Preliminary Study on the Effects of On-Screen Tactile Feedback on Virtual Joystick Interaction

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Abstract

A virtual joystick is a common method of manipulation in mobile games that rely on touchscreen input to manipulate on-screen objects. However, without visual confirmation, users have difficulty reliably perceiving the joystick's center position or the movement direction from the center. The consequent mismatch between the user's perceived touch location and the actual touch location can lead to unintended inputs. To address this issue, we use an inexpensive and easily attachable/detachable screen protector engraved with tactile patterns, thereby providing tactile feedback during joystick use. To examine the effectiveness of this solution, we conducted a study with 12 participants under four tactile feedback conditions: the presence or absence of a center tactile feedback, and the presence or absence of a frame tactile feedback. The results showed that all tactile feedback conditions produced more accurate center positioning and direction inputs than the no feedback condition.

CCS Concepts

• **Human-centered computing → Touchscreens**; **Haptic devices**.

Keywords

Virtual Joystick, Tactile Feedback, Touchscreen, Screen Protector.

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1 Introduction

Many mobile games that rely on touchscreen input use a virtual joystick to manipulate on-screen objects. Unlike physical joysticks, a virtual joystick lacks physical feedback, making it difficult for users to accurately perceive the center position, movement direction, and movement magnitude without visual confirmation. As a result, a mismatch between the user's perceived touch location and the actual touch location occurs, which can lead to unintended center position inputs [12], directional inputs, and movement magnitude.

Adding tactile patterns to touchscreens is a promising approach to solve this issue. In this research, we use an inexpensive and easily attachable/detachable screen protector engraved with tactile patterns by a laser cutting machine to provide tactile feedback for virtual joystick operation. To evaluate the effect of such tactile feedback, we measured users' perceived center position and perceived movement direction of the virtual joystick. Additionally, to explore which type of tactile feedback more strongly affected the perceived center position and movement direction, we tested four conditions formed by combining the presence or absence of center tactile feedback, referred to as center tactile feedback (CTF), with the presence or absence of frame tactile feedback, referred to as frame tactile feedback (FTF). The results of a user study with 12 participants showed that all three conditions with tactile feedback yielded more accurate center positioning and movement direction inputs than the no feedback condition, referred to as no tactile feedback (NTF). Furthermore, no significant differences were observed among the tactile patterns for center position input, whereas for movement direction input, the FTF condition alone was significantly more accurate than the other conditions.

This paper reports empirical findings from a controlled study of on screen tactile feedback for virtual joystick interaction.

- **C1** Tactile feedback significantly improved center position and directional accuracy compared to no tactile feedback in our experimental tasks.
- **C2** The frame pattern yielded higher directional accuracy than the center pattern. The combined pattern did not exceed the best single pattern in terms of directional accuracy.
- **C3** For center position, the three tactile patterns performed similarly. All outperformed the no tactile feedback condition.
- **C4** Subjective responses were consistent with these results. Participants reported that they used the frame pattern as a directional reference and the center pattern for locating the center position.

2 Related Work

Virtual joysticks, which are often used in mobile games that rely on touchscreen input, have received considerable attention in the literature. Multiple studies have investigated their various aspects, including their design, usability, and user experience [2, 3, 18]. Other studies have compared virtual joysticks with physical controllers [9, 20, 27, 28] or experimented with improving the usability of virtual joysticks by providing tactile feedback [1, 25]. Some studies have improved the usability of virtual joysticks by adjusting their position and size [22] or by introducing an improved mathematical model of touch location [15, 21].

Several studies have demonstrated that adding tactile feedback mechanisms to a touchscreen can effectively enhance touchscreen operability; [5, 8, 11, 26] used vibration-based feedback, [16] used auditory and vibration-based feedback, [4, 17] used friction, [19] used an electro-osmotic pressure pump, and [10] used a pneumatic pump.

