A Virtual Button with Tactile Feedback Using Ultrasonic Vibration

Kaoru Tashiro[1], Yuta Shiokawa[2], Tomotake Aono[3], and Takashi Maeno[2]

[1] Keio University, Graduate School of Integrated Design Engineering
Hiyoshi 3-14-1, Kohoku, Yokohama, Kanagawa, 223-8522, Japan
fr041303@a3.keio.jp
[2] Keio University, Graduate School of System Design and Management, Japan
[3] Kyocera Corporation, 1st Section 1st Department Yokohama R&D Center, Japan

Abstract. A virtual button with tactile feedback is realized by use of ultrasonic vibration with amplitude of a few micrometers. Button-like click feeling is displayed by recreating rapid change in reaction force arising from buckling of a mechanical push button utilizing squeeze film effect. First, click feeling display system was constructed based on the principle of perceiving click feeling when pushing a mechanical button. In the system, stimulation are applied to the operators at both buckling and restitution point. Then, by conducting several sensory evaluation experiments, the optimum parameters of the ultrasonic vibration was determined to display button-like click feeling. Finally, by conducting usability test, it was verified that the usability of the virtual button was equivalent to that of a mechanical button.

1 Introduction

With the diffusion of touchscreens, a number of attempts to display tactile information on touchscreens have been conducted. Establishment of the method to display click feeling to the touchscreen will lead to higher operation performance and decrease of unconscious incorrect input. As substitutes of tactile feedback, several methods are proposed, including displaying visual or auditory information such as screen effects and confirmation sound. However, it requires time and effort to recognize the visual information displayed on the screen. Even worse, operator's own finger disturbs seeing the screen. Moreover, as confirmation sounds are heard by people around, it is sometimes difficult to be used in public areas. Hence, displaying tactile information is necessary as an operating feedback for touchscreens. Past studies of tactile feedback for touchscreens include Touch Engine having function to vibrate the back side of the device [1] and Tactile Panel with function to display vibration on its touchscreen [2]. These touchscreens can generate various vibrations to operator's finger touching the touchscreen. The former utilizes piezoceramic bending motor and the latter utilizes conductivity type speaker as an actuator. Products having the same function as Touch Engine are recently being released. These products have minimum feedback performance. However, only simple monotonous vibration is used as feedback. Moreover, high voltage was necessary to recreate button stroke of approximately 100 μm using vibration. Meanwhile, tactile display using ultrasonic

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vibration has been attracting attention for creating large stimulation with low vibration amplitude because of squeeze film effect. We have confirmed that button-like click feeling can be displayed by applying ultrasonic vibration with appropriate amplitude and vibrating time in response to touch motion of an operator [5]. Hence, by creating tactile feedback to touchscreens using ultrasonic vibration, realistic click feeling can be displayed with amplitude of only a few micrometers.

In this study, we develop a virtual button with tactile feedback by utilizing ultrasonic vibration for displaying click feeling. In this study, click feeling is defined as the tactile sensation perceived when pushing a mechanical button such as PC mouse. By utilizing squeeze film effect due to ultrasonic vibration, we recreate buckling feeling that arises when mechanical buttons are being pushed at a certain suppress strength. Then, we verify the usability of the virtual button by conducting sensory evaluation experiments.

2 Principle of Displaying Click Feeling

In this chapter, we explain about the method for displaying click feeling using ultrasonic vibration. First, in 3.1, we explain about principle and characteristics of a mechanical push button. Then, in 3.2, we explain about the principle of perceiving click feeling when applying ultrasonic vibration to human finger pad in response to human touch motion.

2.1 Principle of Perceiving Click Feeling

Click feeling of a mechanical button is perceived when the dome structure of spring component buckles and restitutes as shown in Figure 1 [3]. Figure 2 (a) is a reaction force–stroke length (F-S) curve showing the relationship between reaction force and stroke length changes occurred in normal direction when a mechanical button is pushed or released vertically. In this study, F_b and F_r are defined as the force when buckling starts while pushing and the force when rapid restitution starts while releasing the button, respectively. As shown in Figure 2 (a), in the early stage of pushing phase, force and stroke are positively correlated. As the pushing force reach F_b, relationship between force and stroke turns to be negatively correlated.

