Hindawi
Mobile Information Systems
Volume 2018, Article ID 4237346, 9 pages
https://doi.org/10.1155/2018/4237346

Research Article

Perception-Based Tactile Soft Keyboard for the Touchscreen of Tablets

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Received 11 July 2017; Revised 2 January 2018; Accepted 9 January 2018; Published 13 February 2018

Academic Editor: Maristella Matera

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Most mobile devices equipped with touchscreens provide on-screen soft keyboard as an input method. However, many users are experiencing discomfort due to lack of physical feedback that causes slow typing speed and error-prone typing, as compared to the physical keyboard. To solve the problem, a platform-independent haptic soft keyboard suitable for tablet-sized touchscreens was proposed and developed. The platform-independent haptic soft keyboard was verified on both Android and Windows. In addition, a psychophysical experiment has been conducted to find an optimal strength of key click feedback on touchscreens, and the perception result was applied for making uniform tactile forces on touchscreens. The developed haptic soft keyboard can be easily integrated with existing tablets by putting the least amount of effort. The evaluation results confirm platform independency, fast tactile key click feedback, and uniform tactile force distribution on touchscreen with using only two piezoelectric actuators. The proposed system was developed on a commercial tablet (Mu Pad) that has dual platforms (Android and Windows).

1. Introduction

With advancement in touchscreen technologies, users get used to various functions of mobile devices through touch interactions. One of the most used functions is the soft keyboard input method which is very important for productive interaction on the touchscreen of a mobile device. For this reason, studies to design a better soft keyboard have been actively conducted for the past years. One of the good examples is to analyze and optimize keystroke patterns on touchscreens in order to improve key typing productivity [1–3]. Nevertheless, most of the users are not satisfied even with a better-designed soft keyboard since lack of physical key pressing feedback is the most frustrating thing when typing on a touchscreen. To this end, a low-cost linear motor has been widely used for mobile phones to create synchronized vibrations when phone users type on the touchscreen. However, the vibration generated from a linear motor is far away from a real-like key click effect. Therefore, there is the need of developing a high-definition (HD) tactile feedback technology of key click on the touchscreen of mobile devices including tablets that become popular these days.

To provide real-like key click feedback, designing a new actuator that can mimic a real-like key click movement on a touchscreen is imperative. It is learned that the piezoelectric actuator is prominent for implementing a virtual key click effect on touchscreens since its response is not only very fast, but also precisely controlled by applying input voltage. Despite the strength of piezoelectric actuators, there is very little known about how to utilize them to key click tactile feedback on tablet-sized touchscreens because piezoelectric actuators in general require high voltage (e.g., 100 to 200 V_{pp} for a single-layer ceramic bender) to be operated. Besides, driving multiple piezoelectric actuators at the same time on the touchscreen of a tablet is a challenging issue. To tackle the problem, Han and Kim developed the first prototype of the haptic soft keyboard for a tablet (Microsoft Surface Pro) with four piezoelectric actuators for high-definition key click effects [4].

For the work, a soft keyboard module was implemented under the Windows platform, and a haptic driver system that drives the four piezoelectric actuators at the same time was also developed as a portable prototype. The key pressing event was synchronized with four actuators attached under the touchscreen. The study showed how to use and drive multiple piezoelectric actuators on a commercial tablet for the first time. It also demonstrated the effectiveness of precise key click tactile feedback and the improved typing performance by conducting a user study with the developed prototype. However, the prototype had a significant time delay (over 10 ms) when driving the four piezoelectric actuators at the same time, which resulted in unsynchronized tactile feedback to fast typing. Another problem was nonuniform distribution of tactile feedback on the touchscreen, so a typist often felt unpleasantly strong tactile feedback near the actuators while felt weak at the center of the touchscreen. The other was no verification on other platforms since demanding additional work was needed to test with another platform.

In this study, a new haptic soft keyboard technology is introduced as an extended version of the previous work by Han and Kim in that three issues of the previous work—platform dependency, delayed tactile feedback, and nonuniform tactile feedback distribution on the touchscreen—have been resolved by developing a standalone microprocessor-based tactile feedback module that can be easily integrated with existing tablets. In addition, a perception study to find an optimum threshold of key click feedback strength on a touchscreen has been conducted by using a well-known psychophysical method (two interval one-up one-down adaptive method), and the result was adapted to the developed key click tactile feedback system. This study shows the first work employing perception data to the haptic soft keyboard on tablets and confirming a fast tactile feedback response on both Android and Windows. Additionally, this study showed the possibility of making uniform tactile force distribution on tablet-sized touchscreens with only two piezoelectric actuators. This paper is organized as follows. Section 2 introduces related studies that deal with improving usability of the soft keyboard by analyzing user's typing behaviors or adding haptic feedback. Section 3 presents a new platform-independent haptic soft keyboard developed on both Android and Windows. A perception study conducted by using a psychophysical experiment is described in Section 4. Experimental results for the quantitative evaluation of the developed haptic soft keyboard are reported in Section 5. Finally, discussions and conclusions are presented in Sections 5 and 6, respectively.