The most closely related prior work to ours would be [13, 14, 23], which provide tactile feedback by placing a transparent sheet with holes (an overlay) on the touchscreen. Kincaid [14] showed that such sheets, which are overlaid on a touchscreen and recognized by the underlying application, serve as an accessible tool for blind users. Kane et al. [13] showed that simple transparent overlays can provide tactile guides for touch-based graphical control widgets. Tory et al. [23] found that transparent overlays improved the parameter control performance of dials and sliders on a touchscreen.

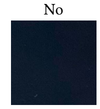
In contrast to the above work, we explore whether tactile feedback provided by an inexpensive and easily attachable/detachable screen protector with grooves can improve virtual joystick operation that requires users to precisely locate and move their finger on the touchscreen.

3 Apparatus

By attaching a screen protector engraved with tactile patterns to the touchscreen of a mobile device (Fig. 1), we provided tactile feedback for virtual joystick operation. We used a laser cutting machine (G-WEIKE LG500[1]) to engrave tactile patterns onto the screen protector, an iPhone 12 as the mobile device, and a DAISO screen protector film for iPhone 12 and 12 Pro[2] as the base material.

Figure 1: A smartphone screen protector with an engraved bump.

Table 1: Four tactile feedback conditions used in the experiment.

	NTF	CTF	FTF	CTF + FTF
Center Tactile Feedback	No	Yes	No	Yes
Frame Tactile Feedback	No	No	Yes	Yes
Engraved Tactile Pattern				

The design of the tactile patterns utilized in this research was based on the virtual joystick in the popular smartphone action role-playing game "Genshin Impact." [3] The positions for CTF and FTF were the same as for "Genshin Impact." To provide finer positional feedback, the diameter of the CTF was set to 1.65 mm—40% smaller than in "Genshin Impact" and was the smallest size the authors could reliably perceive. The FTF's outer diameter was 20.2 mm, which was the same as "Genshin Impact," and its inner diameter was 18.1 mm. These sizes (i.e., the diameter of CTF and the inner diameter of FTF) were determined through a preliminary investigation by four authors. The laser cutting machine was configured in engraving mode at a speed of 250 mm/s with an output power of 10.4 W.

4 Experiment

4.1 Design

To investigate the effects of tactile feedback on virtual joystick operation, we adopted two metrics, perceived movement direction and perceived center position. As a preliminary study to determine which tactile patterns might have the strongest effect, we tested four tactile feedback conditions (Table 1) formed by combining the presence or absence of central tactile feedback with the presence or absence of frame tactile feedback. To assess perception of the joystick's center position and movement direction, participants performed two tasks, a direction input task in which they reproduced the presented direction and a center position input task in which they indicated the perceived central point. The experiment used a

[1]https://www.gwklaser.com/co2/LG500.html

[2]https://jpbulk.daisonet.com/products/4979909968215

[3]https://apps.apple.com/jp/app/genshin-impact/id1517783697?l=en-US

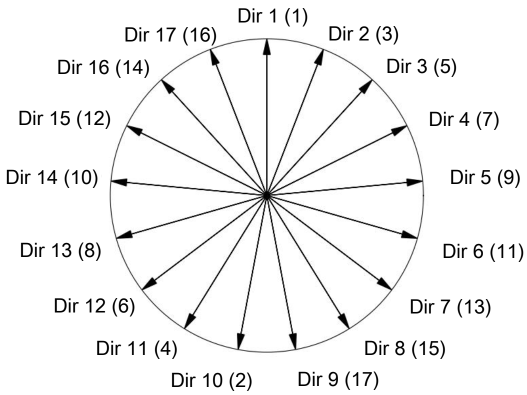


Figure 2: The 17 directions used in Trial 1. The numbers in parentheses indicate the presentation order.

within-subjects design: Each participant completed both tasks under all four tactile feedback conditions and the order of conditions was randomized. The experiment was conducted with the approval of the ethics review committee of our institute (2023R795).