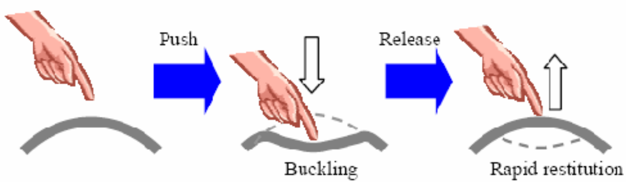

Fig. 1. Buckling and restitution of dome when pushing Button

Then, the relationship turns back to be positively correlated as the button is fully pushed because the whole button is deformed. In the releasing phase, the F-S curve follows the similar trajectory to that of pushing phase. When the pushing force comes

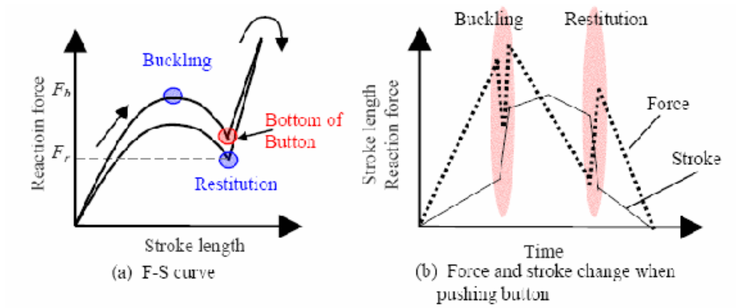

Fig. 2. Image of F-S curve and time scale change of F-S characteristic of push button

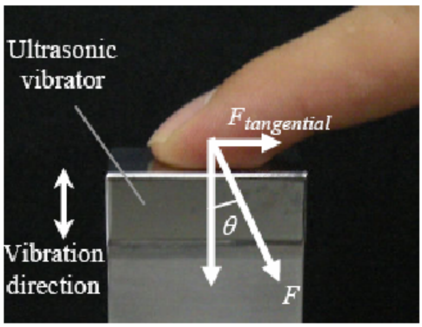

Fig. 3. Finger contact area of ultrasonic vibrator

down to F_r, the restitution force arises upward. Figure 2 (b) shows the rough image of time change in force and stroke of a general button pushing motion. As shown in Figure 2 (b), force and stroke change rapidly at buckling and restitution point. It is considered that click feeling is perceived due to the rapid change in force and stroke [5]. We have confirmed that the difference of buckling force was well distinguished whereas the difference in stroke length was difficult to be distinguished [4]. Hence, buckling force is an important factor for displaying click feeling whereas stroke length is not required to be recreated accurately.

2.2 Principle of Displaying Click Feeling Using Ultrasonic Vibration

In this study, click feeling is displayed by use of squeeze film effect. Squeeze film effect is phenomenon that occurs when two objects having sufficient area compared to the distance approach rapidly. When the fingertip is placed on a rapidly vibrating plate, the squeeze film is generated by the overpressure between the epidermal ridges [6]. It is known that coefficient of friction decreases due to squeeze film effect. In the case of this study, the displaying area of ultrasonic vibrator is touched as shown in Figure 3. In the proposed method, rapid change in force due to buckling of a mechanical button is recreated by temporary decreasing the coefficient of friction between operator's finger pad and displaying area of the ultrasonic vibrator.