2. Related Work

Most of the studies for the soft keyboard focused on analyzing the position of typing fingers and key input patterns on touchscreens to design an improved key input interface. For example, Findlater et al. designed a new QWERTY layout of soft keyboard by utilizing user's typing patterns and behaviors. As a result, typing speed with ten fingers was greatly improved by achieving eyes-free touchscreen keyboard typing [1, 2]. Similarly, Sax et al. also showed that adaptively arranging the keys on the touchscreen to natural positions and movements of user's fingers can significantly improve typing performance [3]. Another research by Goel et al. introduced a new text entry model that adapts user's hand posture information such as two thumbs, the left thumb, the right thumb, or the index thumb to improve typing performance on a mobile touchscreen [5]. From a design perspective, these efforts were all good to provide better usability for typing on touchscreens but physical key typing feedback.

An early effort adding tactile feedback to the touchscreen of a mobile device was made by Poupyrev and Maruyama [6]. They designed and implemented a tactile interface on a PDA touchscreen and tested the usability with 10 participants under two conditions: audio feedback and tactile feedback. The result of their study confirmed that tactile feedback is more effective than audio feedback on a small touchscreen. In a medical perspective, Rabin and Gordon conducted an experiment to investigate the role of tactile cues in typing. Their study showed that tactile cues provide information of the start position of the typing fingers, which is necessary to perform typing movements accurately [7]. These studies initiated the need of tactile feedback technologies on touchscreens of mobile devices.

Brewster et al. further studied the effect of tactile feedback on a mobile device by attaching a commercial actuator to the backside of the mobile device [8]. Their study showed that tactile feedback improves typing speed and accuracy even though the feedback vibrates the backside of the device. Hoggan et al. did a similar study but examined with a specific task: text typing on a touchscreen [9]. The results also showed that tactile feedback significantly improves typing performance on touchscreens. As a commercial application, Koskinen et al. compared pleasant feeling between piezoelectric actuators and linear motors [10]. They found that piezo actuators are slightly more pleasant than the linear vibration motors on touchscreens with commercial mobile phones. Jansen et al. developed a system that can provide localized tactile feedback on touching a surface [11]. Another interesting idea was to add tactile feedback to an error prevention method of existing word processors so that each key provides tactile feedback to prevent errors during text entry [12].

McAdam et al. confirmed improved typing performance on tabletop computers in terms of speed and accuracy but with a different setup attaching tactile actuators to the user's body [13]. After that, Chen et al. investigated the frequency of a real-like key click signal on a touchscreen, which was found to be 500 Hz on the touchscreen of a smart phone [14]. Most recently, Han and Kim developed a prototype of haptic soft keyboard by embedding piezoelectric actuators under the mobile touchscreen which provides high-resolution key click effects on a Windows smart phone and a tablet [4, 15]. The experimental results demonstrated that key click tactile feedback underneath the touchscreen provides better performance in terms of typing speed, accuracy, and efficiency. They also reported that there was a tactile feedback delay (about 11 ms) due to the complexity of the prototype, which needs to be improved.

3. Development of Platform-Independent Haptic Soft Keyboard for Tablets

TA platform-independent haptic soft keyboard that can be integrable to existing tablets was designed as seen in Figure 1. The key idea is how to easily integrate the additional tactile

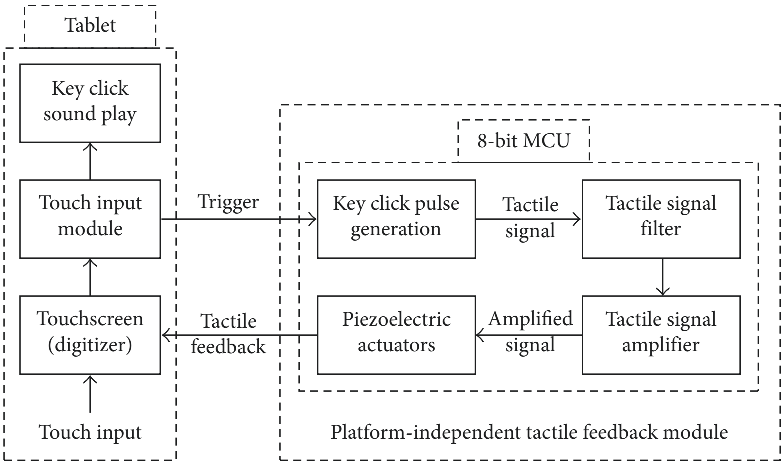


Figure 1: Block diagram of a proposed haptic soft keyboard scheme.