4.2 Participants and Experimental Setup

Twelve undergraduate and graduate students (9 male, 3 female; age range/M/SD: 22–25/23.3/1.07) participated in the experiment. Among the participants, 10 were right-handed, 1 was left-handed, 1 was ambidextrous, and 11 had experience playing mobile games using a virtual joystick. All participants provided written informed consent and received the equivalent of 7.8 USD in local currency as compensation.

During the experiment, which was conducted in our laboratory, participants were seated and used four smartphones, each with one tactile feedback condition. Since our primary aim was to investigate how tactile feedback affects the perceived center position and perceived movement direction, participants held the smartphone under the desk, preventing them from seeing their finger positions directly on the screen, to ensure participants relied on the tactile feedback rather than visual confirmation. This design is based on typical mobile gaming scenarios involving virtual joysticks [18]. That is, users do not fixate their gaze on the joystick itself; instead, they direct their visual attention toward the controlled character or the intended movement direction while operating the joystick peripherally. Therefore, to prevent participants from intensively focusing on the joystick during operation, the experimental setup intentionally restricted visual access to the smartphone screen as in the prior work [7, 18]. A display (EIZO, FlexScan EV2495) was placed on the desk in front of participants to present instructions.

4.3 Task

Participants performed the following tasks for each tactile feedback pattern (condition). The task in each condition consisted of one practice session, two main sessions, and a subjective evaluation, with each session comprising 17 steps. The order of the four tactile

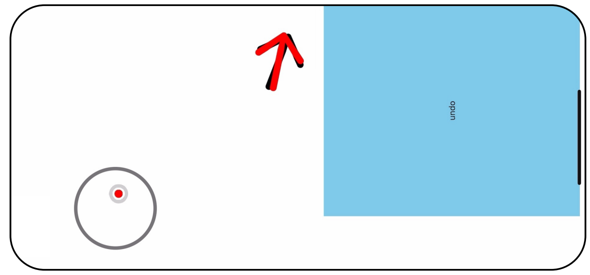


Figure 3: Screen displayed on the desk display during the practice session. The red circle in the lower left indicates the touch-down point, and the red arrow at the top center indicates the input direction. The black arrow at the top center (beneath the red arrow) shows the target direction to be input.

feedback conditions was counterbalanced using a Latin square design. A single step consisted of two trials, a direction input (Trial 1) and a center position input (Trial 2). To eliminate the effects of fatigue, participants were given a break of at least two minutes between sessions. Participants were instructed not to hold the smartphone during these breaks.

4.3.1 Trial 1: Direction Input. In Trial 1, participants first touched down anywhere on the virtual joystick, then moved it in the indicated direction, and finally lifted their finger. The input direction was defined as the vector from the joystick's center to the touch-up point. We partitioned 360° into 17 equal angular intervals (Fig. 2), with Dir 1 corresponding to "up" (0°). This partitioning follows a multidirectional pointing task design based on ISO 9241-411, which standardizes the evaluation of pointing performance across multiple directions. The order of the presented directions was fixed between participants, also following ISO 9241-411, as shown in Fig. 2. A direction was presented visually on the display as a black arrow.

4.3.2 Trial 2: Center Position Input. In Trial 2, participants touched down near what they perceived as the joystick's center, searched on the touchscreen for the center point, and then lifted their finger at the location they judged to be the exact center. Participants were instructed to hold the smartphone in the landscape orientation under the desk using both hands, to operate the joystick with their left thumb, and to refrain from looking directly at the smartphone screen, instead viewing the instructions on the display placed on the desk. In the case of an incorrect input, participants could undo the input by pressing a button displayed on the right edge of the smartphone screen and then retry the trial. During the practice session, the display on the desk showed real-time feedback about the input direction and touch point (Fig. 3); an arrow indicating the current input direction was overlaid on the target direction arrow. In the two main sessions, this visual feedback was removed.