Principle of perceiving click feeling is as follows: As shown in figure 3, it is assumed that the direction of pushing force F is θ in angle to normal direction when the operator pushes the displaying area. Therefore, normal and tangential forces applied by the operator to the vibrator are $F\cos\theta$ and $F\sin\theta$, respectively. Where coefficient of static friction between finger pad and the vibrator surface is μ, friction force is $\mu F\cos\theta$. Hence, finger slips when

$$\mu < \left|\tan\theta\right| \tag{1}$$

is satisfied $\tan\theta$ in pushing action was measured to be between -0.1 and 0.1. When finger slips, θ increases because of fingertip movement, resulting in increase of the right-hand value of (1). Therefore, resisting force tangential to human finger pad and normal force decrease. As stated above, force tangential to human finger pad can be decreased by changing coefficient of friction utilizing squeeze film effect. In this way, the rapid change in force and stroke due to buckling of mechanical buttons can be recreated.

3 Development of Virtual Button with Tactile Feedback

In this study, ultrasonic vibrator is used as the actuator for displaying click feeling. Ultrasonic vibrator is an actuator that consists of metal elastic body and piezoelectric device. It is characterized by high response, high generative force, minute amplitude control and quietness. Numbers of studies displaying various texture using ultrasonic vibration have been reported [7][8][9][10]. Figure 4 (a) shows the overall view of the push button display system. As an ultrasonic vibrator, the Langevin-type ultrasonic vibrator was used in the present study. Figure 4 (b) shows the detail of the vibrator. Driving frequency is close to 28.2 kHz, which is the natural frequency of primary longitudinal vibration mode. In this case, the vibrator vibrates in the direction as shown in Figure 4 (b) to create maximum amplitude of 20 μm. As shown in Figure 4 (a), upper side of the vibrator having flat metal surface is used as tactile displaying area.

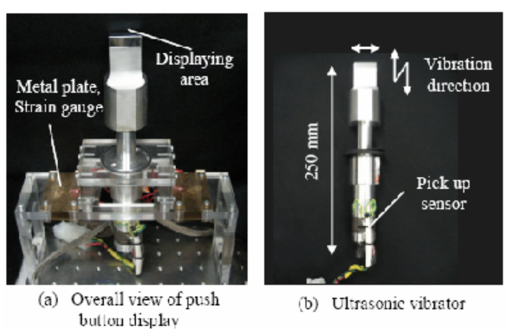

Fig. 4. Push button display

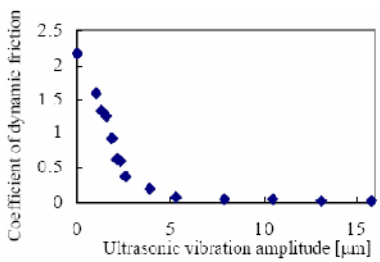

Fig. 5. Relationship between vibration amplitude and coefficient of dynamic friction

Therefore, the vibration is normal to human finger pad. In this case, squeeze film effect occurs between finger and displaying area. Figure 5 shows relationship between amplitude of ultrasonic vibration and coefficient of dynamic friction of the vibrator surface obtained by tracing tactile displaying area of the vibrator with finger pad. The coefficient of dynamic friction was calculated by measuring the tangential force when tracing on the excited vibrator with approximately 1 N of normal force. As shown in Figure 5, coefficient of dynamic friction of the vibrator surface is approximately 2.2 and it decreases to less than 0.5 when ultrasonic vibration with amplitude of 2.5 μm is excited. The displaying area measures 30 mm in width and 15 mm in depth. Operator pushes the displaying area like pushing a real button. By measuring strain of metal plates placed under the ultrasonic vibrator using strain gauge, normal force applied by operator to the vibrator can be measured, as shown in Figure 4 (a). In addition, as shown in Figure 4 (b), pick up sensor is placed in the vibrator. Voltage of sensor output is proportional to the vibration amplitude. Hence, monitoring and control of vibration amplitude is available by use of the sensor output. In this system, intended vibration amplitude can be obtained in spite of an operator's suppress strength by the control system built using FPGA (Field Programmable Gate Array) [11]. It is confirmed that vibration amplitude can be controlled with an uncertainty of 1 % using the system when load is under 10 N.