feedback module into existing tablet touchscreens in minimizing additional work. With the proposed scheme, all has to do is just to get a trigger signal (key press down) from the touchscreen (or digitizer). The trigger signal can be obtained from a key press event of the soft keyboard module or directly from the digitizer driver, regardless of the types of mobile operating systems. The trigger signal initiates generating a tactile pulse (e.g., key click, button down, and slide bar) that becomes an input to tactile feedback actuators. The generated tactile signal is then trimmed by a tactile noise filter. The role of this filter is to remove potential noise components of the generated tactile signal. In many cases, the noise components turn out to be an annoying jitter sound that is formed when piezoelectric actuators are vibrated on the touchscreen. The filtered signal is then amplified by a signal amplifier so that the amplified signal can have sufficient amount of energy to vibrate multiple piezoelectric actuators. All of these steps are synchronized by the clock of the microprocessor. The last thing is to mount actuators onto the touchscreen. In the proposed scheme, the way of mounting is flexible up to the need. For instance, the piezoelectric actuators can be integrated under the touchscreen for an embedded haptic soft keyboard [15] or attached on the touchscreen as a form of a portable cover. In the following, the detail of the development is described.

3.1. Development of Platform-Independent Tactile Feedback Module. A platform-independent tactile feedback module (often called haptic driver) has been developed with a low-cost 8-bit microcontroller (Arduino micro) as shown in Figure 2. This module consists of four sequential blocks: tactile pulse generation, tactile signal filter, tactile signal amplifier, and tactile feedback actuators (piezoelectric actuators). The tactile pulse generation forms a key click pulse by using the pulse width modulation technique. Three parameters, frequency, duty cycle and duration, are taken as the input, and a square waveform is then generated. In the development, the three parameters were fixed to 500 Hz, 50%, and 2 ms for a tactile key click pulse by referring Han and Kim's study [4]. The second step, a tactile signal filter,

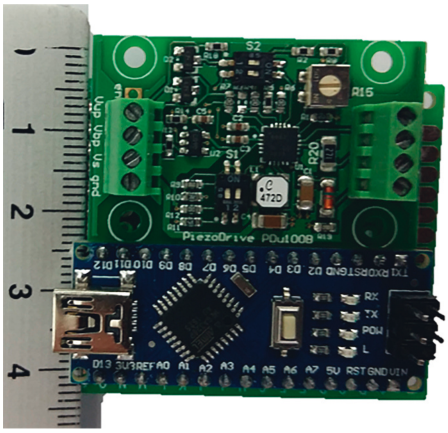


Figure 2: A prototype of the platform-independent haptic driver (40×40 mm) capable of driving two multilayer piezoelectric actuators at the same time.

which removes undesirable sound noise (jitters) when vibrating actuators, was implemented by using a digital smooth filter function of the Arduino library. However, there is a trade-off between reducing the high-frequency components and maximizing the signal energy that is the source of tactile feedback strength on the touchscreen. Finding an ideal trade-off value is another research topic that needs to be studied further in the future.

A tactile signal amplifier plays an important role to vibrate multiple piezoelectric actuators since high voltage is required for a piezoelectric actuator to produce real-like key click feedback on the touchscreen. Based on a pilot study, the minimum voltage that provides a perceptible tactile feeling on the touchscreen was around 80 V_{pp}. The minimum voltage amplification was achieved by using an acoustic signal amplifier (PDU 100) that amplifies up to 100 V_{pp}. For prototyping, an amplifier was used to drive two multilayer piezoelectric actuators ($L \times W \times H$: $32 \times 7.8 \times 0.7$ mm manufactured by Noliac) on the touchscreen. The multilayer actuator generates a bending mode and produces a stroke up to ±475 μm when a 200 V_{pp} square wave is applied.

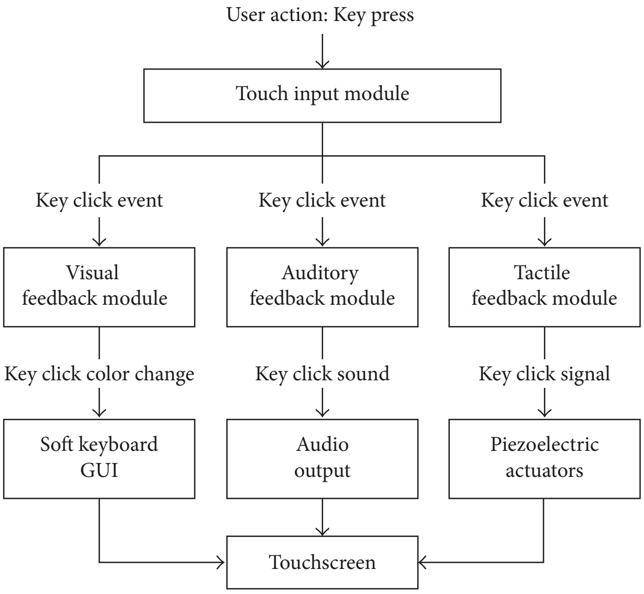


Figure 3: Feedback scheme for the developed haptic soft keyboard.

Figure 4: QWERTY soft keyboard design of the Windows platform.

Figure 5: Design of key typing areas (green) for key press feedback.