In the subjective evaluation, participants completed the five-point Likert-scale questions about the tactile feedback condition they had used (Table 2). After all sessions were completed, we conducted semi-structured interviews that focused on the following topics:

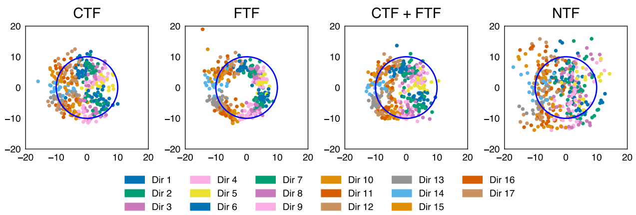


Figure 4: Distribution of touch-up points in Trial 1 for each condition. Circles represent the joystick's frame boundary.

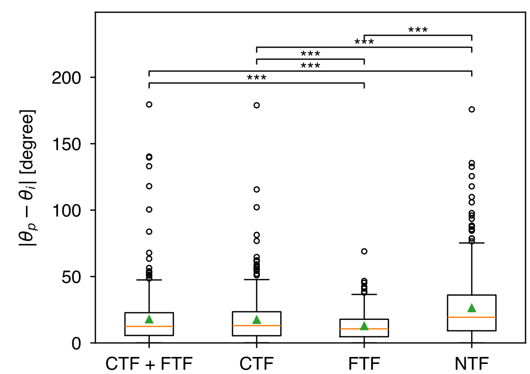


Figure 5: Absolute difference between presented (θ_p) and input (θ_i) directions for each condition. * indicates $p \leq$ 0.001.**

- Which part of the thumb actually touched and perceived the tactile feedback?
- How did you use the tactile feedback to move your thumb?
- How did you touch and utilize the frame and the center tactile patterns, respectively?

The duration of the experiment was approximately 60 minutes per participant. Through the experiment, we obtained 12 participants $\times$ 4 conditions $\times$ 2 sessions $\times$ 17 steps = 1632 data points for each of trial.

5 Result

5.1 Movement Direction

We show the distribution of touch-up points in Trial 1 for each condition in Fig. 4. We analyzed the angular difference between the presented direction and the input direction. To avoid cancellation effects between positive and negative deviations, we used the absolute value of the difference.

First, we conducted an analysis of the combined data across all directions. Fig. 5 shows the absolute angular difference between presented and input directions for each condition. A Shapiro–Wilk test indicated that the absolute differences did not follow a normal distribution for any condition; therefore, we used the Friedman test to examine statistical significance. The Friedman test yielded $p = 5.33 \times 10^{-17} < 0.05$ ($\chi^2 = 78.9$), indicating a significant difference among the conditions. Pairwise comparisons were then conducted using the Wilcoxon signed-rank test with Bonferroni correction. The tests indicated significant differences between all

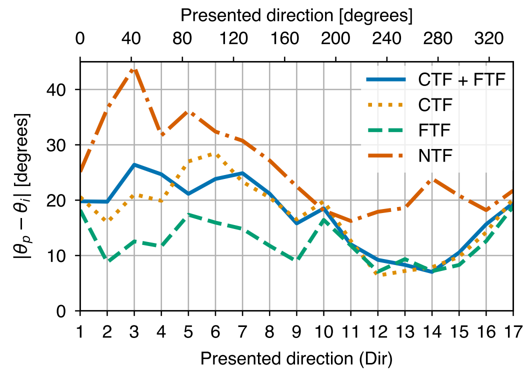


Figure 6: Absolute difference between presented (θ_p) and input (θ_i) directions for each condition, plotted by direction.

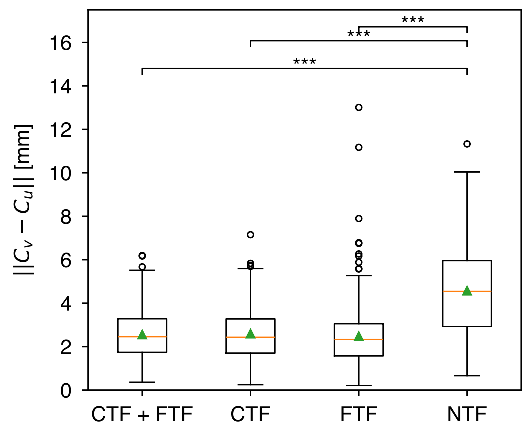


Figure 7: Distance between the true (C_v) and perceived (C_u) center positions for each condition. The y-axis unit is millimeters. * indicates $p \leq 0.001$.**

