

Mouse-based rotation and translation

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We present the results of two experiments to evaluate the effectiveness of different mouse-based techniques for rotating and translating 2D objects. We compare two dual-mouse techniques against two single-mouse techniques. Initially, the two single-mouse techniques outperform both the dual-mouse techniques. However, after two hours of exposure to the four techniques, one of the dual-mouse techniques significantly outperforms the other techniques.

bimanual interaction, symmetric interaction, two-handed input, rotation, translation

1.0 INTRODUCTION

The task of object positioning is common in computer applications, especially drawing and design. While in real life objects can be simultaneously translated and rotated, the availability of a single spatial positioning device has forced designers to perform these tasks separately in the computer interface. The advent of USB means that new drawing programs can integrate a second, separate input stream from a second mouse. The important issue is whether the spatial input from a second device can be used to make the task of rotating and translating objects more efficient. The research presented in this paper aims to answer that question by describing an experiment in which four techniques are compared: a dual-mouse symmetric technique based on the two-handed 'stretchies' described by Kurtenbach et al [12] (each mouse controls the position of opposite corners of the object), a dual-mouse asymmetric technique in which the non-dominant hand controls translation of an object, while the dominant hand rotates the object, and two single-mouse techniques in which the mode switch between translating and rotating is achieved by pressing a keyboard modifier or pressing a different mouse button.

2.0 BACKGROUND

Two-handed interaction has received much attention in the HCI literature, beginning with the seminal research of Myers and Buxton [3]. The dominant trend in this research has been to examine and use Guiard's Kinematic Chain model and guidelines for asymmetric interaction techniques [5,7,8,9,10,17]. In Guiard's model, asymmetric interaction is characterized by assigning different roles to the dominant hand (DH) and non-dominant hand (NDH), with the NDH setting the frame of reference in which the DH works. In addition, the DH works at a finer level of temporal and spatial detail than the NDH.

Symmetric interaction, where the two hands work at the same level of temporal and spatial detail, has received less attention in the HCI literature. In 1998, Leganchuk et al. showed the first performance benefits of symmetric interaction in an evaluation of area sweeping tasks [14]. Balakrishnan and Hinckley studied symmetric interaction and found that visual integration between the tasks of the two hands was important [1]. Casalta et al. found symmetric rectangle drawing to be faster than asymmetric rectangle drawing [4]. In 2004, Latulipe described the theoretical benefits of symmetric interaction as revealed in current Psychology research, which show that the two hands can work together at the same level of detail provided they are working together on a unified task [13]. Recently, Owen et al. studied a symmetric form of spline manipulation [16]. They found little benefit to the symmetric interaction, however their method did not provide any visual integration between the tasks of the two hands.

3.0 EXPERIMENTAL DESIGN

We conducted two object-positioning experiments to test a dual-mouse symmetric technique against a dual-mouse asymmetric technique and two single-mouse techniques (described in Table 1). An alternative technique, in which a

single mouse is used to simultaneously rotate and translate an object using a pseudo-physics algorithm [2,11], is not considered. That type of technique does not offer the same type of precision as the techniques considered here, although a comparison would be interesting.

Technique	Translation	Rotation
Mouse	Drag with left button pressed	Drag with right button pressed
Mouse + key	Drag with left button pressed	Drag with 'r' key pressed
Asymmetric	Drag left mouse with right button pressed	Drag right mouse with left button pressed
Symmetric	Unified steering: drag both mice with buttons pressed	

TABLE 1: Techniques tested in experiments.

The experimental task consisted of the translation and rotation of a right-angled triangle onto a target triangle, to within 25 pixels (distance of target triangle corners from moveable triangle corners). The single-mouse techniques chosen are standard techniques from current software. The dual-mouse asymmetric technique involves using the NDH to control translation of the object, while the dominant hand controls rotation of the object. Because the object rotates around its center, the NDH sets the frame of reference in which the DH works, by controlling the location of the object on screen.

3.1 Stimulus-Response Incompatibility



FIGURE 1: A series of experiment screenshots illustrating the cursors crossing one another during a large rotation symmetric trial. The red circular cursor is controlled by the left mouse and the blue cross-hairs cursor is controlled by the right mouse.

In pilot testing of the experiment an interesting issue arose with the symmetric technique. Whenever the triangle was turned more than $\pm 90^\circ$, the cursors flipped. Initially, the cursor controlled by the right mouse is located on the right side of the triangle and the cursor controlled by the left mouse is on the left, but as the triangle is rotated through vertical, the cursors cross over (see Figure 1). Some pilot subjects found this to be initially confusing. This problem is well-known in psychology as a stimulus-response compatibility issue [6]: the stimulus of moving the right mouse is not compatible with the response of the movement of the cursor farthest to the left on screen. Although we could have avoided this problem by changing to a symmetric shape such as a rectangle, we chose not to, because we consider this an important issue to investigate.

3.2 Experiment 1

16 undergraduate (non-computer-science) students were subjects for the first experiment. Eleven of the students were female, five were male. All subjects self-identified as right-handed. The experiment session was a repeated measures design, consisting of four conditions, one for each technique described above. For each condition, there were ten practice trials, followed by 40 randomized trials. The order of the four conditions was randomized across subjects. Each experimental session lasted roughly 40 minutes and subjects were paid C\$10 for their participation.

In each trial, subjects were asked to position a green triangle over top of an identical red triangle which was in a different location and orientation on screen. In each trial, the red target was the same distance from the green triangle, but in a variety of directions. In addition, the red target triangle was rotated around its center by some angle. The angles of rotation were $\pm 30^\circ$, $\pm 60^\circ$, $\pm 120^\circ$ and $\pm 150^\circ$. Thus, each trial varied in the direction of translation and in the amount of rotation required to align the green triangle with the red target triangle.