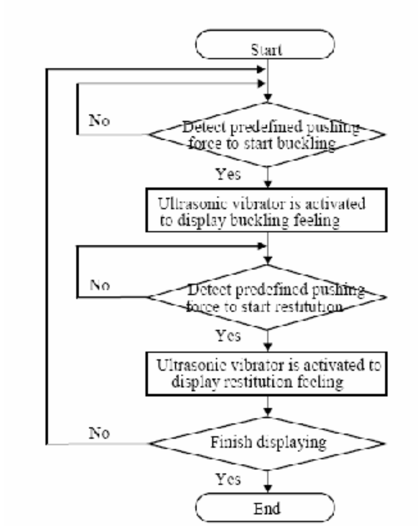

Fig. 6. Flow of the push button display system

One of the characteristics of our system is that operator's pushing force is used as the trigger for starting vibration. In most of the past studies of click feeling display [1][2], tactile feedbacks were displayed after configured time delay from touching the screen. The problem of this control method is that it has no robustness against various applications of buttons or characteristics of the operators because the same feedbacks are displayed in spite of various pushing motion. Moreover, it is difficult to display click feeling perceived when releasing a button using this control method because the stimulation was applied according to the configured time delay. In our system, we display more button-like click feeling compared to the past studies by displaying both pushing and releasing feeling of click utilizing the operator's pushing force information measured in real-time. Figure 6 shows the flow of the click feeling display system. In the system, ultrasonic vibration whose amplitude and vibrating time are configured in advance is excited when pushing force measured in real-time reaches the buckling load and restitution load, respectively. First, output obtained by strain gauge is converted to force in PC with control cycle of 1 KHz. When measured force reaches to predefined value, AC voltage with frequency of 28.2 kHz is applied to the vibrator via FPGA, oscillator and amplifier. Amplitude of ultrasonic vibration decayed by the operator's suppress strength measured by pick up sensor is fed back to FPGA and compensated to be intended amplitude. The response velocity of ultrasonic vibrator to excite intended vibration amplitude after activating signal is approximately 0.6 mm/s. Vibration amplitude, time and trigger force of both buckling and restitution can be set independently.

4 Verification

4.1 Survey of Parameter Value for Displaying Click Feeling

A simple sensory evaluation experiment was conducted to survey the appropriate value of vibration parameters for displaying click feeling. The task for examinees were to evaluate existence or non-existence of click feeling displayed using the constructed system on a 5-point scale, from 1 (do not perceive click feeling at all) to 5 (clearly perceive click feeling), when vibration amplitude, time and buckling load F_b of the system were changed, respectively. The averages of each evaluation value were calculated. Examinees were six males in their twenties. Sin curve with frequency of 28.2 kHz was utilized as the waveform of the vibration. Vibration amplitude and time of release click feeling were set to the same value as those of push click feeling. Restitution load F_r was set to 0.1 N less than buckling load F_b. Parameters not surveyed, for example vibration time and trigger force when surveying vibration amplitude, were set to intermediate value of surveying range of each parameter.