pairs except (CTF + FTF, CTF). Specifically, (NTF, CTF) yielded $W = 8.91 \times 10^{-11}$, $p = 5.34 \times 10^{-10}$, $r = 0.32$; (NTF, FTF) yielded $W = 1.24 \times 10^{-22}$, $p = 7.44 \times 10^{-22}$, $r = 0.49$; (NTF, CTF + FTF) yielded $W = 7.75 \times 10^{-10}$, $p = 4.65 \times 10^{-9}$, $r = 0.30$; and (CTF, FTF) yielded $W = 1.44 \times 10^{-6}$, $p = 8.65 \times 10^{-6}$, $r = 0.24$.

Next, we analyzed each direction separately. Fig. 6 presents the absolute angular difference between presented and input directions for each condition, plotted for the 17 directions (see Fig. 2 for the direction indices). Since the absolute differences for all directions and conditions did not satisfy normality, we again used the Friedman test for each direction. For directions showing significant effects, we conducted pairwise Wilcoxon signed-rank tests with Bonferroni correction. Table 3 lists the direction indices and the pairs of conditions in which significant differences were observed.

5.2 Center position

In Trial 2, the touch-up point was recorded as the participant's perceived center of the virtual joystick. We computed, for each condition, the Euclidean distance between the true center and the perceived center. Fig. 7 shows these distances for each condition.

Table 2: Items asked as five-point Likert-scale questions under each tactile feedback condition. × indicates that the item was not asked under that condition; ✓ indicates that it was asked.

	NTF	CTF	FTF	CTF + FTF
Could you perceive the center tactile?	×	✓	×	✓
Did the center tactile help recognize finger position?	×	✓	×	✓
Did the center tactile help recognize finger movement direction?	×	✓	×	✓
Could you perceive the frame tactile?	×	×	✓	✓
Did the frame tactile help recognize finger position?	×	×	✓	✓
Did the frame tactile help recognize finger movement direction?	×	×	✓	✓
Which was more perceptible: center or frame tactile?	×	×	×	✓
Which tactile helped more in recognizing finger position?	×	×	×	✓
Which tactile helped more in recognizing finger movement direction?	×	×	×	✓

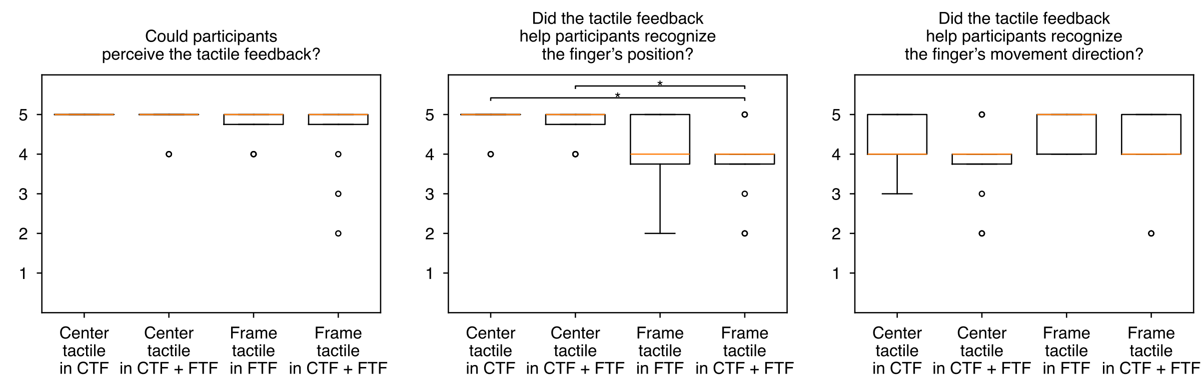


Figure 8: Subjective evaluations for each condition. * indicates $p \leq 0.05$.

