A Study on Effective Tactile Feeling of Control Panels for Electrical Appliances

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Abstract. This study focuses on the fact that tactile factors, compared to visual factors, have not been effectively applied to enhance the usability of control panels. It also evaluates the effectiveness of allocating a rough/smooth feeling to the surface of each button in a control panel according to its operational function. The first experiment reveals relationships between some of the impressions concerning the operation of electrical appliances and the rough/smooth feeling when touching the surface of buttons. Moreover, it provides specific information on what degree of roughness/smoothness should be applied to what types of functional buttons. The second experiment demonstrates that the usability of control panels can be enhanced by providing a rough/smooth feeling to each button, considering suitability with respect to operation impressions. In addition, results indicate that users may feel discomfort when the rough/smooth feeling does not correspond to operation impressions.

Keywords: Tactile feeling, operation impression, control panel.

1 Introduction

An overwhelming majority of human interfaces for controlling electrical appliances are control panels composed of a set of buttons or keys. Because they are very easy to manipulate and can be placed in a compact space, such control panels are expected to continue to find wide use.

Usually, the surfaces of all buttons/keys on a control panel are made of the same material, and the "control feeling," that is, the stimulus when we touch buttons/keys, is simple and uniform. Therefore, distinguishing between buttons/keys on a control panel greatly depends on visual factors such as labels and colors. For example, the button to start an appliance is typically colored green and the button to stop it is colored red so users can intuitively distinguish them [1]-[8]. (The color scheme may be different in different cultures.) However, whether users can always look at buttons/keys in the correct operational sequence depends on situations.

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Another technique to help distinguish buttons/keys is by providing a tactile factor represented by a point or bump on the surface [9][10]. This is applied in several electrical appliances such as TV remote controls, lighting switches, and car audio systems. Although the point on the surface can help users distinguish a button or key, it cannot necessarily supply meaning, such as what the key does or what the operation results in.

Thus, compared with visual factors, tactile factors have not yet been effectively applied to enhance the usability of control panels. In addition to focusing on this point, the present study discusses effective methods to apply tactile factors to control the interfaces of electrical appliances.

In a previous study, we conducted research whether users typically associated particular tactile feelings with specific impressions, as they may associate particular colors with specific impressions [11]. We found that cool/warm and rough/smooth feelings on the surface of buttons/keys are related to impressions concerning degrees, such as big/small or bright/dark. This suggests that properly designed cool/warm and rough/smooth feelings on the surface of buttons/keys help users intuitively understand the meanings of operations, and increase cognitive satisfaction.

Based on the above prospects, in this study, we validate the relationship between impressions that particularly concern the operation of electrical appliances and a rough/smooth feeling, which is comparatively easy to apply to a button/key surface. Furthermore, we experiment with how the rough/smooth feeling on a button/key surface affects users' cognitive experience. Our aim is to clarify whether tactile feelings on button/key surfaces that suit operation impressions can enhance control panel usability.

2 Experiments on the Relationship between the Rough/Smooth Feeling and Operation Impressions

The aim of this experiment was to determine users' impressions concerning the operation of electrical appliances and to clarify the relationship between these impressions and the rough/smooth feeling users' experience when they touch buttons/keys on a control panel. In the following experiments, button/key surfaces were provided different roughness/smoothness using sandpaper of different grades.

2.1 Pilot Study

The relationship between the degree of response or sensation of a sensory organ and the intensity of the stimulus is approximately logarithmic. Therefore, we first conducted the following pilot study to determine the relationship between the degree of the rough/smooth feeling when users touched buttons and the physical roughness/smoothness as quantified by the fineness of the sandpaper's grains (F). Nine grades of sandpaper were prepared (F = 40, 80, 120, 150, 180, 220, 280, 320, 400; a larger number indicates smoother sandpaper). Sandpapers of different grades were attached to the surface of two buttons (Fig. 1), which were placed in a half-open box (Fig. 2) so that the button surfaces were not visible. Subjects (9 students, 18–23 years old) placed a hand into the box and alternatively touched the two buttons with a forefinger. Next, they marked how much rougher (or smoother) the upper button was than the lower button on a line marked −3 to +3 (Fig. 3). Each subject evaluated all

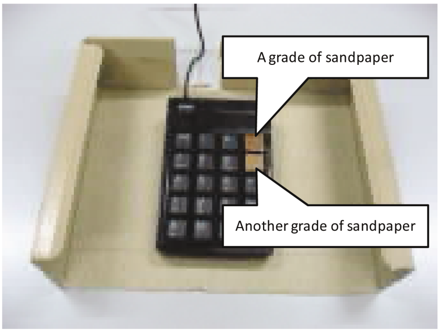

Fig. 1. Different grades of sandpaper attached to the surface of different buttons

