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Midair Click of Dual-Layer Haptic Button

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Abstract— **In this study, we propose a method to create a quasi-click sensation in midair based on two types of tactile stimulation methods that create different sensations both in the intensity and quality. We consider two-layers of regions in the space that forms a virtual button. A user's hand is tracked by a sensor and stimulated by the two methods according to the hand position. When the user's hand is in the upper or lower layer, the hand skin is stimulated weakly or strongly by the two methods, respectively. These two states indicate a neutral position and action completion. This midair click was enabled by a recent finding where an ultrasound focus motion on the skin produced a stronger perception than amplitude modulation given at a constant position. We conducted experiments to confirm whether two haptic layers can be perceived. In addition, we investigated whether a blind operation of button selection can be performed.**

I. Introduction

An essential function of mechanical input devices as a mouse and keyboard is to provide users with two types of contact status, indicating a neutral position and action completion. When a user operates a mouse, the user's finger can always feel the mouse surface perceiving a slight contact sensation, thus enabling the finger to remain on the mouse surface. Owing to a neutral position, the user can quickly send the input intention to the computer by a click action, perceiving the action completion by haptic feedback.

Such a haptic feedback is desirable in the midair haptic interfaces. Midair haptic feedback was realized using air vortex [1], air jet [2], and ultrasound [3]. In the case of ultrasound, it enables a localized distribution to be created in the user's hand [4] [5]. This feedback enables the user to operate aerial virtual buttons efficiently and comfortably even in a blind situation. However, providing such a haptic feedback is difficult because the ultrasound stimulation is weak and cannot produce clearly two distinguishable states of quality and intensity of the haptic stimulation.

In this study, we propose a method to create a quasi-click sensation in midair based on a recent finding of lateral modulation (LM). LM can create a stronger tactile sensation than amplitude modulation (AM) by more than 10 dB [6] [7]. In addition to the intensity difference, the tactile feel quality by LM is different from that by AM because LM stimulates a superficial mechanoreceptor while AM mainly stimulates the Pacini corpuscle.

The concept of the quasi-click is shown in Fig. 1. Consider two-layer regions in the space. The hand is tracked by a sensor, and stimulated by AM and LM when the hand enters the upper layer (AM layer) and the lower layer (LM layer), respectively. A user can find the location of a virtual button and place his/her hand on it by the AM sensation and confirm the button push by LM sensation. This AM-LM stimulation provides the two states seen in the mouse click. Furthermore, it is applicable as a midair version of the full press/half press used in a camera-shutter button, or force touch (Apple) [8].

The remainder of this paper is as follows. First, we describe the implementation of this dual-layer haptic button. We conduct experiments to confirm whether two haptic layers can be perceived. Next, we investigate whether a blind operation of button selection can be performed.

II. Dual-Layer Haptic Feedback

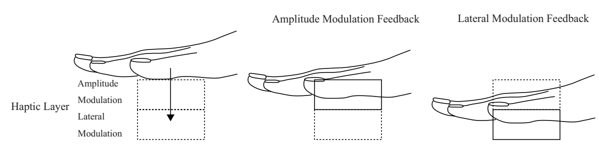

Fig. 1. Midair click using dual-layer haptic feedback. The intensity and quality of haptic feedback are switched according to the hand position.

A. Mid-air tactile display

In this study, an ultrasound phased array produces midair haptic sensation using the radiation pressure [9]. Figure 2 shows the arrangement of the phased array. The ultrasound focus was generated by nine units of phased arrays driven at 40 kHz [10] [11]. The aperture size of the phased array is 576 mm (W) × 454.2 mm (H). The XY coordinates of the focus were determined by the position of the user's hand. The hand position was measured by Realsense Depth Camera SR300 (Intel).

