Design and Evaluation of a Handled Trackball as a Robust Interface in Motion

Chiuhsiang Joe Lin, Chi-No Liu, and Jun-Lung Hwang

Department of Industrial Engineering, Chung-Yuan Christian University,
200, Chung Pei Rd., Chung- Li, Taiwan 32023, R.O.C.
hsiang@cycu.edu.tw

Abstract. In this study, a handled trackball was developed aiming at future use in a vibration environment within cockpits, ships, or other carriers. The study was to determine an optimal handle posture for the handled device from combinations of three forward slopes (0°, 15°, and 30°) and lateral slopes (0°, 15°, and 30°). The device was also compared with a table trackball for basic operation properties. An experimental cursor movement task was used to measure the response time of each design, accompanied by subjective fatigue and usability evaluations. The results found that the forward 30° and lateral 30° combination reached the top cursor movement performance without imposing undue fatigue to the operator. The study suggests using the forward 30° and lateral 30° handled trackball as the optimal design solution to maintain the performance when the operation of the trackball is under severe vibration environment.

Keywords: handled trackball, vibration environment.

1 Introduction

With the development of the information technology, computers have become an indispensable tool in our daily life and pointing devices, such as mice, trackballs, and touch screens, are particularly important to simplify the operation for users. Mice and trackballs are the most commonly used NKIDs (Non-Keyboard Input Devices) in the application of computer equipment. However, inappropriate operation or design of these devices may decrease performing efficiency and even bring about CTDs (Cumulative Trauma Disorders) to the muscles or bones of users after operation for a relatively long time, and the social, production, medical and human resource costs paid for CTDs are very high [4].

Most previous research assumed that computers were operated in a static environment with the mouse as the key control device for the operation. In their research on the operation of mouse, trackball, touch pad, tablet, and track point for linear motion, Accot and Zhai [1] found that the mouse required the least time for the linear motion, while it took the most time for the trackball to finish the motion. However, mouse operation is not suitable in every environment. It is not the best choice, for example, for radar or monitoring systems or other HCIs (Human Computer Interfaces) on ships. These systems operate in a non-horizontal or vibration

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environment where users must balance themselves using additional support force [3] and, thus, have difficulties in operating the usual devices. It is therefore important to find out a way for stable operation of the HCIs. The trackball is usually a better choice than the mouse under motion environment, because it is fixed on the work surface and will not move with the external motion. However, when the body is subject to severe motion, there is a need for the hand to grasp on a firm object to maintain stability. At the moment of severe vibration, it is difficult to operate the table trackball. Accordingly, this study suggests using a handled trackball to provide support for users and facilitate smooth operation of the HCIs in a vibration environment. The trackball is placed on top of the handle and two buttons are positioned at the front of the handle as shown in Figure 1. The handled trackball is inserted in the armrest of the operator seat. The handled trackball is used in the same way as a normal trackball except that the handle provides secure grasp for the hand as the ship or carrier is subject to severe wavy movement. The idea is that the operator can be seated stably and the trackball can be operated with the thumb (for the trackball), index finger and middle finger (for the two buttons), while the ring and little fingers can grasp the handle to keep a stable posture of the hand and arm while the body is subject to motion.

How to design the angles and orientation of the handle becomes a critical design question in this study. A review of past studies on handled tool was first performed. Woodson et al. [10] found that the slope angle of the handle might affect the position of the wrist and forearm, making them fatigued or painful, so they suggested a forward slope of 0~10° to solve this problem. Some researchers suggested a proper grasp forward slope of 33° [5] and a handle with a minimum length of 100mm or an ideal length of 115~120mm [8]. In the research on the relationship between six diameters (25, 30, 35, 40, 45, 50mm) of handles and the grip strength, Kong and Lowe [7] found that users felt most comfortable and the highest grip strength value is acquired with diameters of 30, 35 and 40mm. A diameter between 38mm and 51mm resulted in the least muscle movement to operate a round handle [6]. It exerted higher force on the handle and could operate for a longer time before becoming fatigued. Brumfield and Champoux [2] further pointed out that a movement from 10° of flexion to 35° of extension was enough for the wrist to operate the handle in normal conditions, though it could move to a much larger extent.

Based on these recommendations and considerations, a trackball was instrumented on the handle with nine angle configurations. This study is designed to analyze the angle of the handled trackball. The study aims at finding a comfortable and productive position for the handled trackball.

