feedback patterns were also significantly different (Friedman test, $p = 0.002$).

Moreover, the rank of the predicted input performance resulted in significant differences depending on the tactile feedback patterns (Friedman test, $p = 0.003$). The participants stated that they felt they could enter the given expressions more quickly and accurately when tactile feedback patterns were generated during the typing task. From the aspect of suitability, preference, and predicted input performance, patterns 1 and 2 generally show similar rankings. Although pattern 2 has slightly outstanding features of suitability and predicted input performance, users preferred pattern 1 as tactile feedback in mobile touch devices. This result may indicate that users are more familiar with a tactile feedback pattern similar to pattern 1 (Touch pattern), which is used mainly in commercial mobile touch devices, and they do not want to be bothered with excessive feedback when they concentrate on typing.

V. Conclusion

This study showed an investigation of tactile feedback patterns for a button GUI on mobile touch devices. A new bumper case was implemented using an EAP film–type actuator providing a wide range of tactile feedback expressions. In addition, a software architecture was introduced that included a haptic library operating on a mobile touch platform.

Several tactile feedback patterns were designed for a tapping gesture to manipulate a button GUI. In addition, the designed tactile patterns were evaluated through three user experiments. The first set of experimental results showed that tactile patterns responding to the touch and release gestures with a rapid response time and short falling time, respectively, provide the feeling of physically clicking a button. The T + R pattern was ranked as the best tactile pattern for simulating physical button-clicking feedback. In the second experiment, this pattern also ranked as the most suitable touch feedback for typing tasks on both an EAP film–type actuator and a linear resonant actuator. Most users stated that short and clear patterns, such as a simple pulse with impact, are suitable for a button GUI because they felt the impact was similar to the sensations felt while typing on a keyboard. Moreover, they reported that a vibration sensation, such as a buzzing, is uncomfortable for button-click feedback because it feels like an alert or warning.

This study also showed how these various patterns affect the input performance of button GUI manipulation. A comparison of the two designed tactile feedback patterns (T + R and Touch patterns) and no feedback suggest that tactile patterns have a significant positive effect on the number of typing errors. In addition, T + R tactile feedback patterns, including the error correction time, have a significant positive effect on the input speed for the typing tasks performed in this study. The participants stated that the typing tasks were conducted more quickly and correctly when the proposed tactile feedback patterns were provided, which was confirmed by the actual results. User interviews and questionnaires showed that most users want to be provided tactile feedback in interactions with mobile touch devices, and suggested that patterns are more acceptable than the tactile feedback currently used on commercial devices.

This study evaluated different tactile feedback patterns used during interaction with a button GUI to find the most appropriate, as well as assessing their effect on typing performance. We hope that these research results will be applied to various mobile touch devices, such as smartphones and tablet PCs. Further research efforts are required to expand to other kinds of touch gestures and GUIs, such as a dragging gesture on a scroll bar and the flicking gesture on a list GUI.

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