B. Dual Haptic Layer

Figure 3 shows the configuration of the dual-layer haptic button. The user's hand position was measured, and stimulated by AM and LM when the hand enters upper and lower layers, respectively. The hand position was used for only layer switching. The focal position of the AM/LM layer was fixed. The AM frequency is 150 Hz. In the LM, the LM vibration amplitude and the frequency were 4.5 mm and 50

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Hz, respectively, where the LM vibration amplitude was defined as the displacement amplitude of the focal spot on the skin. The depths of the AM layer and LM layer were 50 mm and 100 mm, respectively. The output of the nine phased arrays was 144 mN with the maximum intensity. In this experiment, the driving intensities of the phased array on the AM and the LM layers were 10 % and 100 %, respectively.

The AM and LM stimuli convey the two states of a neutral position and action completion, respectively, and produce a quasi-click sensation. To increase the contrast between the two stimuli, we selected specific AM and LM frequencies such that the tactile feel quality and perceived strength were clearly different following the previous study [7].

III. Experiment

In this experiment, we presented the tactile sensations of the above-mentioned haptic button and evaluated whether the difference can be perceived by the palm. Next, we presented three buttons on the space and investigated whether the buttons could be operated in a blind state. Informed consent was obtained from all individual participants included in the study.

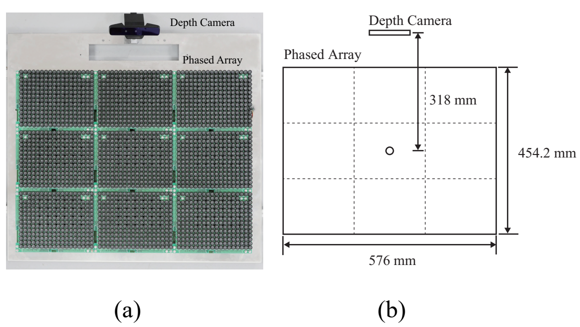

Fig. 2. Prototype device. (a) Photograph of the phased array. (b) Schematic diagram of a nine-unit phased array and depth camera.

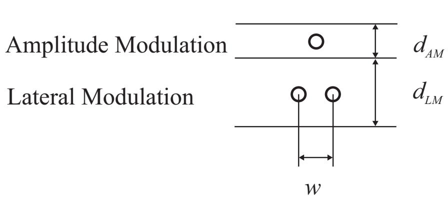

Fig. 3. Schematic diagram of the dual-layer haptic button. The depth d of each layer indicates the region where the AM or LM stimulus is presented. w indicates a value twice that of the LM vibration amplitude.

A. *Experiment 1: Identification of the tactile sensation*

The experiment setup is shown in Fig. 4. The experimental procedure is as follows. Before the experiment, the participants were explained that the haptic button was consisted of two layers and were directed to find the upper AM layer by themselves. They were informed that the positions of the buttons were on the front side and the lower side of the initial hand position of Fig. 5. They wore the headphones and listened to white noise to interrupt the audible sounds from the phased array. They identified the height of the top surface of the two tactile layers by matching the center of the palm with the XY coordinates of the focal point. The hand position of the participants were guided manually by the examiner to the starting position. The participants, with their eyes closed, identified the surface position of the upper AM layer first, followed by the position of the lower LM layer. They freely moved their hands to find the button position, and held the position of their right hand and answered "yes" to inform the examiner that the search was completed. Subsequently, the examiner measured the position of the participants' hand and completed the task. No time limit was imposed for the answers. The answers were obtained from the average of three trials. There were a total of eight participants. All participants were male, aged 23-27 years.

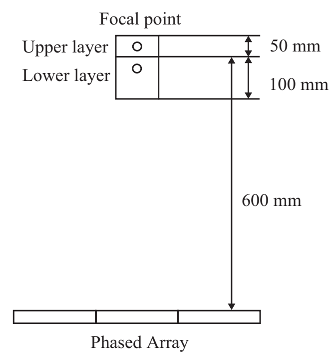

Fig. 4. Experimental setup (front view). The top-surfaces of the upper (AM) and lower (LM) layers were located at heights of 625 mm and 575 mm.