Table 3: Pairs showing significant differences and their p-values for each presented direction.

Presented Direction	Compared Pair	p-value
Dir 3	(FTF, NTF)	0.0151
Dir 4	(FTF, NTF)	0.00144
Dir 5	(FTF, NTF)	0.000148
Dir 6	(CTF, FTF)	0.0135
Dir 6	(FTF, NTF)	0.00224
Dir 7	(FTF, NTF)	0.00840
Dir 8	(FTF, NTF)	0.0289
Dir 9	(CTF, FTF)	0.0107
Dir 9	(FTF, NTF)	0.0320
Dir 12	(CTF, NTF)	0.0320
Dir 13	(CTF + FTF, NTF)	0.000148
Dir 13	(CTF, NTF)	0.00224
Dir 13	(FTF, NTF)	0.00656
Dir 14	(CTF + FTF, NTF)	0.00508
Dir 14	(CTF, NTF)	0.00193
Dir 14	(FTF, NTF)	0.00445

A Shapiro-Wilk test revealed that the distance distributions for all conditions violated normality; hence, we used the Friedman test to assess differences. The Friedman test yielded $p = 1.07\times10^{-66} < 0.05$ ($\chi^2 = 309$), indicating significant differences among conditions. Pairwise comparisons were then conducted using the Wilcoxon signed-rank test with Bonferroni correction. The tests revealed significant differences between the NTF condition and all other conditions. Specifically, (NTF, CTF) yielded $W = 7099,\ p = 5.05 \times 10^{-47},\ r = 0.72$; (NTF, FTF) yielded $W = 7561,\ p = 8.38\times10^{-46},\ r = 0.71$; and (NTF, CTF + FTF) yielded $W = 7852,\ p = 4.83\times10^{-45},\ r = 0.72$. All effect sizes ($r$) exceeded 0.7, indicating large effects ($|r| \geq 0.5$) across these comparisons according to Cohen's benchmarks [6].

5.3 Subjective Evaluation

Fig. 8 shows the subjective ratings for tactile detection, finger position recognition, and finger movement direction recognition. Shapiro-Wilk tests indicated that the subjective ratings for each metric and each condition violated normality; therefore, we used the Friedman test for significance testing. When the Friedman test revealed significance, we conducted pairwise Wilcoxon signed-rank tests. Those revealed significant differences in "did the tactile feedback help finger's position recognition" between the frame tactile and center tactile of the CTF + FTF condition ($W = 0.0,\ p = 0.0498$), and between the frame tactile of the CTF + FTF condition and the center tactile of the CTF condition ($W = 4.5,\ p = 0.0486$). Fig. 9 presents the subjective evaluation comparing the center tactile and frame tactile of the CTF + FTF condition. The results show that center tactile was more easily perceived and more helpful for finger

