Modified Control-Response Ratio for Move and Rotation Operations on a Large Multi-touch Interface

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Abstract. This study focused on the effect of the control-response ratio (C/R ratio) of a multi-touch interface for move and rotation operations. The experiments were conducted to collect data on user performance and subjective evaluation to analyze the effects of five levels of the C/R ratio. Forty-five participants, 15 male and 30 female, were given tasks to complete. The results showed that in overall operations, subjective satisfaction was highest with the C/R ratio 1/1, but in the usability analysis among the C/R ratios 1/1, 1/2, and 2/1, there was no significant difference. Specific operations that analyzed the effects of the C/R ratio showed in the move operations the best C/R ratio was located between 1/1 and 1/2, and in the rotation operations, the difference among the C/R ratios 2/1, 1/1, and 1/2 was not significant. The best C/R ratio might be located among the three values. The results show that on a mid-size multi-touch screen, a modified C/R ratio may help users in pan and rotation operations to improve performance and satisfaction.

Keywords: C/R ratio, multi-touch, large touchscreen.

1 Introduction

Multi-touch interfaces are becoming an important part of consumer information products. The control/response ratio (C/R ratio) is a main factor in the design of these positioning devices. This study examined user performance and satisfaction to understand the appropriate C/R ratio of a multi-touch interface.

This study focused on the effect of the C/R ratio of a multi-touch interface for move and rotation operations. Multi-touch is defined as operating on the screen with two or more fingers, and it is a type of direct control with the screen as the input device. The C/R ratio is a ratio of the movements of the control and system response. For a direct manipulation interface such a multi-touch touchscreen, a C/R ratio of 1/1 seems to be natural. It is intuitive to use and learn for natural mapping. However, on a large-size touchscreen, the long travel distance may result in poor efficiency and muscle fatigue [1]. A modified C/R ratio may help users extend the range beyond the physical limitation. At first, users will find the response of the direct operation does not coincide with control. They may learn a new mental model similar to that of indirect operation. The purpose of this study was to investigate whether different C/R ratios are necessary for various tasks.

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Sanders and McCormick [2] extended the human-machine interface C/R ratio concept and general application. The original term display was replaced by system response. The C/R ratio is the reciprocal of gain. Low gain is low sensitivity. High gain is high sensitivity. It is explained by the knob interface, and the concept can be applied to the mouse's sensitivity.

Stevenson et al. [3] adjusted the C/R ratio of the mouse to compare user performance. The result showed a high C/R ratio provided an advantage in accuracy. When the input interface is replaced with a multi-touch one, the C/R ratio is not an obvious factor to investigate. North et al. [4] mentioned that the single-touch operation was developed in the original one-click mouse operation. Multi-touch operation may require a different concept model. Perhaps in different tasks, the required sensitivity is different.

Literature related to multi-touch is mostly about the performance and satisfaction of task-based operations. For example, Fiorella, Sanna, and Lamberti [5], Yee [1], and Esenther and Wittenburg [6] used various multi-touch control modes to analyze user performance and satisfaction. In the literature, the three most commonly used multi-touch control modes are moving, rotation, and scaling. A previous pilot study tested the C/R ratio with 1/2, 3/4, 1/1, 4/3, and 2/1 and found the best C/R ratio was not the same for the efficiency of different operating tasks. However, the appropriate C/R ratio cannot be found in the range 1/2 to 2/1. And user satisfaction was affected by the participants' previous experience [7].

2 Experimental Design

The principal aim of the study was to gain insight into the influences of the control-response ratio in the multi-touch interface for move and rotation tasks. Performance and satisfaction were the main issues explored.

Forty-five subjects participated in the study, 15 male and 30 female. The age ranged from 20 to 26 years (Mean = 21.53, SD = 1.38), and they spend an average of 6.73 hours (SD = 2.33) using a computer every day.