2 Method

2.1 Participants

Six male and four female students (mean age: 25.3; mean height: 165.6cm) participated in the experiment. No participant was colorblind, suffered from eye diseases, or hand-arm problems. Each participant had a normal eyesight or at least 0.8 visual acuity after correction. The dominant hand was the right hand for all of them.

The participants were requested to fill in the "Personal Basic Information and Informed Consent Form of the Experiment" before the experiment commenced.

2.2 Equipment

This study utilized a desktop computer (Pentium □/1.70GHz, 256MB RAM) with a screen (Samsung 17" LCD, Model: SyncMaster 172B). The display resolution was set to 1024*768 pixel. The study used a table trackball (Macally, Model: Langend Ball) and a handled trackball (USB Geek, Model: Fish Handheld Mouse DH1), the latter was modified according to suggestions of ideal handle dimensions from the literature as the following: length 120mm [8], diameter 40mm [6], [7]. The handle angles were instrumented at three lateral slopes 0°, 15°, 30° and three forward slopes 0°, 15°, 30°. The experimental task was written in Microsoft Visual Basic 6.0 and executed in the Windows XP environment.

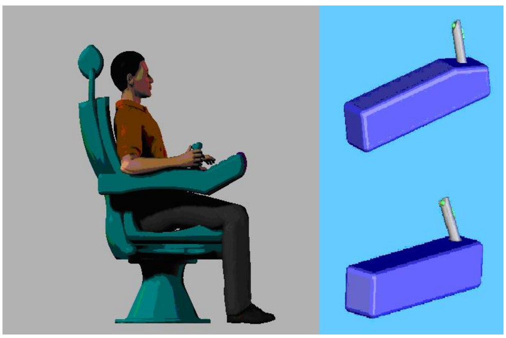

Fig. 1. The handled trackball inserted in the armrest of a seat, allowing the operator to stably operate the trackball under motion environment. Two handle slope configurations were shown here.

2.3 Experimental Task and Design

A cursor movement task was carried out with the experimental interface as shown in Fig. 2. A yellow question mark appeared in the center of the screen at the beginning of the experiment. A participant was requested to move the cursor using the pointing device to click the question mark button and activate the operation. A target shown as the red love heart symbol appeared randomly at one of the angles of 0°, 45°, 90°, 135°, 180°, 225°, 270°, or 315° and the participant was requested to move the cursor and click on the target as quickly as possible. The red heart symbol disappeared when it was clicked and the yellow question mark appeared again at the center of the screen. Then the participant continued the remaining actions as randomly appeared until the experiment was completed. The target appeared 5 times at each angle in a random order and a total of 40 (5 × 8) actions were to be completed for the experiment. The size of each red heart target was $0.8cm^2$ and the distance between the target and the center was 11cm. The click time for each action was recorded by the system automatically.

There are three factors for the experiment, the target angle, forward slope angle, and lateral slope angle. The target angle contains the eight different angles, 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°. The forward and lateral slope each contains three angles 0°, 15°, and 30°. In the first part of analysis, the click time was analyzed against the three factors. For the purpose of comparison, the normal table trackball was added in the experiment. In the second part of analysis, the nine handle slope configurations and the table trackball were considered as one factor, namely the device type. The click time was analyzed against the target angle and the device type. The participant was treated as the block for the experiment. There were five replications due to the five occurrences at each target angle.

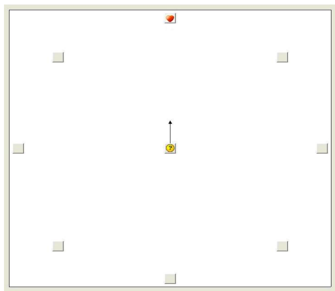

Fig. 2. The experimental task, with the question mark as the start and the red heart as the target, was to move the cursor as quickly as possible to the target and click on it

2.4 Subjective Evaluation

In addition to the task performance measure, the experiment result is enhanced with the subjective evaluation of the participants. An evaluation form is issued to each participant to complete after the experiment is completed. The participants are requested to rate the seven fatigue questions (neck and shoulder, right upper arm, right forearm, right wrist, right palm, right index finger, and right thumb) and four usability questions (hard to slide this trackball, hard to control this button, hard to grasp this sloped angle, and this performance is not good) on the form. The questions were rated with responses between one and five. A higher score indicates higher fatigue perception or higher dissatisfaction to the device usability.

