See-through Window vs. Magic Mirror: A Comparison in Supporting Visual-Motor Tasks

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ABSTRACT

There are two alternative display metaphors for Augmented Reality (AR) screens: a see-through window or a magic mirror. Commonly used by task-support AR applications, the see-through display has not been compared with the mirror display in terms of user's task performance, even though the "mirror" hardware is more accessible to general users. We conducted a novel experiment to compare participants' performance when following object rotation cues with the two display metaphors. Results show that participants' overall performance under the mirror view was comparable to the see-through view, which indicates that the augmented mirror display may be a promising alternative to the window display for AR applications which guide moderately complex three-dimensional manipulations with physical objects.

Keywords: Augmented Reality, display metaphor, visual-motor.

Index Terms: H.5.1 Multimedia Information Systems

1 INTRODUCTION

See-through window and magic mirror are the two major display metaphors among AR applications. The setup of a see-through window follows the spatial relationship of eyes-screen-workspace, with the camera pointed in the direction of the user's gaze. The magic mirror is implemented as eyes-workspace-screen, with the camera pointed towards the user. Displays applying the former metaphor include head-mounted display (HMD), heads-up display (HUD) and handheld display; while the latter mainly includes desktop monitor and large projection display.

Task-support AR applications, such as maintenance and assembly, mainly apply the see-through window metaphor. Most AR applications with the magic mirror metaphor are designed for enhancing traditional mirror usage, such as an augmented makeup mirror [1]. We argue that the magic mirror can be used as an alternative display metaphor for task-support applications since see-through devices are too expensive to own, and handheld devices are not ideal to support bimanual manipulation tasks.

Mirror reversal is one of the major concerns to cause inferior performance under a mirror view. To investigate to what extent this negative effect exists, we conducted an experiment to compare users' visual-motor performance when following virtual cues in both a mirror and see-through view. These cues relate to rotating of a tangible object held in the hands, which requires relatively high level of eye-hand coordination.

2 RELATED WORK

Savardi et al. [4] conducted experiments on people's naive predictions regarding the movement of an object observed from the mirror, and found participants believed reflections move the same way when they see movements parallel to the mirror, but the opposite when orthogonal. Jeon et al. [2] compared users' performance in matching a virtual teapot registered on a 2D marker to a target virtual teapot, under three different camera viewpoints (on the user's head, behind the user, in front of the user). Although results showed that users spent the longest time to finish the task when the camera is fixed in front of them, it cannot inform our research question due to distinguished differences in task (match shape vs. follow action cue), apparatus (eye-workspace-screen vs. eye-screen-workspace) and frame of reference (table vs. body).

3 METHOD

We conducted a within-subject experiment to compare the speed and accuracy of a user manipulating a simplified Rubik's cube (2x2x2) while following augmented guidance under two viewing conditions: mirror and see-through. Figure 1 shows what the participant sees from the display under each condition:

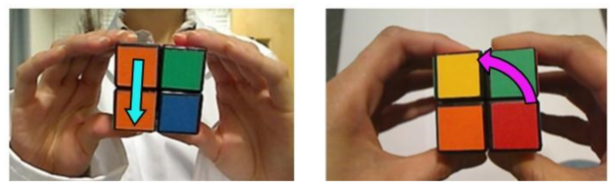

Figure 1: Augmented mirror view (left) and see-through view (right)

There are two null hypotheses for the experiment:

H_{0A}: There is no significant difference between the mirror and see-through views in the speed of following rotation instructions.

H_{0B}: There is no significant difference between the mirror and see-through views in the accuracy of following rotation instructions.

3.1 System Implementation

The system detects the state of the Rubik's cube by applying a sequence of filters to recognize the four squares of its front face. HIS color space [3] and K-nearest neighbor classifier are applied to identify the six different colors of the Rubik's cube. The pattern recognition is implemented based on OpenCV2.0. The system generates a sequence of random rotations with equal occurrence frequency. Once the pattern of the expected face is detected by the camera, the system superimposes the next rotation arrow and calculates the next expected face pattern. This process repeats until the last rotation in the sequence is detected.

3.2 Experiment Design

The experiment consisted of two sessions: mirror and see-through. The order is counterbalanced across participants. In each session the participant completed three tasks. Each task required the participant to manipulate the Rubik's Cube by following a sequence of visual cues as quickly and as accurately as possible. There were sixteen possible rotation cues (Figure 2). We measured the response time individually for each rotation. This was calculated by the time interval between the appearance of a new visual cue and its next cue after the system detected that the

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expected rotation had been completed. We counted user errors by reviewing the video recording of the screen. Participants were informed that they need to keep their fingers out from between the camera and the front face of the cube after each rotation. After the experiment, we asked the participant to rate the system in terms of ease of following the instructions, confidence and comfort in a five-level Likert scale and which condition of the system is more natural to use.