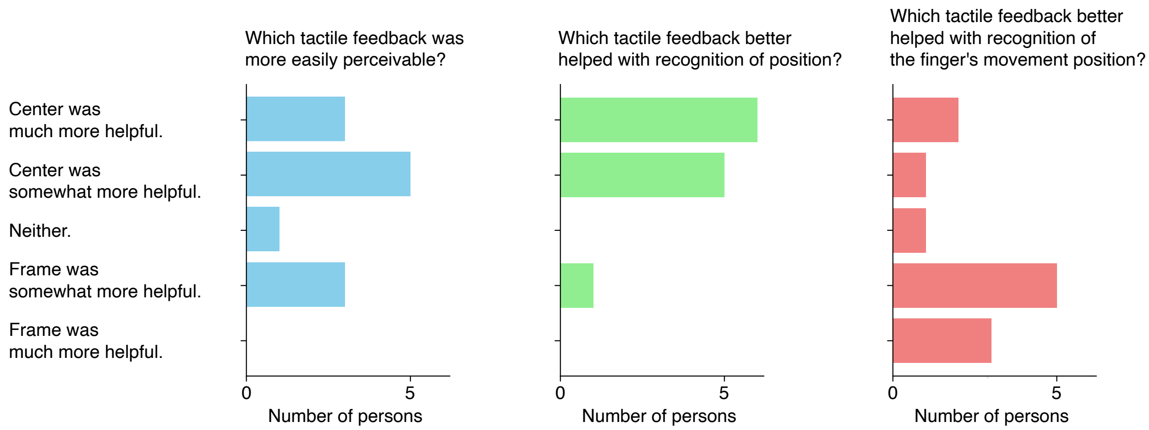


Figure 9: Subjective feedback on tactile feedback in the CTF + FTF condition.

position recognition, whereas the frame tactile was more helpful for finger movement direction recognition.

6 Discussion

6.1 Movement Direction

6.1.1 Analysis by Tactile Feedback Condition. We analyzed the data by tactile feedback condition. Tactile conditions (CTF, FTF, CTF + FTF) yielded significantly more accurate inputs than the NTF condition. Among them, the FTF condition achieved the highest accuracy. This result aligns with participants' comments indicating that the frame tactile was effective for recognizing finger movement direction, as well as with the subjective ratings showing that the frame tactile aided direction perception. Moreover, the fact that the FTF condition was significantly more accurate than the CTF condition, suggests that the frame tactile is most effective for movement direction input. Although the CTF + FTF condition also included the frame tactile, it was significantly less accurate than the FTF condition. Analyzing the distribution of touch-up points (Fig. 4) helps explain these results; No touch-ups occurred near the center under the FTF condition, while some touch-ups appeared near the center under the CTF + FTF condition. We assume that when both types of feedback were present, participants sometimes relied on the center feedback and thus did not make full use of the frame tactile. Consequently, the CTF + FTF condition produced results similar to those of the CTF condition. The lack of a significant difference between the CTF + FTF and CTF conditions reinforces this interpretation.

6.1.2 Analysis by Direction. Next, we analyzed the data by direction. For directions from upper-left to upward (Dir 15–17, 1, and 2) and from downward to lower-left (Dir 10 and 11), no significant differences were found among conditions, suggesting that tactile feedback had little effect in these angular ranges. Under the FTF condition, accuracy was significantly higher than in the NTF condition for rightward directions (Dir 3–9) and leftward directions (Dir 13 and 14). In particular, for five of the rightward directions (Dir 3–5, 7, and 8), only the FTF condition achieved significantly higher accuracy than the NTF condition, indicating that the frame tactile is especially effective for rightward movement direction input. For leftward directions (Dir 13 and 14), tactile conditions (CTF, FTF, and CTF + FTF) were significantly more accurate than the NTF condition, implying that both the center tactile and frame tactile effectively support movement direction input when the target lies to the left. This tendency aligns with the findings reported by Trudeau et al. [24], who demonstrated that thumb abduction movements (moving the thumb outward—corresponding to leftward movements when using the left thumb) are performed more accurately than adduction movements (moving the thumb inward—corresponding to rightward movements when using the left thumb). Our experimental results under all tactile conditions showed the same pattern with this observation, suggesting that thumb abduction movements can be executed with high precision even in the absence of visual feedback. Furthermore, the presence of tactile feedback in leftward directions, where thumb movements are biomechanically easier to perform, appears to amplify this effect, enhancing directional input accuracy.

6.1.3 Effect Sizes and Practical Significance. The pairwise Wilcoxon signed-rank tests with Bonferroni correction revealed moderate effect sizes according to Cohen's benchmarks [6]. Specifically, comparisons between the NTF and tactile conditions (CTF, FTF, CTF + FTF) showed medium effect sizes: (NTF, FTF) yielded $r = 0.49$, approaching the large threshold; (NTF, CTF) yielded $r = 0.32$; and (NTF, CTF + FTF) yielded $r = 0.30$. These results indicate that the presence of any tactile feedback substantially reduced directional error compared to no feedback. In contrast, comparisons among tactile feedback conditions yielded small effect sizes ($|r| \leq 0.24$), suggesting that varying the tactile patterns provided little additional benefit.