3 Results

3.1 Results of the Experimental Task

In the first part of analysis of variance, the click time was analyzed against the target angle, forward slope, and the lateral slope angle. Both the target angle and forward slope were significant, but the lateral slope was not (Table 1). The click times at the target angles 0°, 90°, 180°, and 270° are shorter than those at the diagonals. For the three forward slopes, the shortest click time appeared at the 30° forward slope. Two interaction terms were significant, target angle by forward slope ($F(14,3519)=3.28$, $P<0.001$), and forward slope by lateral slope ($F(4,3519)=7.78$, $P<0.001$).

Knowing that the forward slope angle is the dominating factor, a combination of forward and lateral slopes must still be determined to reach a final design. In the second part of analysis, the click time was analyzed against the target angle and the device type which contains the nine slope combinations and the table track ball. The target angle and the device type were significant (Table 1). The interaction was also significant ($F(63,3911)=2.66$, $P<0.001$). The results of the target angle were similar to the first analysis. In this analysis, the shortest click time appeared when the handled trackball was operated at the forward-lateral slope combination of 30°-30°, while the longest click time appeared when it was operated at the forward-lateral slope combination of 0°-30° and 0°-0° (as confirmed by the Duncan test shown in Table 1). With this analysis, the final design slope angle was reached as the forward-lateral slope combination of 30°-30°. Compared to the performance of the table trackball, the click times for some slope configurations were higher and the others were lower. The click time values for the handle instrumented device were comparable with that of the table trackball, indicating that the handle instrumentation did not seem to change the pattern of use while providing additional hand grasp.

Table 1. Summary of Means, ANOVA, and Duncan test results for the two analyses

Click time by target angle and handle slope				
source	level	average	$F_{n,m}$	p-value
Target angle	270°	1.78^{A}	$F_{7,3159}$ 130.5	<0.001
	0°	1.80^{A}		
	90°	1.83^{A}		
	180°	1.99^{B}		
	315°	2.29^{C}		
	135°	2.31^{C}		
	45°	2.44^{D}		
	225°	2.63^{E}		
Forward slope	30°	2.06^{A}	$F_{2,3519}$ 22.13	<0.001
	15°	2.13^{B}		
	0°	2.22^{C}		
Lateral slope	15°	2.10	$F_{2,3519}$ 1.09	0.338
	0°	2.12		
	30°	2.13		

Click time by target angle and device type of pointing device				
source	level	average	$F_{n,m}$	p-value
Target angle	0°	1.79^{A}	$F_{7,3911}$ 106.6	<0.001
	270°	1.82^{A}		
	90°	1.86^{A}		
	180°	2.01^{B}		
	315°	2.27^{C}		
	135°	2.33^{CD}		
	45°	2.40^{D}		
	225°	2.59^{E}		
Device type	30-30	1.99^{A}	$F_{9,3911}$ 7.46	<0.001
	30-0	2.04^{AB}		
	15-15	2.06^{ABC}		
	15-0	2.12^{BCD}		
	table	2.13^{BCD}		
	30-0	2.14^{CD}		
	0-15	2.14^{CD}		
	15-30	2.20^{DE}		
	0-0	2.26^{E}		
	0-30	2.26^{E}		

* A, B, C, D, and E indicate the grouping by Duncan tests ($p<0.05$). The values with the same alphabet have no difference between their means.

3.2 Subjective Evaluation Results

Limited by the page allowance of the paper and the fact that the major interest of this study is to determine an optimal angle for the handled trackball as used in the setting described above, the results of the subjective evaluation were presented and summarized for the slope angle and the device type only.

3.3 Analysis of Fatigue Questionnaires

The analysis results of the fatigue questionnaires were summarized in Table 2. The forward slope had significant effects on the fatigue of the right upper arm, right forearm, right wrist, and right thumb. However, the lateral slope was not significant for any part of the body. The Duncan test (Table 3) further demonstrates that the forward slope of 30° brings about lower fatigue to the right upper arm, right forearm, right wrist, and right thumb, while the forward slope 0° brings about higher fatigue to these parts of the body.