Three out of the 2560 trials were thrown out because the subjects did not complete them. In these cases the subjects moved the mouse or mice so fast that they lost the triangle and could not reacquire it. The results across all trials are summarized in the second and third columns of Table 2.

With all trials considered, the two single mouse techniques are superior to the two dual mouse techniques. However, when we separate the results between trials in which the angle of rotation was less than 90° in either direction, and

trials with larger rotations, the results are different for the symmetric technique (see Table 2). For small rotations, the symmetric technique is clearly faster than the other three techniques. Yet, for large rotations, the symmetric technique is clearly much slower than the other techniques. We believe this difference is a result of the stimulus-response compatibility issue described earlier.

Technique	All Trials		Small Rotation Trials		Large Rotation Trials	
	Mean (sec)	StdDev	Mean (sec)	StdDev	Mean (sec)	StdDev
Mouse	4.20	2.11	4.02	2.17	4.46	2.01
Mouse + key	4.21	2.23	3.90	1.90	4.68	2.50
Asymmetric	4.82	2.42	4.88	2.48	4.74	2.32
Symmetric	4.45	4.54	3.29	1.96	6.22	6.40
ANOVA F-ratio for Mean	7.74, $p_{3, 2498} \leq 0.0001$		50.95, $p_{3, 1493} \leq 0.0001$		14.39, $p_{3, 987} \leq 0.0001$	

TABLE 2: Experiment 1, first 40 minutes of exposure to task and techniques. Results over all trials, trials with small rotations, and trials with large rotations. Each subject performed 24 small rotation trials ($\leq 90^\circ$) and 16 large rotation trials per condition.

The results support our belief that the crossing cursors do indeed cause confusion and increase completion time. However, we don't believe symmetric interaction techniques should be dismissed because of this issue. For small rotations, the symmetric technique is 18% faster than the next fastest technique (mouse and key). This difference is statistically significant. Of course, the symmetric technique is the slowest technique for large rotations. The difference across the four techniques for large rotations has a smaller F-ratio, but is still significant. So the symmetric technique is better for small rotations and worse for large rotations. There is no data to suggest that large rotations are less common than small rotations in modeling tasks. However, it seems likely that small rotations would be more common simply because any symmetric object would not require rotations beyond a magnitude of 90° . If this is the case, then the symmetric technique advantage is even more significant than our results suggest. Experiment 2 was designed to further examine how users perform large rotations with the different techniques over time.

3.3 Experiment 2

In the second experiment, six subjects were randomly recruited from the 16 subjects who participated in Experiment 1. These six subjects were asked to return and perform Experiment 1 three more times over a period of four days. The purpose of Experiment 2 was to examine the change in the completion time of trials as the subjects became more accustomed to the task and the techniques. We hypothesized that over the course of four experiment sessions, the symmetric technique would emerge as the most efficient, as users became accustomed to the cursors flipping. The results across all trials are summarized in the second and third columns of Table 3.

Technique	All Trials		Small Rotation Trials		Large Rotation Trials	
	Mean	StdDev	Mean	StdDev	Mean	StdDev
Mouse	4.08	3.15	4.04	3.50	4.15	2.54
Mouse + key	3.91	2.70	3.77	2.64	4.13	2.77
Asymmetric	4.10	3.03	4.14	3.16	4.06	2.82
Symmetric	3.61	2.46	3.13	1.72	4.34	3.14
ANOVA F-ratio for Mean	12.2, $p_{3, 3792} \leq 0.0001$		29.53, $p_{3, 2272} \leq 0.0001$		1.33, $p_{3, 1512} \leq 0.0001$	

TABLE 3: Experiment 2, 2 hours of exposure to task and techniques. Results (in seconds) over all trials, trials with small rotations, and trials with large rotations

The results in Table 3 show that the total completion times for the task using the symmetric technique improve dramatically over only a few sessions. The total completion time also improved significantly for the dual mouse asymmetric technique, indicating that dual mouse interfaces require some learning. However, the symmetric technique is faster than the asymmetric technique in both experiments and this seems natural given the symmetric nature of the task. The completion time improvement for the symmetric technique was evident for both the trials with small rotations and the trials where the rotation was large enough to cause the cursors to flip (see Table 3). The difference in performance for the four techniques is significant for small rotations and is not significant for large rotations. It seems

likely that subjects' ability to deal with the crossed cursors is due to the linkage of the cursors to an object, which the users understand to be flipped over. However, this is an area that needs more detailed examination.

4.0 CONCLUSIONS

Our experiments demonstrate that the symmetric dual-mouse technique is faster than both the asymmetric and single-mouse techniques for simultaneous rotation and translation of objects, after some training. Users are able to perform the symmetric task with great speed for rotations of less than 90, faster than with any of the other techniques tested. Although users experienced some initial difficulty using the symmetric technique for trials requiring larger rotations, due to the flipping of the cursors, the follow-up experiments showed that this difficulty disappeared quickly with repeated exposure. After approximately 2 hours of use, the symmetric technique was the faster of the four techniques overall. These promising results lead us to believe that two-handed symmetric interaction techniques, which combine other types of transformations, are good avenues for exploration. In general, the addition of two degrees of freedom may allow combinations of actions which mitigate the need for expensive mode-switches.

5.0 ACKNOWLEDGEMENTS

We would also like to acknowledge the support of members of the Computer Graphics Lab, especially Erin Lester, Stefanus DuToit, Kevin Moule and Robert Kroeger.

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