The proposed tactile feedback module can be integrated into either the touch input module or the soft keyboard module of any type of operation systems. For the proposed tactile feedback, a key press down event is used for sending a trigger signal to the tactile feedback module. In developing a prototype, the proposed tactile feedback module was integrated into the touch input module of a tablet (Mu Pad II, 1.8 GHz CPU, 2 GB RAM) that has dual operating systems, Android and Windows. Besides, visual and aural feedback modules were also implemented as seen in Figure 3. For the visual feedback, each key color is changed to show which key is pressed or released while the aural feedback plays a key click sound. For the haptic feedback, actuators attached to the touchscreen are simultaneously bent to make the entire touchscreen be vibrated for a real-like key click effect.

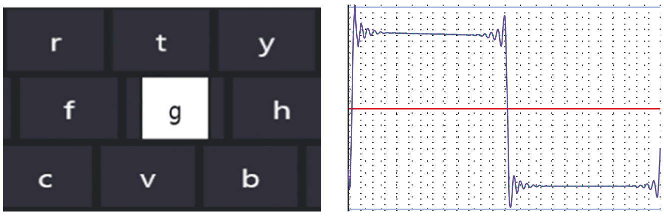
3.2. Implementation of a Soft Keyboard Module on Dual Platforms (Windows and Android). A platform-independent soft keyboard module was designed and implemented on a table device (Mu Pad) that has dual platforms, Windows and Android. For the QWERTY soft keyboard design interfacing with the tactile feedback module, the QWERTY design provided in the mobile with Windows platform (Figure 4) was used for the implementation on both platforms, Windows and Android. With implementing the same soft keyboard scheme on the different platforms, the developed tactile feedback module was able to objectively be compared in terms of performance and expendability. The implemented soft keyboard module consists of getting a key press input from the digitizer (touchscreen) and displaying feedback signals (vision, touch, and/or sound) to user's typing actions.

To reduce mistyping on the keyboard, key-pressable areas were defined as shown in Figure 5, and those areas were synchronized with feedback modules so that feedback for key press confirmation can be provided only when user's finger touches the defined areas. The feedback signals for the three modalities, vision, touch, and audio, were designed differently as seen in Figure 6. For the visual feedback, the color of a pressed key is changed to white while tactile and aural feedback signals are used for the same acoustic signal, a 500 Hz square wave (one cycle), by referring a prior study [4], but the tactile signal is generated by pulse width modulation (PWM) of an 8-bit microprocessor (Arduino micro), and the generated tactile signal is automatically sent to the developed haptic driver that drives multiple piezoelectric actuators on the touchscreen of the tablet (Mu Pad).

4. Towards Perceptible Tactile Feedback for a Key Click Effect on Touchscreens

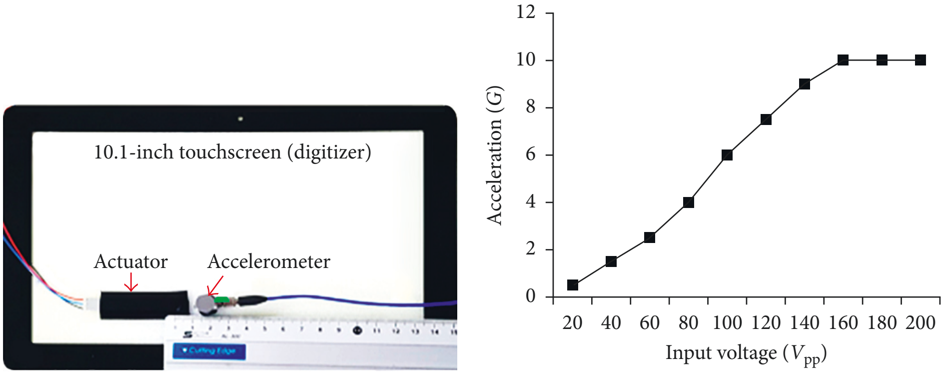
A psychophysical experiment was designed and conducted to measure a detection threshold—barely perceptible magnitude—of key click tactile feedback on touchscreen of a commercial touchscreen. Twelve volunteers (7 males and 5 females: average age 23.75 years old) took part in the experiment. All of the participants were right handed by self-report. None of the participants had experience on haptic-assisted mobile devices or similar experiments. For the perception study, a commercial 10.1 inch touchscreen of Samsung Galaxy tab was used for the experiment. Prior to the psychophysical experiment, key click tactile feedback strength on the touchscreen driven by a multilayer piezoelectric actuator (manufactured by Noliac) was calibrated by an accelerometer to quantify haptic perception levels for a key click effect (Figure 7). The piezoelectric actuator was tightly mounted on the touchscreen, and an accelerometer (PCB 352A24, Sensitivity $10.2\,\mathrm{mV/(m/s^2)}$) was positioned 5 mm to the edge of the piezoelectric actuator. Acceleration was then measured with incrementing 20 V_{pp} as the input (a 500 Hz square wave), and the measured values are plotted in Figure 7. The plot shows that the acceleration on touchscreen monotonically increases to 160 V_{pp}, which is the performance of the piezoelectric actuator used for this study.