When the slope angles were considered together, the device type had significant effects on the fatigue of the right upper arm, right wrist, and right palm (Table 2). The Duncan test result is presented in Table 4. The interest here is to check whether the

Table 2. Summary of the ANOVA results of fatigue questionnaires

Items	Forward slope	Lateral slope	Device type
Neck and shoulder	□	□	□
Right upper-arm	*	□	□
Right forearm	*	□	*
Right wrist	*	□	*
Right palm	□	□	*
Right index finger	□	□	□
Right thumb	*	□	□

*: P-value<0.05 □: P-value>0.05

Table 3. Duncan test results of forward slope on significant fatigue questions

Forward slope	Right upper-arm		Right forearm		Right wrist		Right thumb	
	Average	Duncan	Average	Duncan	Average	Duncan	Average	Duncan
30°	2.43	A	2.80	A	3.13	A	2.93	A
15°	2.83	AB	3.13	A	3.30	A	3.17	AB
0°	3.07	B	3.67	B	3.93	B	3.53	B

* A and B indicate the grouping by Duncan tests (p<0.05). The values with the same alphabet have no difference between their means. Lower values indicate less fatigue.

Table 4. Duncan test results of device type on significant fatigue questions

Device type	Right forearm		Device type	Right wrist		Device type	Right palm	
	Average	Duncan		Average	Duncan		Average	Duncan
15-15	2.50	A	15-15	2.70	A	15-0	2.30	A
30-30	2.60	A	30-0	3.10	AB	30-0	2.50	AB
30-15	2.90	AB	30-15	3.10	AB	30-15	2.60	AB
30-0	2.90	AB	30-30	3.20	AB	30-30	2.60	AB
15-0	3.10	ABC	15-0	3.40	ABC	15-15	2.70	ABC
0-15	3.50	BC	0-15	3.70	BC	0-30	2.80	ABC
0-30	3.60	BC	15-30	3.80	BC	15-30	3.10	ABC
15-30	3.80	C	0-30	3.90	BC	0-15	3.10	ABC
table	3.80	C	table	4.10	C	0-0	3.30	BC
0-0	3.90	C	0-0	4.20	C	table	3.50	C

* A,B and C indicate the grouping by Duncan tests (p<0.05). The values with the same alphabet have no difference between their means. Lower values indicate less fatigue.

best performance slope combination 30°-30° showed any adverse fatigue effect. It can be seen that the 30°-30° device was among the lowest fatigue group, while the table trackball and the 0°-0° device were among the highest fatigue group.

3.4 Analysis of Usability Questionnaires

The ANOVA results were summarized in Table 5. The forward slope had significant effects on three questions: hard to control this trackball, hard to grasp this sloped angle, and this performance is not good. The lateral angle was not significant in any of the questions. The Duncan test (Table 6) further demonstrates that the highest score appeared at the forward slope 0°. This indicates that the participants agreed that the handled trackball was not easy to operate or grasp when its forward slope was at 0°.

Table 5. Summary of ANOVA results of usability questionnaires

Items	Forward slope	Lateral slope	Device type
Hard to slide this trackball	□	□	□
Hard to control this button	*	□	*
Hard to grasp this sloped angle	*	□	*
This performance is not good	*	□	*

*: P-value<0.05 □: P-value>0.05

Table 6. Duncan test results of forward slope on significant usability questions

Forward slope	Hard to control this button		Hard to grasp this sloped angle		This performance is not good	
	Average	Duncan	Average	Duncan	Average	Duncan
30^0	1.90	A	2.77	A	3.00	A
15^0	1.97	A	3.07	AB	3.13	A
0^0	2.43	B	3.57	B	3.87	B

* A and B indicate the grouping by Duncan tests (p<0.05). The values with the same alphabet have no difference between their means. Lower values indicate lower unusability.

Table 7. Duncan test results of device type on significant usability questions

Device type	Hard to control this button		Device type	Hard to grasp this sloped angle		Device type	This performance is not good	
	Average	Duncan		Average	Duncan		Average	Duncan
30-30	1.80	A	15-15	2.40	A	15-15	2.70	A
15-30	1.90	A	30-0	2.60	A	30-30	2.80	AB
30-15	1.90	A	30-30	2.70	AB	15-0	3.00	AB
15-0	2.00	A	30-15	3.00	ABC	30-0	3.00	AB
15-15	2.00	A	15-0	3.10	ABC	30-15	3.20	ABC
30-0	2.00	A	0-15	3.10	ABC	0-15	3.70	BCD
0-15	2.30	AB	table	3.10	ABC	0-30	3.70	BCD
0-0	2.50	AB	0-30	3.70	BC	15-30	3.70	BCD
0-30	2.50	AB	15-30	3.70	BC	table	4.00	CD
table	3.00	B	0-0	3.90	C	0-0	4.20	D

* A,B,C and D indicate the grouping by Duncan tests (p<0.05). The values with the same alphabet have no difference between their means. Lower values indicate less fatigue.