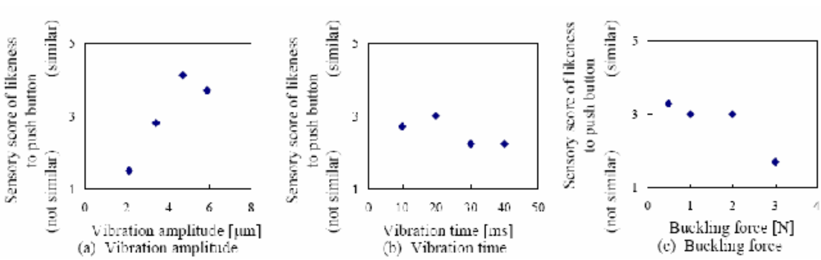

Fig. 7. Relationship of sensory evaluation score and changeable parameter

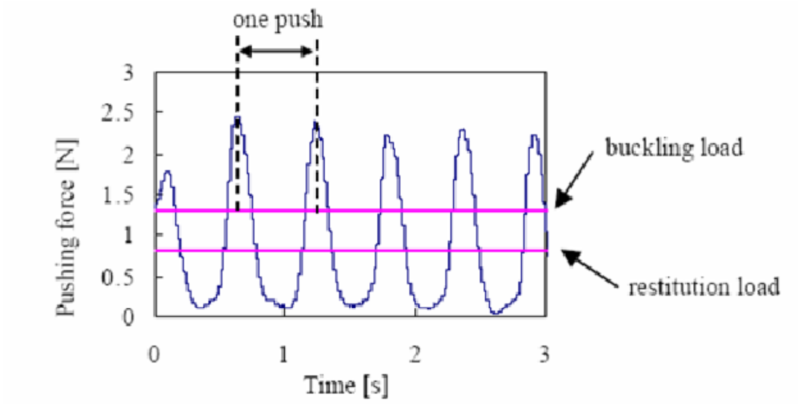

Fig. 8. Average of pushing force

Figure 7 (a), (b) and (c) show the results of the experiments to survey vibration amplitude, time and trigger force, respectively. As shown in Figure 7, click feeling was perceived when vibration amplitude was between 4 and 6 μm. Click feeling became more similar to real buttons when vibration time was between 50 and 100 ms and trigger force was between 0.5 and 2.0 N, respectively, compared to other values. Hence, click feeling more similar to real buttons can be displayed by combining the largest evaluated values of each parameter.

4.2 Usability Test

Experiment was conducted to verify the usability of the virtual button with tactile feedback. Examinees were asked to push two types of virtual button, with tactile feedback and without tactile feedback, 30 times, respectively. Each time examinees pushed the button normally, number shown in console increased so that examinees could count the number of pushes. Changes of pushing force of each examinee were measured throughout each test. The changes of values were compared to those measured when pushing a real mechanical button at the same experimental condition. Amplitude and vibrating time of ultrasonic vibration were set 4.7 μm and 20 ms, respectively, based on the result of previous section. Buckling and restitution load of the virtual button were set 1.3 N and 0.8 N, respectively, to coordinate with the mechanical button used for comparison. The task was conducted in two different conditions for each button. First, examinees were asked to push each button at a speed of two times per second, and second, four times per second. Examinees had at most 1 minute to practice pushing the button with correct rhythm before each task using metronome. Buttons were pushed with the most suitable way for each examinee. Examinees were ten males and females in their twenties, visual and auditory information masked. Considering difference between learning level, the tasks were conducted in different order among the examinees.

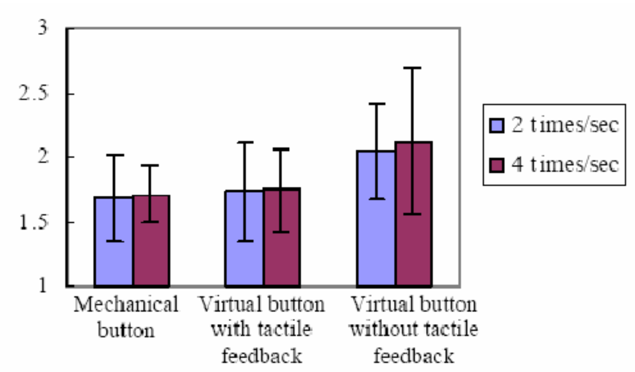

Fig. 9. Average of pushing force

Figure 9 shows an example of the change in pushing force of an examinee. One push was defined as the period between the point when pushing force exceeds the buckling load 1.3 N and fall below restitution load 0.8 N, as shown in Figure 9. Averages of twenty peak-to-peak values of the change in pushing force, from fifth to twenty-fifth push, were evaluated. Figure 10 shows the averages and standard deviations of the peak-to-peak values of the change in pushing force. From Figure 10, we can say that examinees applied larger force in virtual button without tactile feedback compared to other two buttons. By conducting one sided test, it was found that the difference of the averages between virtual button with tactile feedback and without tactile feedback was significant, whereas the difference of the averages between virtual button with tactile feedback and the real mechanical button was not significant, in 95% confidence interval. Moreover, by conducting interview, all examinees said that pushing the virtual button with tactile feedback was as easy as pushing the mechanical button. Hence, we can conclude that the virtual button with tactile feedback using ultrasonic vibration has similar usability as a real mechanical button.