6.2 Center Position

6.2.1 Analysis by Tactile Feedback Condition. Tactile conditions (CTF, FTF, CTF + FTF) yielded significantly more accurate center position inputs than the NTF condition, although there were no statistically significant differences among the three tactile conditions. While 11 of the 12 participants reported in the subjective evaluation that the center feedback was more helpful for recognizing finger position, the frame tactile also appears to have supported accurate center position input. Indeed, some participants explicitly commented that they used the frame tactile to find the center.

6.2.2 Effect Sizes and Practical Significance. The effect size analysis demonstrated very large differences between the NTF and tactile conditions (CTF, FTF, CTF + FTF): (NTF, FTF) yielded $r = 0.70$; (NTF, CTF) yielded $r = 0.72$; and (NTF, CTF + FTF) yielded $r = 0.71$. These effect sizes correspond to large effects ($|r| \geq 0.50$), underscoring the considerable improvement in center position accuracy when tactile feedback is present. In contrast, effect sizes for comparisons among tactile feedback conditions were small ($|r| \leq 0.10$), reinforcing the finding from Trial 1 that the primary performance gains are derived from the presence of feedback, regardless of its specific configuration.

7 Limitations and Future Work

7.1 Misalignment Between Perceived Tactile Point and Touch Point

In the FTF condition (Fig. 4), touch-up points were shifted to the left of the actual tactile feedback. Some participants commented that they lifted their finger precisely where they perceived the frame tactile, and we infer that many others similarly touched up at the perceived feedback location.

This suggests a discrepancy between the point where the tactile stimulus is perceived and the actual touch-up point. A similar phenomenon has been reported in prior work [12]. Future studies should investigate the relationship between perceived tactile location and the actual touch location in depth, as this would allow us to adjust the tactile pattern so that the actual touch point aligns more closely with the intended point.

7.2 Tactile Pattern

In this research, we tested only four tactile feedback patterns, which were defined by combining the presence or absence of a center tactile and the presence or absence of a frame tactile; a diverse range of design space should be explored in future research (e.g., a gradient pattern in which tactile intensity changes from the center outward across the entire joystick area, or a series of concentric circular tactile feedback). Future work should also include user studies with these alternative tactile configurations and should examine the level of tactile resolution that users can reliably perceive.

7.3 User Study

All participants in our experiment were young adults, and most were male. To avoid demographic bias in future studies, it will be important to recruit a more diverse participant pool. Regarding the scope of the preliminary investigation, this research focused solely on perceived center position and movement direction. As a result, the presence of tactile feedback made it easier for participants to perceive both the center position and the movement direction, suggesting potential reductions in erroneous directional inputs during real gameplay. However, on the basis of these results alone, generalization to real gameplay operations remains difficult. Future work should examine how tactile feedback influences users' perception of movement magnitude. Moreover, as a more ecologically valid user test, it will be important to investigate the impact of tactile feedback on in-game character movement, thereby simulating a realistic application scenario.

8 Conclusion

To prevent unintended inputs when using a virtual joystick, we applied a screen protector with engraved tactile patterns to a smartphone, thereby providing tactile feedback during virtual joystick operation. To investigate the effect of this tactile feedback on the user's perceived center position and movement direction of the virtual joystick, we conducted experiments using four tactile patterns that combined the presence or absence of center tactile feedback and frame tactile feedback. Experiments with 12 participants revealed that the three conditions with tactile feedback resulted in more accurate inputs for both center position and movement direction than did the condition without tactile feedback. Additionally, regarding movement direction input, the condition with only frame tactile feedback was significantly more accurate than the other conditions, while for center position input, no significant difference was observed among the tactile patterns. In the future, we plan to explore other tactile patterns not included in this experiment and conduct user studies in more practical environments, such as character movement tasks.

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