The device type was significant on the usability questions, hard to control this trackball, hard to grasp this sloped angle, and this performance is not good (Table 5). The Duncan test (Table 7) further demonstrates that the 30°-30° device was among the lowest unusable group, while the table trackball and the 0°-0° device were among the highest unusable group.

4 Discussion

In the cursor movement experiment, the longest click time appeared at the forward-lateral slope combination of 0°-0° among all types of pointing devices. If we compared this with the result of the subjective evaluation, there seemed to be possible reasons for this poor performance. First, the fatigue questionnaires show that the highest rating for the right forearm and wrist at this slope configuration. This indicates that the participant had the strongest fatigue perception possibly resulting from the stress on the muscle of the right forearm and right wrist at this slope combination. Additionally, for the two questions "hard to grasp this sloped angle" and "this performance is not good", the ratings were, respectively, near 4 and beyond 4 points at this slope combination, indicative of uneasy grasp and poor performance. Based on careful observation of the grasping posture of the participant, it was found that when grasping the handled trackball in the posture and using the thumb to operate the device, the coupling between the palm and the surface of the handle was poor, bringing about stress and fatigue to the muscles of the palm and thumb. All of this confirmed that the 0°-0°slope resulted in the poor posture and therefore poor task performance.

It is interesting to note that the cursor task found that more time was required to click the target diagonally than to locate it horizontally or vertically, which is consistent with the finding of Thomas and Henry [9].

The study found that the forward slope was the dominating factor in determining a good grasp posture for the hand and arm. For the forward slope, the result of the shortest click time at 30° is similar to the argument of Hsu and Cheng [5] that a 33° forward slope is most suitable for handle operation. The better performance of the handled trackball at the forward slope of 30° than the forward slope of 15° or 0° can be partly attributed to the fact that the muscle of the wrist and arm relaxes easily at the forward slope of 30° and the stress on the muscle of the thumb, wrist, and arm becomes greater with reduction of the angle. Since the muscle becomes tighter with increase of stress, pain and fatigue are brought about as a result. Accordingly, the forward slope of the handle is decisive for comfort of the user when operating the handled trackball.

Analyses also suggested that the forward-lateral slope combination of 30°-30° were a good design choice. First, this slope configuration reached the shortest click time in the cursor movement task. Second, the usability questionnaires show that the lowest perception of "hard to control this button" appeared at this particular posture. Lastly, both the subjective fatigue and usability evaluations showed that this configuration was among the lowest fatigue and unusable group in several questions. All of this suggests the forward-lateral slope combination of 30°-30° should be used for the design.

This study included the table trackball as a comparison. For the table trackball, the highest fatigue rating was given to the right palm, probably because more forearm pronation combined with thumb and finger movement leads to more exertion. Also, the palm of the right hand is completely placed on the device and thus cannot grasp it smoothly in comparison with ordinary mouse devices. Consequently, the index finger and the palm cannot relax easily and can suffer from undue stress and fatigue. Since most participants never used the handled trackball, the study initially suspected that the performance or subjective impression might be affected by such instrumentation. The study therefore used the table trackball as a control, so that the performance of the new device can be judged and compared with the control. Based on the results of the study, both the performance and subjective rating of the handled trackball are comparable with the usual table trackball. But the handled design offers several design characteristics to allow the user to securely grasp the handle while simultaneously operating the trackball and buttons. When the operator is subject to severe motion, such design provides better stability for the hand and arm posture. Future experimentation is planned to test the design under motion (vibration) environment.

5 Conclusion

The study designed a handled trackball aiming at providing better grasp and stability for the operator to perform computer tasks while in motion. Several handle slope configurations were tested and evaluated for their cursor movement performance and subjective rating of fatigue and usability. The study found that the forward slope was the dominating factor in the handle posture design. The performance of the handled trackball at the forward slope of 30° was better than that of 15° or 0°. The lateral slope had no significant effects on task performance, subjective fatigue or usability. The result also identifies that the handled trackball had the best performance when it was operated at the forward-lateral slope combination of 30°-30°. There were no apparent shortcomings when evaluated by subjective fatigue and usability characteristics. The handled design provides the user with firm grasp while simultaneously working on the trackball. This allows the operator to overcome unstable hand and arm postures disturbed by motion when the device is placed on a ship or motored carrier. Accordingly, this study suggests substituting the handled trackball with the forward-lateral slope combination of 30°-30° for the table trackball to improve the performance of the operation under motion environment.

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