5 Conclusion

We developed a virtual button with click feeling similar to real buttons by use of ultrasonic vibration with amplitude of a few micrometers. First, we constructed click feeling display system based on the principle of perceiving click feeling when pushing a mechanical button. The rapid change in force arising from buckling and restitution of mechanical buttons was recreated by utilizing decrease in friction due to squeeze film effect. In addition, by measuring operator's pushing force and utilizing it as the trigger for starting vibration, we enabled to display click feeling for both pushing and releasing. Then, simple sensory evaluation experiments were conducted to determine the appropriate value of vibration parameters for displaying click feeling. Finally, usability of the virtual button was verified. As a result, the usability of the virtual button was nearly equivalent to that of a real button. Precise examination for optimization of parameters and imitation of buttons is the challenge for the future.

References

1. Poupyrev, I., Maruyama, S., Rekimoto, J.: Ambient touch: designing tactile interfaces for handheld devices. In: Proceedings of the 15th annual ACM symposium on User interface software and technology, pp. 51–60 (2002)
2. Akabane, A., Murayama, J., Yamaguchi, T., Teranishi, N., Sato, M.: Examination on Signal Generating the Sensation of Depressing for a Touch Panel with a Tactile. Journal of Human Interface (in Japanese) 8(4), 591–598 (2006)
3. Ninomiya, K., Ymaji, T., Sakiyama, F., Kaizu, M., Yokoyama, T.: Metal Dome Sheet for Mobile Phones. Fujikura Technical Review (in Japanese) (99), 27–31 (2000)
4. Fujimoto, T.: Quantification and improvement of the touch in switch operation. Statistical Quality Control (in Japanese) 36, 1837–1843 (1985) (extra edn.)
5. Tashiro, K., Shiokawa, Y., Aono, T., Maeno, T.: Realization of Button Click Feeling by use of Ultrasonic Vibration and Force Feedback. In: World Haptics 2009 (in press)
6. Biet, M., Giraud, F., Lemaire-Semail, B.: Squeeze Film Effect for the Design of an Ultrasonic Tactile Plate. IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control 54(12), 2678–2688 (2007)
7. Watanabe, T., Fukui, S.: A Method for Controlling Tactile Sensation of Surface Roughness Using Ultrasonic Vibration. In: Proceedings of IEEE International Conference on Robotics and Automation, vol. 1, pp. 1134–1139 (1995)
8. Biet, M., Giraud, F., Lemaire-Semail, B.: New Tactile Devices using Piezoelectric Actuators. In: Proc. 10th International Conference on New Actuators, Germany, pp. 989–992 (2006)
9. Winfield, L., Glassmire, J., Edward Colgate, J., Peshkin, M.: T-PaD: Tactile Pattern Display through Variable Friction Reduction. In: World Haptics 2007, Japan, pp. 421–426 (2007)
10. Shiokawa, Y., Tazo, A., Konyo, M., Maeno, T.: Hybrid Display of Realistic Tactile Sense using Ultrasonic Vibrator and Force Display. In: IEEE/RSJ International Conference of Intelligent Robots and Systems, pp. 3008–3013 (2008)
11. Ogahara, Y., Maeno, T.: Torque Control of Traveling-Wave-Type Ultrasonic Motors using the Friction Contact Model. Transactions of the Japan Society of Mechanical Engineers, Series C 72(714), 441–448 (2006)