Fig. 2. Half-open box including the control panel

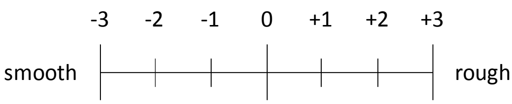

Fig. 3. Scaled line used to evaluate how rougher or smoother the upper button is compared to the lower button

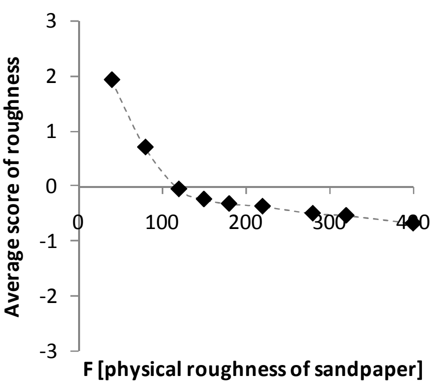

Fig. 4. Relationship between physical roughness and sensitive roughness.

combinations of the nine grades of sandpaper in randomized order. We analyzed the data using Scheffe's paired comparison and obtained the result shown in Fig. 4. The horizontal axis corresponds to the F values (physical roughness of sandpaper) and the vertical axis corresponds to the average roughness score. We could confirm that the rough/smooth feeling is approximately expressed by the logarithm of the F value. From the result, we chose five grades of sandpaper (F = 40, 80, 180, 280, 400) so that the difference in the rough/smooth feeling between each pair is about the same, and performed the following experiment to clarify the tionship between operation impressions and the rough/smooth feeling.

2.2 Experimental Method

We surveyed the methods in which buttons/keys are included in the control panels of popular electrical appliances, and compiled operational impressions as word pairs (e.g.,

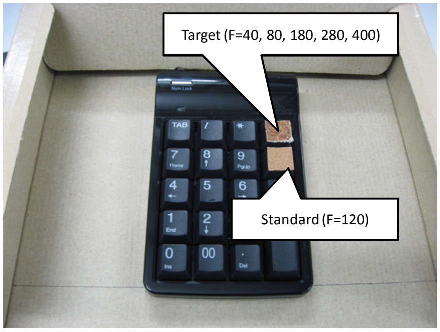

Fig. 5. Upper button with target sandpaper and lower button with standard sandpaper

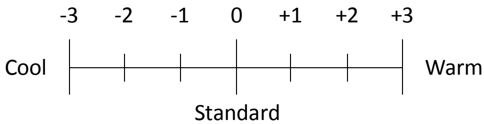

Fig. 6. Scaled line used to evaluate subjects' response on touching the target button compared to the standard button

Table 1. Thirty types of operation impressions

Impression (Word pair)
Stop / Start
Below / Above
Reduce / Increase
On / Off
Close / Open
Dark / Light
Cool / Warm
Receive / Send
Weak / Strong
Low / High
Backward / Forward
Small / Big
Stable / Swing
Back up / Proceed
Positive / Negative
Extract / Insert
Slow / Fast
Near / Far
Light / Heavy
Put / Get
Cancel / OK
Pull / Push
Shorten / Extend
Tumble / Raise
Behind / Front
Manual / Automatic
Short / Long
Release / Catch
Left / Right
Cut / Connect

Start/Stop). Furthermore, we removed extremely lized impressions and combined more common ones, finally selecting 30 types of operation (Table 1). In the experiment, the abovementioned five sandpaper grades were used as the evaluation target, and another grade of sandpaper (F = 120) was used as the evaluation standard. A "target" sandpaper and the standard one were attached to the buttons (Fig. 5). Subjects (20 students, 21–25 years old) first touched the standard button and then the target button with a forefinger. Next, they evaluated the impression that came to their mind on touching the upper button, and how intuitive the association was compared to when touching the lower button, and scored each line on −3 to +3 scale. For example, if they felt warm more strongly when they touched the upper button than when they touched the standard button, they gave a positive score to the cool/warm line, as shown in Fig. 6. We did not let subjects know which grade of sandpaper was attached to the target button they were touching. However, we did not place the buttons inside a box but

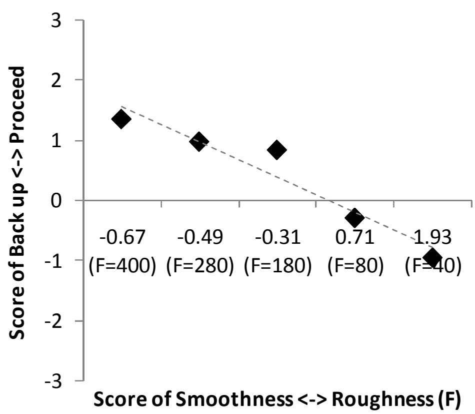

Fig. 7. Relationship between the rough/smooth feeling and the Back up/Proceed impression

allowed the subjects to observe them because, in real-world situations, users can generally see the control panel.