Figure 8 shows the experimental setup used for conducting a psychophysical experiment that measures a detection threshold on the index finger. Participants took a five-minute



(a) (b)

Figure 6: Visual feedback (a) and a 500 Hz square wave for tactile and aural feedback (b).



(a) (b)

Figure 7: A commercial touchscreen with an attached piezoelectric actuator: tactile feedback calibration on touchscreen with an accelerometer (a) and the measured acceleration values for increasing input voltage on the actuator (b).

Figure 8: Experimental setup of a perception study on key click tactile feedback.

training session to understand the experiment procedure including the finger positioning on the touchscreen before starting the main experiment. During the experiment, the waveform (one cycle of a square wave pulse at 500 Hz) in Figure 6 was repeatedly sent to the piezoelectric actuator though the developed haptic driver and tactile feedback module. Participants wore a headphone and listened to white noise so that they can focus on the provided tactile cue during the experiment. A well-known psychophysical method called a two interval one-up one-down method (2I1U1D [16]) that adaptively measures participants' perception was employed to measure a detection threshold of tactile key click effect on touchscreen from the six participants. On each trial, the participant was asked to respond whether the presented stimulus on the touchscreen has a key click tactile feedback signal—one has a tactile feedback signal and the other has no tactile signal. The participant had to respond yes if he/she felt the key click feedback on the touchscreen.

By the rule of the 2I1U1D method, the magnitude of input voltage (V_{pp}) was increased after each incorrect response and decreased after each correct response. For each series of trials, the initial value was set to 200 V_{pp} and then changed by 4 dB during the first 4 reversals and then changed by 1 dB for 12 reversals. Note that the initial larger step size (4 dB) allows finding the convergence level quickly while the following smaller step size (1 dB) plays a role to improve the resolution of the final perception level. Each participant repeated three trials, and the final detection threshold was estimated by taking the average of the three trials. It took each participant 20 to 30 minutes to complete all trials including the training session. From the psychophysical experiment, the estimated detection threshold of the key click tactile feedback was $1.17 \pm 0.22\ G$ (m/s^2). The detection threshold provides a guideline of perceptible key click tactile feedback on touchscreens. With the obtained perception data, a modified tactile soft keyboard was designed as shown in Figure 9. From the new design, the tactile force adjustment computes globally equalized tactile force levels on the entire touchscreen by referring the perception detection threshold. Without this function, a typist feels a stronger tactile force near the piezoelectric actuator (near the bezel of the touchscreen) but a weak force at the center of the touchscreen. The perception database provides an ideal tactile force level that can be adaptively set to personal preferences. Finally, a prototype was developed

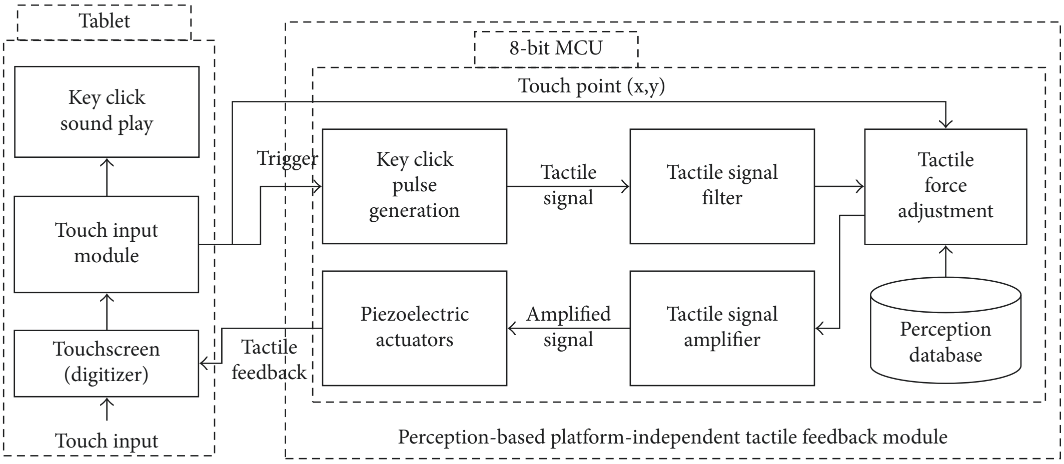


Figure 9: Perception-based tactile soft keyboard of tablets.

on a tablet (Mu Pad), and two piezoelectric actuators were mounted next to the home button on the bezel of the touchscreen to generate tactile key click feedback.

5. Experimental Results with the Integrated Tablet (Mu Pad)

5.1. Experimental Design. Three experimental measurements were performed to quantitatively test performance in terms of the similarity of tactile key click, force feedback distribution on a touchscreen, and delay time with the developed soft keyboard system (Windows and Android) on the Mu Pad tablet integrated with the developed tactile feedback module. For the first and second experiments, an accelerometer was used for measuring acceleration values that were recorded as waveform profiles for the similarity measured with a prerecorded physical click waveform and as force values on the touchscreen for ensuring the force distribution on a 10.1-inch touchscreen.