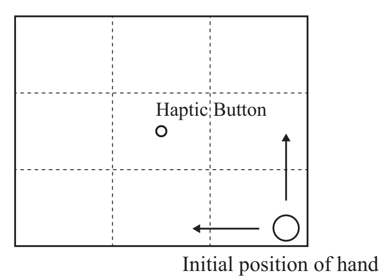

Fig. 5. Experimental setup (top view). The participants placed their hands at the initial position (Z = 800 mm) and started the experiment.

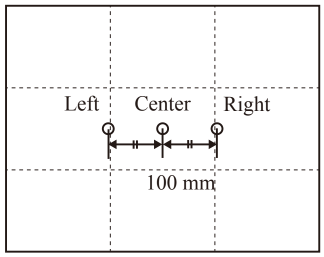

Fig. 6. Experimental setup (top view). Three buttons are arranged at intervals of 100 mm.

B. Experiment 2: Tactile button operation

In this experiment, which was carried out in a manner similar to experiment 1, three haptic buttons were placed in different positions. Figure 6 shows the arrangement of the haptic buttons. The experimental procedure is as follows. Before the experiment, the participants were informed that three buttons were presented side by side in the horizontal direction; however, they were not informed of the distance between the adjacent buttons. At the start of the experiment, the examiner informed the participant with letters and orally which button they must select out of the three. The participants were orally informed of the start of the experiment. With their eyes closed, they placed their right hand in the same position as that in experiment 1 and identified the position of the instructed button in the same manner as that in experiment 1. Next, they identified the position of the top surface of the lower LM layer. The position of the button was presented randomly to them. The answers were obtained from the average of three trials.

IV. Results

A. Experiment 1

Figure 7 shows the position of the haptic layer perceived by the palm. "Distance" indicates the distance from the phased array surface. The error bars indicate the standard deviation. The average of the positions of the top surface positions of the perceived AM and LM layers were 649.6 and 575.5 mm, respectively. The range of the identified top-surface heights of the upper and lower layers were 47.4 and 44.7 mm, respectively.

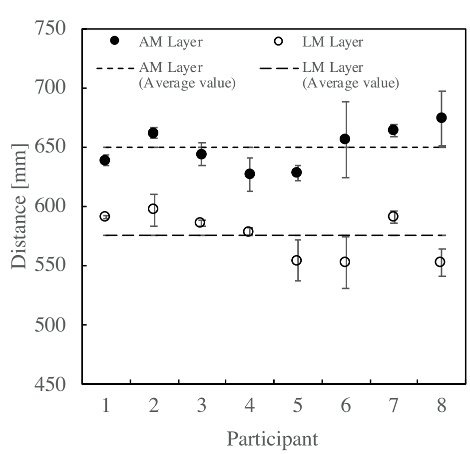

Fig. 7. Perceived top surfaces of two layers. Error bars show the standard deviations of the position that the participants identified.

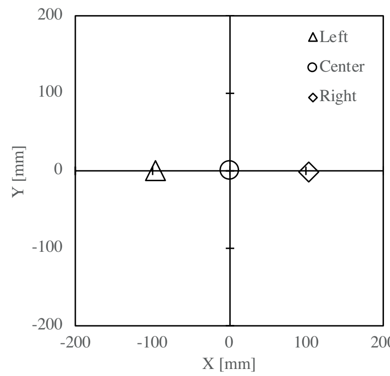

Fig. 8. Three perceived focal points. The plots show the average values of all the participants.

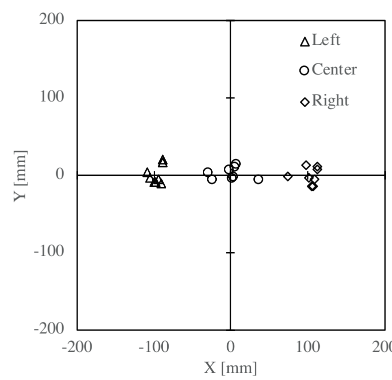

Fig. 9. Three perceived focal points. The plots show the answered value of the eight participants.