2.3 Results

We analyzed the data using ANOVA to examine the relationship between the rough/smooth feeling as quantified by the pilot research and each operation impression. As an example, Fig. 7 shows a significant effect of the rough/smooth feeling on the Back up/Proceed impression. From this chart, we can see that the smoother the surface of the button, the stronger the impression of "Proceed." We applied correlation analysis to the other operation impressions, and found that 21 operation types were significantly correlated to the rough/smooth feeling.

3 Experiments on Effectiveness of Applying the Rough/Smooth Feeling to Control Panels

The aim of this experiment was to examine whether allocating the rough/smooth feeling to each button in accord with the operation impressions enhances control panel usability.

3.1 Method

Experimental Systems. Focusing on 4 of the 21 operation types that have a significant correlation to the rough/smooth feeling, we assembled a simple control panel that included functional buttons corresponding to these impressions as an experimental system. Its design is based on the ordinary control panels of air conditioning systems, and it consists of a PC and a keypad. A display window visualizing each parameter was presented on the PC monitor, and the control buttons to change them was replaced by the keypad. The allocation of the buttons was also presented on the PC monitor. Fig. 8 shows the display window seen on the PC monitor, and Fig. 9 shows the allocation of the buttons.

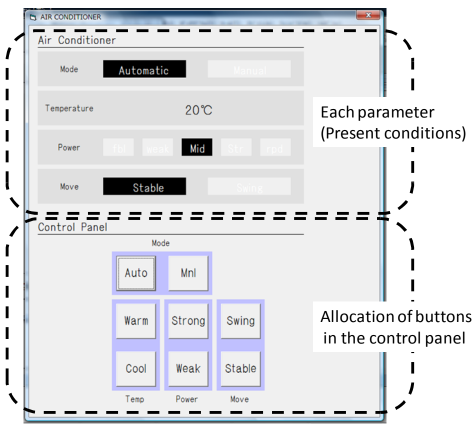

Fig. 8. Display window on PC monitor

Task. After beginning the task, subjects monitored the information in the display window. During the task, instructions to change a parameter appeared to the right of each parameter. For example, the instruction to change the temperature from the present condition (25°C) to 27°C was presented, subjects were required to correctly and quickly operate the control panel and completely change the parameter according to the instruction. The experimental air conditioning system then ran at the automatic mode

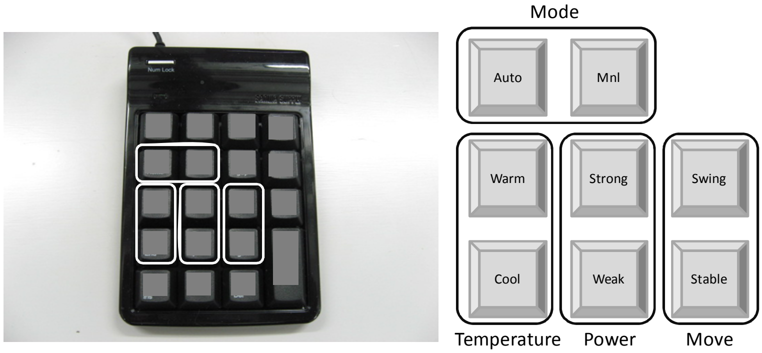

Fig. 9. Allocation of buttons

normally. Thus, subjects had to switch the mode from automatic to manual before changing a parameter, and also had to switch the mode back from manual to automatic afterward. For example, when the abovementioned instruction was given, they touched the "Mnl" button to switch the m ode, touched the "Warm" button twice to shift the temperature up to 27°C, and touched the "Auto" button to switch the mode again. The duration of a task was set at 180 [s]. During a task, instructions were provided six times. The timing of the instructions was random, but the intervals were set at more than 20 [s].

Experimental Conditions. We prepared the following three conditions.

(C-1) Use a control panel with buttons that all felt the same:

Subjects performed the task using a control panel in which the same seals were applied to the surface of every button, so that they experienced the same tactile feeling whichever key they touched.