5.2. Data Collection. An acceleration profile (waveform) was measured with an accurate accelerometer (PCB 352A24, Sensitivity $10.2\,\mathrm{mV/(m/s^2)}$) as a 500 Hz square wave (one cycle), a haptic key click signal, was sent to two actuators attached to the bezel of the touchscreen. For measuring discrete tactile feedback strength on the touchscreen, the same accelerometer was placed at six different positions that were equally spaced and premarked on the touchscreen. Acceleration values were recorded five times for each point and then averaged when one cycle of 500 Hz square wave (100 V_{pp}) was applied to the two piezoelectric actuators activated by a key press event from both Windows and Android. The last measurement was conducted to test the delay time from pressing a key on the touchscreen to driving the piezoelectric actuators through the developed haptic driver. The measurement was repeated ten times both on Android and Windows, respectively, and measured values were averaged to be compared.

5.3. Results. The first experiment was to verify whether the key click tactile feedback on the touchscreen is a real-like key click effect. For this, the measured acceleration waveform was compared with the acceleration waveform recorded from a mechanical key pad by Chen et al. [14]. The comparison result is shown in Figure 10. The blue curve is the measured waveform in this study, and the black curve is the waveform recorded from a mechanical key pad. It is obvious that there are good matches in peaks and valleys. Note that the first peak is most important to mimic a real-like key click effect.

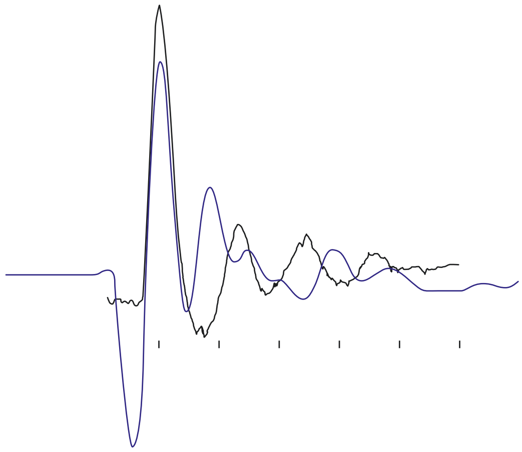


Figure 10: Comparison of the measured acceleration waveform (blue) on the touchscreen of Mu Pad with the acceleration waveform (black) recorded from a mechanical key pad by Chen et al. [14].

The second experiment was to quantify tactile force distribution on the touchscreen of the integrated tablet since vibrations generated by piezoelectric actuators on the bezel of a tablet are diminished in strength while traveling from a side to the center. So the goal of this experiment is to investigate the diminishing by visualizing tactile feedback strength on the touchscreen of the soft keyboard. As the result, all averaged values are graphically visualized in Figure 11. The stronger tactile feedback is colored in the redder. From the distribution image, it is clear that tactile feedback is not equally distributed over the soft keyboard. The reddest area on the arrow keys, right next to a piezoelectric actuator, is too strong (larger than 2 G), whereas the areas of the

FIGURE 11: Acceleration distributed on the touchscreen of the tablet (Mu Pad): the measured values were superimposed onto the soft keyboard image to visualize the tactile strength generated from two piezoelectric actuators attached on the bezel. Note that red means stronger tactile feedback.

FIGURE 12: Equalized acceleration distributed on the touchscreen by the tactile force adjustment function that computes globally equalized tactile forces concerning the distance between actuators and key locations.

backspace key and the "q" key are relatively weak (1.3 to 1.4 *G*) though the strength is slightly over the estimated detection threshold (1.14 *G*). The issue can be resolved by the tactile force adjustment function in Figure 9. To achieve globally equalized tactile feedback over the soft keyboard, the desired tactile strength was set to 1.5 *G* by referring the estimated detection threshold (1.14 *G*) since the estimated detection threshold is barely detectable. The equalized distribution is seen in Figure 12. Overall, tactile forces are well distributed over the soft keyboard with an ignorable less force on the backspace key.

The last experiment was conducted to measure the time from pressing a key on the touchscreen to driving the piezoelectric actuators through the developed haptic driver. The results were 1.9 ms and 2.1 ms on Android and Windows, respectively, which shows that there is no big difference between Android and Windows when the proposed tactile soft keyboard system was integrated. A further experiment has been conducted to compare with the previous study by Han and Kim [4]. Han and Kim's approach was to drive piezoelectric actuators by using an audio play function with a prestored key click waveform on a Windows tablet. The time reported in their study was over 10 ms. To objectively compare the result, the same experimental condition (playing a prestored key click waveform) was implemented on the Windows platform of Mu Pad, and the result was compared with the proposed tactile key click system (i.e., generating a key click waveform directly from the developed haptic driver). The numerical result of Han and Kim approach was 3.9 ms which is slower than the new result (2.1 ms) of the proposed approach in this study. It confirms that the proposed approach in this study outperforms in terms of a fast response of tactile feedback on touchscreens. The fast response of tactile feedback is imperative since a fast typist on a tablet may not get tactile feedback on time. This study shows a promising direction of haptic soft keyboard technologies by improving the responsiveness.