B. Experiment 2

Figure 8 shows the average values of the answers of each button position of all the participants. The average values of the perceived left, center and right button's X-axis are -95.9, 1.1 and 102.5 mm, respectively.

Figure 9 shows the position of the tactile button perceived by the palm. The origin of the graph corresponds to the XY coordinate of the center of the phased array.

Figure 10 shows the Z-axis value of the participants' answers. The average values of the perceived left, center and right button's Z-axis are 586.2, 584.1, and 586.0 mm, respectively. The ranges of the answered height of the button were 46.3 (left), 53.7 (center), and 31.1 mm (right), respectively.

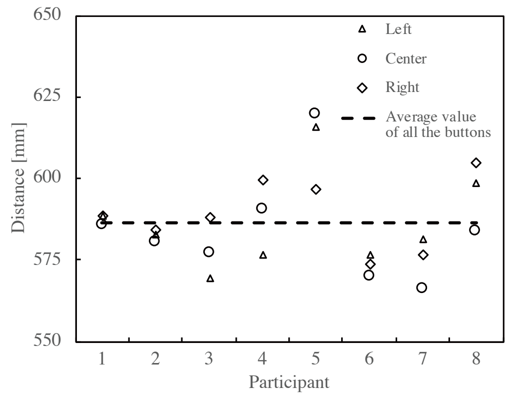

Fig. 10. Perceived top surface of the lower layer. The average value of participants' answers for all the buttons was 586.4 mm.

V. Discussions

Experiment 1: The result of Fig. 7 shows that the participants perceived the surface of each layer surface correctly. The surface of the LM layer was set at a position of 600 mm, while the average height perceived by the participants was 575.5 mm. This indicates that the presented button was pushed deeper than the author's assumption. However, this result still suggests that the user's hand could stop at the LM layer surface and feel the two-step feedback. As a subjective comment by the authors, the difference in stimulation between the AM and LM layers was clearly perceived. The AM layer presents a stimulus that eases the perception of the button position. The LM layer increases the resistance to the action of pushing the button compared to that in the AM layer. No repulsive force exists to push back the hand, but when moving from the AM layer to LM layer, a weak click feeling was felt by the palm.

Experiment 2: Among the 72 trials in Experiment 2, three participants answered four times in total at different positions. This may be because they could not touch the three buttons simultaneously with their palm. However, this result indicates that the participants could operate the button correctly with a probability of 94.4%, suggesting that a sufficiently practical interface can be realized by an improved button placement.

The result of Fig. 10 shows the difference in the position of the LM layer identified by the participants. The height of the button perceived by the participants exhibited a range of 53.7 mm in the case of the center button. One of the reasons for this error is that the haptic layer was thick. In the experiment, the participants were instructed to identify the top surface of each haptic layer, but AM stimulation and LM stimulation were presented in a range of 50 mm and 100 mm, respectively. The other factor is that the participants were not restricted when identifying the position of the haptic layer as to whether to explore from the higher side or from the lower side. Nevertheless, we confirmed that the participants could stop the button operation within the specified range after receiving the two-step feedback.

VI. Conclusion

A dual-layer haptic button produced in midair was proposed and evaluated in this study. A user finds the button position and its surface by AM stimulation to the user's palm. The AM stimulation was provided when the user's hand was in the AM (upper) layer of thickness 50 mm. The completion of the click was conveyed by the LM stimulation provided when the user's hand was in the LM (lower) layer of thickness 100 mm.

The experimental results indicated that the top surfaces of the AM and LM layers were recognized independently within the errors of 12.4 and 9.4 mm, respectively, in the standard deviation. Each haptic layer was identified without symbolic learning of tactile pattern differences. In addition, the three buttons were explored within the errors of 7.2 (center), 20.2 (left), and 12.9 mm (right) in the standard deviation, and its accuracy rate was 94.4 %. The participants in the blind state could explore by hand where a specified button was located out of the three.

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