(C-2) Use a control panel with buttons that had rough/smooth feelings corresponding to operation impressions:

Based on the result of the first experiment described in section 2, a rough/smooth feeling corresponding to operation impressions was allocated to each button. Specifically, two grades of sandpaper (F = 40, 400) were attached to the surface of two different buttons to shift a parameter in different directions so that the rough/smooth feeling corresponded to the impressions of the directions. For example, in the case of the

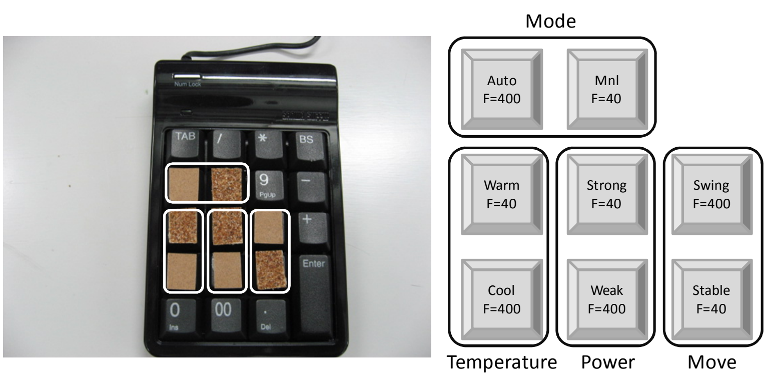

Fig. 10. Allocation of rough/smooth feeling that suits operation impression (C-2)

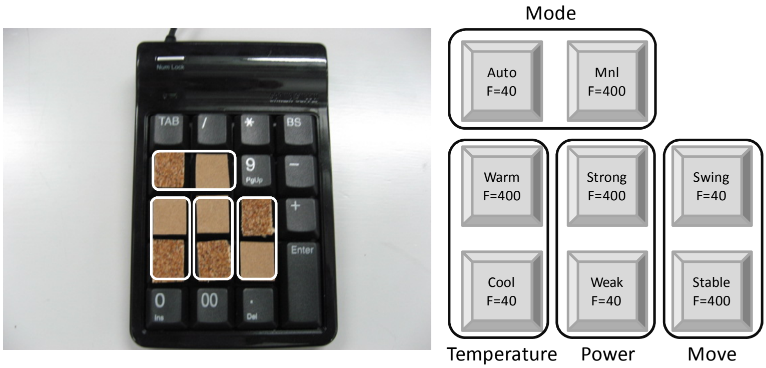

Fig. 11. Allocation of rough/smooth feeling that is opposite to each operation impression (C-3)

"Warm" and "Cool" buttons to change the temperature, the rougher button (F = 40) was attached to the former, and the smoother button (F = 400) was attached to the latter. Fig. 10 shows which grade of sandpaper was allocated to which button in this condition.

(C-3) Use the control panel with buttons that had rough/smooth feelings opposite to the operation impressions:

In contrast to C-2, rough/smooth feelings that did not correspond to operation impressions were allocated to each button. For example, in the case of the "Warm" and "Cool" buttons to change the temperature, the smoother button (F = 400) was attached to the former, and the rougher button (F = 40) was attached to the latter. Fig. 11 shows which grade of sandpaper was allocated to which button in this condition.

Other. Subjects were 12 students, 20–25 years old. After they understood the procedures of the task and practiced it, they performed the task once per condition. To eliminate the order effect, we managed their trial order carefully. Moreover, we adjusted the temperature and light to keep the experimental environment comfortable. We recorded all the actions that subjects performed during the task. We also conducted a recollection test in which subjects were required to write down what instructions were given, the order of the instructions, and what operations they performed to accomplish each of them one minute after they finished each task.

3.2 Results

Correctness of Selection. We defined the case where subjects were instructed to shift a parameter in one direction but shifted it in the opposite direction as a selection error. For example, if they touched the "Cool" button although they were instructed to shift the temperature up from 25 to 27°C, it was counted as a selection error. Fig. 12 shows the frequency of selection errors (per task). We can see that the frequency of this error was lower in C-2 (with a suitable rough/smooth feeling). On the other hand, the frequency of this error in C-3 (with opposite rough/smooth feeling) was as high as that in C-1 (without a rough/smooth feeling), and individual differences were large. This seems to be because subjects could intuitively and naturally select the correct button when the rough/smooth feeling on the surface corresponded to the impression of the

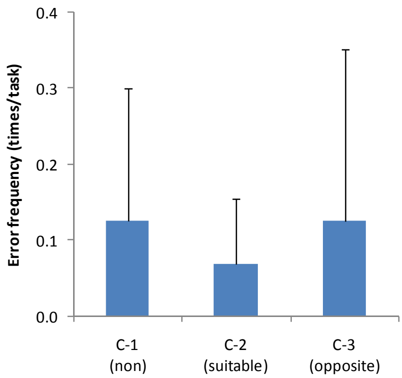

Fig. 12. Frequency of the selection error (per task)