6. Discussions

To the best of my knowledge, the detection threshold measured in this study is the first result ever reported for touchscreens. The detection threshold was used as a lower bound perception value to ensure a tactile key click effect. By taking this approach, people can surely feel the tactile feedback on 10.1-inch touchscreens, and the use of energy (mobile battery) driving multiple actuators can also be optimized. This is important in that adding tactile key click feedback to existing tablets should not be a burden due to battery consumption. This study shows a practical example how to utilize human perception data though further studies are needed to apply for various form factors in terms of the size and material of touchscreens.

When designing a tactile soft keyboard for mobile devices, one of the challenging issues is how to make the tactile feeling realistic although the feeling itself could be relative. To quantify the tactile feeling, an acceleration profile (waveform) was measured and compared with the acceleration waveform reported by [14]. Based on pilot studies conducted in this study to figure out primary features that are most important to imitate a key click effect, the pattern of peaks of the acceleration waveform was a key to simulate a key click effect on a touchscreen. As seen in Figure 10, as long as the largest and the second largest peaks are well formed like the physical key click, the tactile feedback was felt as a real-like key click on a planar touchscreen surface. However, the acceleration waveform is determined by piezoelectric actuators that provide accurate force bending the mounted touchscreen. Actuators used in this study were all best-performed multilayer actuators manufactured by Noliac. Therefore, making the similar effect with even lower quality of piezoelectric actuators is another research topic that will be done in the near future.

Equalizing force feedback on a 10.1-inch touchscreen is not simple since the vibration force is diminished as the distance from an actuator increases. Figure 11 shows the stronger forces near the attached actuators, which is not desirable. There are two solutions to solve this issue. One is to directly control the input power of the piezoelectric actuator with respect to the location where a key click effect should be delivered. In general, the larger voltage is required to get the bigger movement from the actuator (Figure 7). The other is to change the amplitude of an input tactile signal (e.g., a square wave) that will determine the movement of the actuator in the end. In this study, the first solution was used since it was learned that the resolution of the tactile feedback force with a piezoelectric actuator is significantly low with the second approach. This is because the mapping between the magnitude of the input signal and the input voltage of the actuators is not linear.

In addition, the performance of key click tactile feedback on touchscreens is greatly influenced by the characteristics of actuators to be mounted. The actuators should be able to provide high-definition tactile forces that make various types of virtual touch feelings on touchscreens. Piezoelectric actuators are in general precision actuators that convert electric energy into linear motions with high speed and resolution. Due to this reason, piezoelectric actuators are suitable for implementing a virtual key click effect on touchscreens of mobile devices. However, high voltage (e.g., 200 V_{pp} for a single-layer piezoelectric plate) is typically required for a piezoelectric actuator to be sufficiently vibrated on a touchscreen to imitate a mechanical key click effect. Due to the limitation of input voltage with a tablet device, handling multiple piezoelectric actuators is a challenging problem. Han and Kim developed a most advanced tactile key click feedback with multiple piezoelectric actuators on a Microsoft Surface Pro tablet [4]. However, there was over 10 ms delay time to get tactile feedback from pressing a key and so tactile feeling was not synchronized well. The prototype of a haptic driver was also a bit bulky to be integrated with existing commercial tablets. The last problem was that the developed haptic soft keyboard module was not completely independent from the Windows platform. The present study can be considered as an improved version of the Han and Kim's work by resolving those issues of the prior study.

The present study focused on developing a platform-independent haptic soft keyboard system so that the tactile feedback module can be integrated into existing commercial tablets (or mobile devices) by putting the least amount of effort. For this reason, a dual platform tablet with a 10.1-inch touchscreen, widely used in these days, was chosen as a test device. As explained earlier, the developed tactile key click feedback module can be simply integrated by using a pulse-generating function of each platform that sends a trigger signal to the haptic driver generating a key click signal. The platform independency was proved by results of delay time that are almost same between Android and Windows. This is because a tactile signal is created from the separated haptic driver but not from the operating system like Han and Kim's work. Further, the proposed scheme outperforms the prior study in terms of response time, which also resulted from being less dependent on the operating system. One of the important contributions in the present study is to employ human perception on key click tactile feedback on a commercial touchscreen. According to a prior study, Han and Kim [4], one cycle of square waveform at 500 Hz was used for a real-like key click tactile effect, and the effect was quantitatively proved by analyzing the acceleration profile.