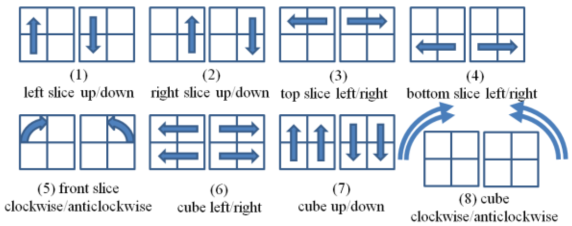

Figure 2: Sixteen different rotation cues

3.3 Apparatus and Procedure

The system is composed of a desktop PC (Intel Pentium CPU 3.20GHz, 6.00 GB RAM), an 8-inch VGA monitor (LILLINPUT 809GL-80NP/C/T with 4:3 aspect ratio) and a Logitech Webcam Pro 9000 (30 frames per second video). The setup for the mirror view and what the participant sees from the monitor are shown in Figure 3(a). During the experiment, the participant holds the Rubik's Cube in front of him or her with the front face of the cube facing directly at the webcam. The setup for the see-through view and what the participants see from the monitor is shown in Figure 3(b). The participant holds the Rubik's Cube behind the monitor. The height of the chair that the participant sits on is 47cm. The distance between the bottom of the screen and the ground is 80cm. The screen is angled at 25 degrees above the horizontal in both conditions.

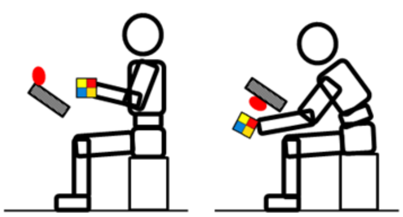

Figure 3: Setup of mirror view (left) and see-through view (right)

The experiment contains seven steps: the experimenter 1) demonstrates the system with the first viewing condition; the participant 2) practices a trial task multiple times as needed; 3) finishes three formal tasks; 4) takes a 15 minute break to avoid fatigue; 5) repeats steps 1-3 with the second view; 6) completes a questionnaire; 7) and follow-up interviews.

4 Result

Fifteen participants (8 male and 7 female, aged between 15 and 55 years old) recruited from the university and the local area via online advertisement took part in the experiment.

4.1 Speed and Error

Figure 4(a) shows the rotation speed under the two viewing conditions. The mean value under the mirror view (2674 ms) is slightly longer than the one under the see-through view (2459 ms). However a paired *t*-test was conducted and the result did not show a significant difference between mirror and see-through views across the participants: $t\,(14) = 1.4$, $p = 0.183 > 0.05$.

On the other hand, the mean number of errors made under the mirror view (2.53) is smaller than the see-through view (3.47). The boxplot shown in Figure 4(b) reveals that the median of the mirror view (2.00) is bigger than the median of the see-through view (1.00). The latter sample, however, is more dispersed and has multiple outliers when the participants made significantly more errors. A nonparametric Wilcoxon Paired Signed Ranks Test was conducted since neither of the samples was normally distributed. We did not find a significant difference between the two views in the number of errors: $z = -1.06$, $p = 0.916 > 0.05$.

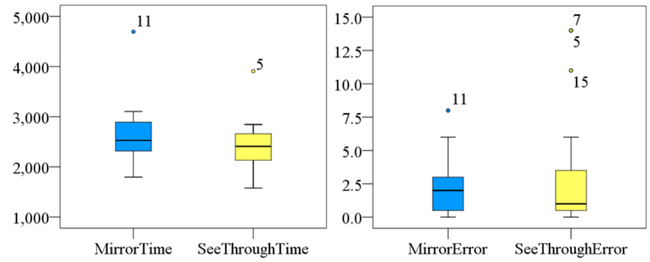

Figure 4: Boxplot of time per rotation (left) and number of errors (right) under the two viewing conditions.

4.2 Subjective Results

13 out of 15 participants preferred the first view they experienced. The remaining two both started with the mirror view. One had no preference. The other explained in the follow-up interview that he had previous experience with commercial AR games using a see-through metaphor. In addition, we asked participants to rate the degree of ease of following instructions, confidence and comfort of both viewing conditions and results show that there is no significant difference in any of the above user experiences.

5 Conclusion

We conducted a novel comparison of user performance in a visual-motor task between AR displays with the magic mirror and see-through window metaphors. The results reject neither null hypothesis, which suggests that users' overall performance under the mirror view is comparable to the see-through view, despite the fact that this would appear less likely to be intuitive under mirror reversal. To state our findings conservatively, although there may be an effect that would be detectable with a larger experimental sample, our results indicate that the size of such an effect, if present, is only small. In addition, we found that it is easy for the majority of users to adapt to the first viewing condition of an AR system to which they are introduced regardless of whether it is a mirror or see-through view. In view of the results above, the AR mirror seems a bimanual-friendly and economical alternative for task-support applications, especially when using a mobile handheld hinders bimanual activities and HMDs remain expensive and intrusive for consumer users.

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