The previous pilot study tested the C/R ratio from 2/1 to 1/2 but did not find significant differences in performance [7]. This study extends the range of the C/R ratio from 4/1 to 1/4 so that the sensitivity ranges from the lowest to the highest. The five levels of the C/R ratio, gain value, and sensitivity are shown in Table 1.

Table 1. Five C/R ratio levels and the related gain and sensibility

C/R Ratio	4/1	2/1	1/1	1/2	1/4
Gain	1/4	1/2	1/1	2/1	4/1
Sensitivity	Lowest	Low	Standard	High	Highest

For evaluating the performance, three performance indexes and subject satisfaction data were collected. The variables are defined as follows:

- Time: the time participants spent completing each task.
- Errors: the number of tasks the user did not complete correctly.
- Touch number: the number of times that the user put his (her) finger on the screen.
- Satisfaction: the satisfaction was evaluated after the participant completed each task using a Likert scale with five levels ranging from "very difficult to use (1 point)" to "very easy to use (5 points)."

2.1 Apparatus

The experiment was designed to compare performance and satisfaction in difference C/R ratios for a multi-touch interface. The configuration of the experiment environment is shown in Fig. 1. A computer with Microsoft Windows 7 operating system that supported multi-touch and a 23-inch Acer T231H infrared optical multi-touch screen with the highest resolution 1920x1080 (pixel) and viewable size 509.76x286.74 (mm) were used in the experiment.

The experiment system was designed with Adobe Flash CS5 that supported multi-touch function. The objects used in the tasks were set in 320x240 pixels with a poker pattern. The poker pattern can reduce a participant's cognitive problems for image direction. Five percent of the target boundary was set as the tolerance (Fig. 2). Only when participants did not put the object in this area was counted as an error. The participants operated the two multi-touch modes on the objects to complete all the tasks.

Fig. 1. The configuration of the experiment environment

Fig. 2. The inside and outside error range of the targets was limited to 5%

2.2 Tasks

Two tasks were used in this experiment. All the tasks should have been completed with a single hand. The move task was set as the participant using two fingers to drag the object from the start point to the target area, as shown in Fig. 3. The rotation task used two fingers to drag the object from the horizon to the vertical, as shown in Fig. 4.

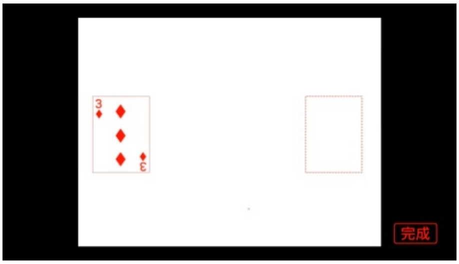

Fig. 3. Move task

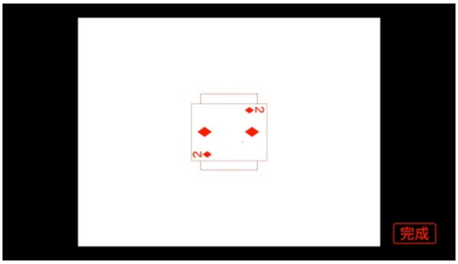

Fig. 4. Rotation task

2.3 Procedure

The experiment asked the participants to follow the instructions for performing the move and rotate tasks using one hand. The tasks with different C/R ratios were arranged with the Latin matrix to avoid the participants' learning effect.

The participants operated the two multi-touch modes on the objects to complete all the tasks. The error range of the target size was set at 5%. If the object was not moved or rotated within the error range and the participants clicked the "Finish" button, the system logged an error record. The system popped up a window to alert participants to continue the experiment until they had correctly placed the target within the error range. Participants were asked to rank their satisfaction with each task on the pop-up screen (see Fig. 5) after completing each task.

Fig. 5. The satisfaction evaluation screenshot

The study was a within-subject design. Each participant was tested with all ten tasks of two modes and five C/R ratio levels. Satisfaction was evaluated upon completion of each task.

3 Results

Table 2 presents the mean and standard deviation (SD) of each variable with a different C/R ratio in the rotate and move tasks. The C/R ratio values are set in descending order, that is, from low sensitivity to high sensitivity.