7. Conclusions

In the present study, a platform-independent haptic soft keyboard module that has the least dependency to mobile operating systems has been designed and developed. The proposed haptic soft keyboard module consists of three parts: soft keyboard with feedback, a mini haptic driver, and piezoelectric actuators. The soft keyboard with feedback (visual, tactile, and aural feedback) was implemented on a dual platform tablet to prove the platform independency. A mini haptic driver that can generate tactile key click pulses and remove noise was developed with an 8-bit microprocessor (Arduino) so that it can be simply integrated into existing tablets. The haptic driver was specially designed to drive multiple piezoelectric actuators that produce sufficient tactile forces on the touchscreen. In addition, a psychophysical experiment has been conducted to estimate the human perception (detection threshold) on key click tactile feedback. By applying the obtained perception data to the haptic soft keyboard module, perceivable and uniformly distributed tactile feedback was implemented on the touchscreen. Experimental results confirm that the proposed haptic soft keyboard outperforms the previous study by Han and Kim in terms of platform independency, uniform tactile feedback, and synchronized tactile feedback (delay time). The knowledge learned through this study can be an informative guideline to engineers, researchers, and designers who are actively involved in design or development of soft keyboard on mobile devices. Tactile key click on touchscreens must be a promising technology that greatly improves the usability of mobile input methods or multimedia-related interaction. However, there are still many open questions that need further research. One of them is localized tactile feedback with less number of piezoelectric actuators. As future work, a further study will be conducted to investigate a feasible solution on the topic.

Conflicts of Interest

The author declares that there are no conflicts of interest.

Acknowledgments

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (2015R1D1A1A01060715).

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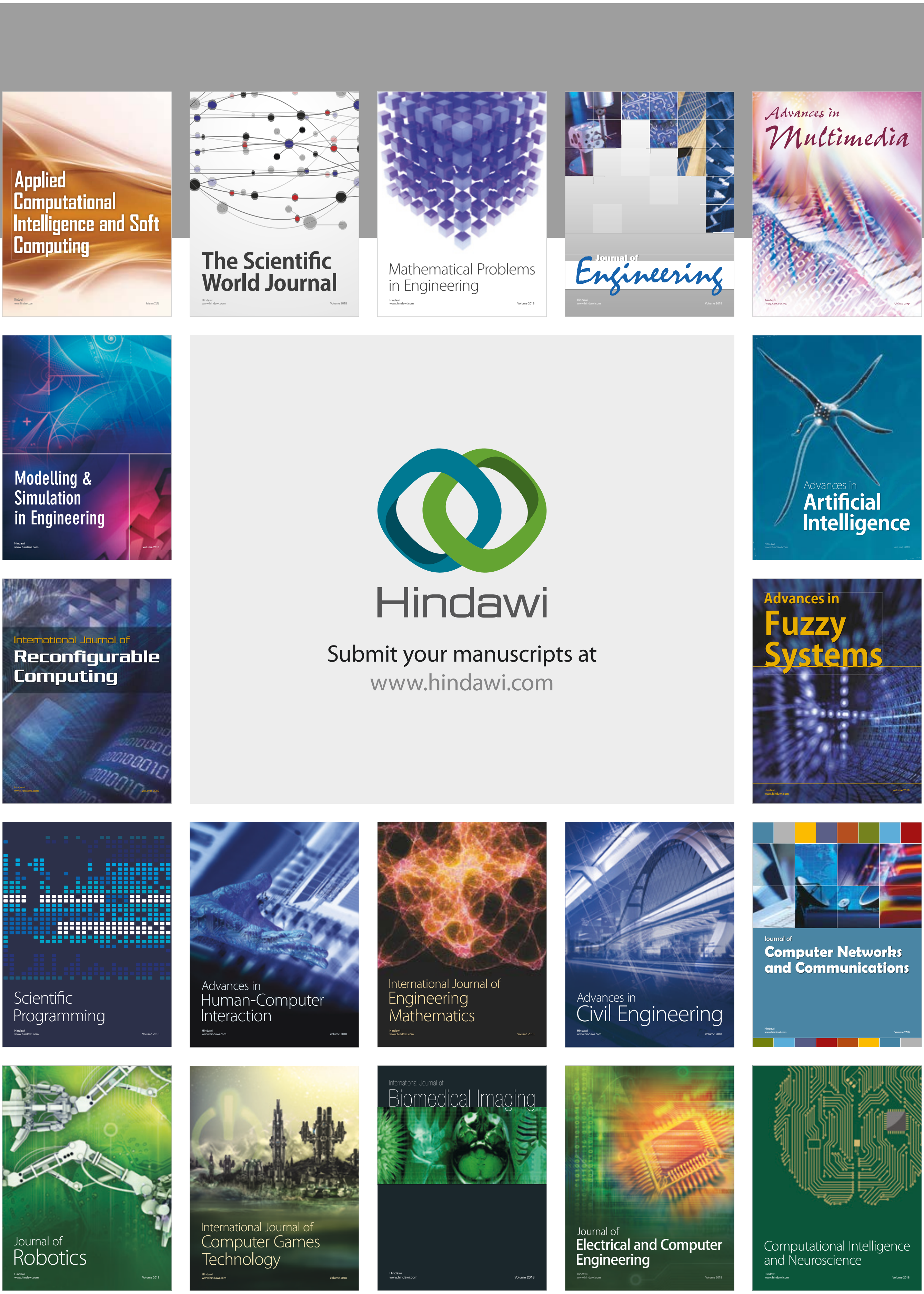

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