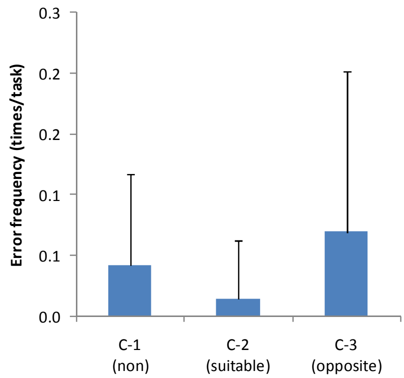

Fig. 13. Frequency of the adjustment error (per task)

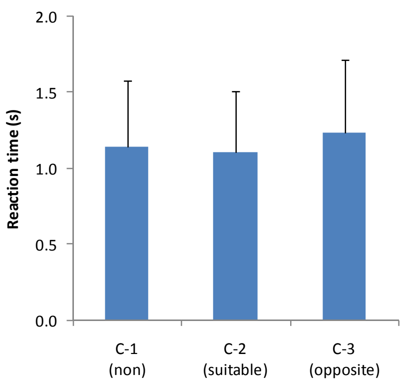

Fig. 14. Average reaction time

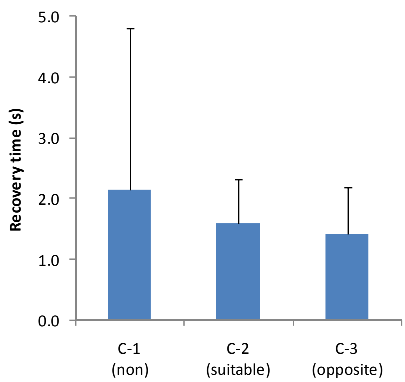

Fig. 15. Average recovery time

direction in which they shift a parameter. This suggests that the control panel design that considered the impressions associated with tactile feelings was effective in helping subjects correctly select buttons.

Accuracy of Manipulation. We defined the case where subjects manipulated a button too many times in changing a parameter as an adjustment error. For example, if they shifted the temperature to exceed 27°C by carelessly touching the up button more than twice, although they were instructed to increase the temperature from 25°C to 27°C, it was counted as an adjustment error. Fig. 13 shows the frequency of adjustment errors (per task). We can see that the frequency of this error was lower in C-2 than in other conditions. On the other hand, the frequency of this error was particularly high in C-3. This seems to be because subjects could have a detailed realization of the operation when they were touching the button with a rough/smooth feeling that suited the operation impression. This suggests that the control panel with a suitable tactile feeling could enhance the accuracy of operation.

Quickness of Reaction. We analyzed the duration from when an instruction to change a parameter appeared on the display window until when subjects touched a button corresponding to it. For example, if the instruction to shift the temperature from 25°C to 27°C appeared, the time until subjects first touched the "Warm" button was measured as the reaction time. Fig. 14 shows the average reaction time. A difference appeared between C-2 and C-3, although it was small. The reason seems to be that use of the control panel composed of buttons that did not suit the operation impressions confused subjects and negatively affected their cognitive processes. This suggests that the control panel design that ignores the impressions associated with rough/smooth feelings may damage their performance.

Quickness of Recovery. We analyzed the duration from when the abovementioned selection error occurred to when subjects touched the correct button. For example, if a subject touched the "Cool" button after being instructed to increase the temperature from 25°C to 27°C, the time from then until the subject touched the "Warm" button to recover from the error was measured as the recovery time. Fig. 15 shows the average recovery time. We can see that the time tended to be shorter in C-2 and C-3 than in C-1. This indicates that when the surface of every button feels the same, it was not easy for the subjects to notice that they selected the wrong button because they could not distinguish the buttons by tactile feelings. Thus, we can understand that the control panel in which different feelings were allocated to different buttons helped them notice their errors.

4 Conclusion

In this study, we proposed a more widespread use of tactile factors to enhance the usability of control panels on electrical appliances, and evaluated the effectiveness of this approach. First, we clarified that certain relationships existed between some of the impressions concerning the operation of electrical appliances and the rough/smooth feeling experienced in touching the surface of buttons. Moreover, we obtained specific information on what degree of roughness/smoothness should be attached to what type of functional buttons. Second, we found that the usability of the control panel was enhanced by allocating the rough/smooth feeling to each button considering the fit with the operation impressions. On the other hand, we pointed out that users might feel discomfort and confusion when rough/smooth feelings on the surface of the buttons did not correspond to the operation impressions.

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