Table 2. Satisfaction, error, touch numbers, and the completion time with the C/R ratio

C/R Ratio	Task	4/1	2/1	1/1	1/2	1/4
		Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
Satisfaction	Rotation	2.02 (1.00)	2.82 (0.84)	**3.01 (0.97)**	2.66 (1.04)	2.06 (1.01)
	Move	2.48 (1.08)	2.97 (0.88)	**3.92 (0.90)**	2.89 (0.88)	2.17 (0.94)
Error	Rotation	0.07 (0.29)	**0.00 (0.00)**	0.03 (0.18)	0.03 (0.18)	0.23 (0.52)
	Move	**0.00 (0.00)**	**0.00 (0.00)**	**0.00 (0.00)**	0.03 (0.18)	0.13 (0.37)
Touch Num.	Rotation	10.58 (10.82)	4.23 (1.91)	**3.66 (1.70)**	4.79 (3.29)	6.69 (4.80)
	Move	8.62 (2.46)	4.46 (1.73)	**2.50 (1.00)**	3.29 (1.49)	4.79 (2.80)
Time	Rotation	49.64 (56.82)	**18.16 (10.08)**	19.72 (15.03)	26.26 (21.55)	44.86 (39.58)
	Move	19.68 (9.98)	14.52 (6.78)	**10.92 (7.09)**	19.27 (20.37)	29.19 (21.05)

The C/R ratio with the highest satisfaction scores for the rotation task was 1/1 (Mean = 3.02, SD = 0.97); the lowest error was 2/1 (Mean = 0.00, SD = 0.00); the lowest touch number was 1/1 (Mean = 3.66, SD = 1.70); and the lowest completion time was 2/1 (Mean = 18.16, SD = 10.8). For the moving task, the highest satisfaction score was 1/1 (Mean = 3.92, SD = 0.90); the lowest number of error was 1/1, 2/1, and 4/1 (Mean = 0.00, SD = 0.00); the lowest touch number was 1/1 (Mean = 2.50, SD = 1.00); and the lowest completion time was 1/1 (Mean = 10.92, SD = 7.09).

The analysis of variance (ANOVA) and Duncan post hoc test were conducted to compare the differences among the C/R ratios in each variable. The results of the ANOVA and Duncan test are presented in Table 3. All the variables had significant differences among the C/R ratios ($p < .000$). The rotation and moving task satisfaction scores of the C/R ratio 1/1 were significantly higher than the others. The number of errors for the C/R ratio 4/1 was significantly higher than the others in the rotation and moving tasks. There were no significant differences between the C/R ratios 1/1, 1/2, 2/1, and 1/4. The moving task touch numbers in the C/R ratio 1/1 were significantly lower than the others. The touch numbers for the rotation task for the C/R ratios 1/1, 1/2, and 2/1 were similar, there were no significant differences between them, and they were significantly lower than those for 4/1 and 1/4. The shortest completion time of the C/R ratios were for 1/2, 1/1, and 2/1 in the rotation task, which were significantly shorter than for 4/1 and 1/4. The moving task completion time for the C/R ratios 1/1 and 1/2 was the fastest, which was significantly faster than others.

Table 3. The ANOVA analysis and Duncan post hoc analysis. (*** $p < .001$)

C/R Ratio	Task	ANOVA		Post Hoc Test
		F	P	Duncan
Satisfaction	Rotation	19.625	.000 ***	(1/1, 1/2) ≥ (1/2, 2/1) > (4/1, 1/4)
	Move	44.928	.000 ***	(1/1) > (1/2, 2/1) > (1/4) > (4/1)
Error	Rotation	9.137	.000 ***	(4/1) > (1/4, 2/1, 1/1, 1/2)
	Move	8.725	.000 ***	(4/1) > (2/1, 1/1, 1/2, 1/4)
Touch Num.	Rotation	22.508	.000 ***	(1/4) > (4/1) > (2/1, 1/2, 1/1)
	Move	124.234	.000 ***	(1/4) > (4/1, 1/2) > (2/1) > (1/1)
Time	Rotation	17.136	.000 ***	(1/4, 4/1) > (2/1, 1/1, 1/2)
	Move	20.262	.000 ***	(4/1) > (1/4, 2/1) > (1/2, 1/1)

4 Discussion

4.1 C/R Ratio in the Moving Task

Moving is a general operation, and the most frequently used in touch interface. The results have shown that the C/R ratio 1/1 had the highest subjective satisfaction score. The C/R ratio 4/1 had highest number of errors, and there was no significant difference among the others. The touch numbers for the C/R ratio 1/1 were significantly lower than for the other ratios. The completion time for the C/R ratios 1/1 and 1/2 was significantly faster than for the others. All the evidence demonstrates that in the move operation the best C/R ratio was located between 1/1 and 1/2.

The results are similar to those for a previous pilot study [7] that found there was no significant difference in completion time, number of errors, and touch numbers among the C/R ratios 2/1, 4/3, 1/1, 3/4, and 1/2 in the moving task. However, the subjective satisfaction of the C/R ratio 1/1 was significantly higher than for the others.

4.2 C/R Ratio in the Rotation Task

In the rotation task, the C/R ratios 1/1 and 1/2 had higher subjective satisfaction scores than the others. The number of errors for the C/R ratio 4/1 was higher than for the others, and the difference among the C/R ratios 1/2, 1/1, 2/1, and 1/4 was not significant. The touch numbers among the C/R ratios 1/1, 1/2, and 2/1 were similar but significantly lower than the others. The completion times among the C/R ratios 1/2, 1/1, and 2/1 also were similar and significantly lower than those for the C/R ratios 4/1 and 1/4. These results illustrated that the performance among the C/R ratios 2/1, 1/1, and 1/2 was not significantly different. The best C/R ratio might be located from 2/1 to 1/2.

Similar results were also found in a previous pilot study [7]. There were no significant differences in subject satisfaction and objective performance among the C/R ratios 2/1, 4/3, 1/1, 3/4, and 1/2.

4.3 C/R Ratio and Operation

The C/R ratio is one of the factors influencing the interface design that affect the performance of the task operation. The optimal C/R ratio is related to the task attributes with the travel and adjusts the time. The ratio is also related the controller and the display [2].

The C/R ratio has been discussed for computer pointer devices, such as the mouse. For example, Stevenson et al. [3] adjusted the C/R ratio of the mouse to compare user performance. The result showed a high C/R ratio provided an advantage in accuracy. The mouse is an indirect pointer device; thus, the proportion of the control area size and display size affect the C/R ratio. However, when the input interface is replaced by a direct multi-touch interface, the proportion of the control and display is the same, and the C/R ratio is not an obvious factor to investigate. North et al. [4] mentioned that single-touch operation was developed in the original one-click mouse operation. Multi-touch operation may require a different concept model. Perhaps in different tasks, the required sensitivity is different.

The results of this study demonstrated that the optimal C/R ratio for different operation tasks in the multi-touch interface should be different. Especially in the mid-size multi-touch screen, a modified C/R ratio may help users in pan and rotation operations to improve performance and satisfaction.

5 Conclusion

The purpose of this study was to explore the C/R ratio with move and rotation operations on a mid-size multi-touch screen. The experiment was conducted to collect data. The experiment found that the best C/R ratio for the move operation was located between 1/1 and 1/2, and for the rotation operation was located between 2/1 and 1/2. The results illustrated that on a mid-size multi-touch screen, the best C/R ratio for different operation tasks may be different.

The results provide a reference for multi-touch interface design, but future research and data need to be verified. The experiment was limited to hardware and software. In future research, the experiment and device need more revision. More operation tasks and levels of the C/R ratio should be added to obtain more accurate data to validate the findings, and to provide more relevant results for design and research reference.

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