6 Degrees-of-Freedom Manipulation with a Transparent, Tangible Object in World-Fixed Virtual Reality Displays

David J. Zielinski*
Duke Immersive Virtual Environment
Duke University, USA

Derek Nankivil †
Department of Biomedical Engineering
Duke University, USA
Johnson & Johnson Vision Care Inc.

Regis Kopper‡
Department of Mechanical Engineering
and Materials Science
Duke University, USA

Abstract

We propose *Specimen Box*, an interaction technique that allows world-fixed display (such as CAVEs) users to naturally hold a plausible physical object while manipulating virtual content inside it. This virtual content is rendered based on the tracked position of the box. Specimen Box provides the weight and tactile feel of an actual object and does not occlude rendered objects in the scene. The end result is that the user sees the virtual content as if it exists inside the clear physical box. We conducted a user study which involved a cognitively loaded inspection task requiring extensive manipulation of the box. We compared Specimen Box to Grab-and-Twirl, a naturalistic bimanual manipulation technique that closely mimics the mechanics of our proposed technique. Results show that performance was significantly faster with Specimen Box. Further, performance of the control technique was positively affected by experience with Specimen Box.

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities

1 Introduction

Even though user-fixed displays (e.g., head-mounted displays) offer convenient advantages such as mobility and affordability, world-fixed displays (e.g., CAVE-type displays) show advantages which invite further research on usable and efficient interaction techniques. Researchers have found that CAVEs lead to increased presence and reduced simulator sickness [4] when compared to HMDs. Further, world-fixed displays utilizing DLP projectors are able to offer very high frame rates which are not foreseeable for user-fixed displays. Auto stereo world-fixed displays also may offer unencumbered operation. Collectively, world-fixed displays present a number of potential benefits that should be explored through new techniques. We propose Specimen Box [5], a world-fixed display technique for tangible manipulation of virtual objects.

Specimen Box embodies an object manipulation technique, in a 26cm clear acrylic box, where users can pickup, touch and feel the box, but can't quite physically reach its contents (figure 1). By using this interaction metaphor, Specimen Box affords natural manipulation, while maintaining plausibility of the inner object, through consistent tracking and realism of its perspective rendering.

*e-mail:djzielin@duke.edu
†e-mail:dnankivi@its.jnj.com – This work was carried out entirely at Duke University without consult or influence by Johnson & Johnson Vision Care Inc. As of June 2016, Derek Nankivil is employed by Johnson & Johnson Vision Care Inc.
‡e-mail:regis.kopper@duke.edu

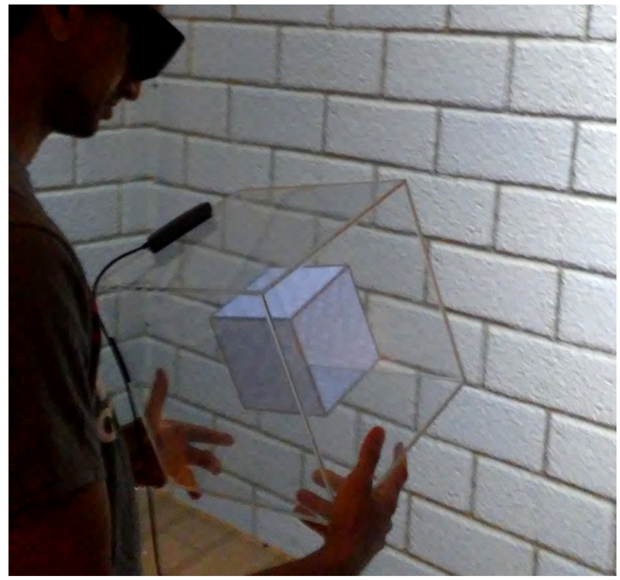

Figure 1: A user utilizing the proposed Specimen Box interaction technique

2 Related Work

Passive haptics, or tangible interfaces, offer a compelling way to increase user experience beyond indirect input through game controllers and wands. Studies conducted by Insko [3] used a VR pit simulator with passive haptics cues by raising up a walkway off the floor slightly so that the edge of the walkway could be sensed by users. This passive haptics ledge led to a significant increase in heart rate and skin conductivity responses.

Researchers have realized that tangible objects may be employed in world-fixed displays. Early work by Encarnação et al. on the "Translucent Sketchpad" [2] utilized the idea that the user could hold a clear prop (in their case the sketchpad) for the user to write and interact on. By co-locating the rendered image (from their VR workbench / single wall setup) the user was able to virtually write on the sketch pad. While the use of a transparent prop is similar to our technique, "Translucent Sketchpad" pursues a pen and paper metaphor for interaction, while we pursue a 2 handed box grabbing metaphor.

3 User Study

In order to evaluate the Specimen Box interaction technique, we conducted a user study. Our goal was to understand the differences between Specimen Box and a virtual object manipulation technique that closely mimicked the biomechanics of Specimen Box. We decided to compare our technique to Cutler et al's Grab-and-Twirl method [1]. This method closely matches how users handle objects in the real world.

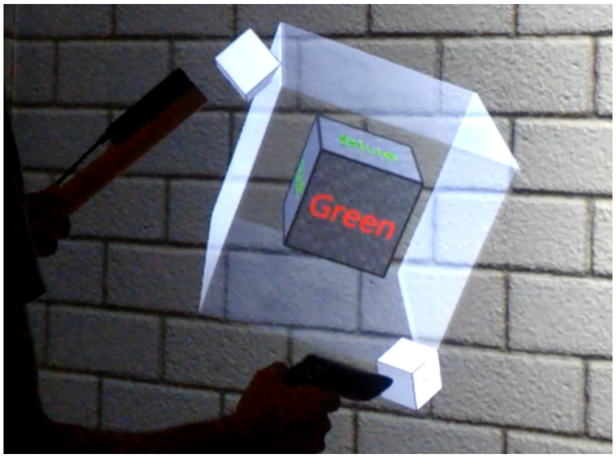

Figure 2: Example of user performing an inspection task with the Grab-and-Twirl manipulation technique. Note that a virtual acrylic box is rendered.

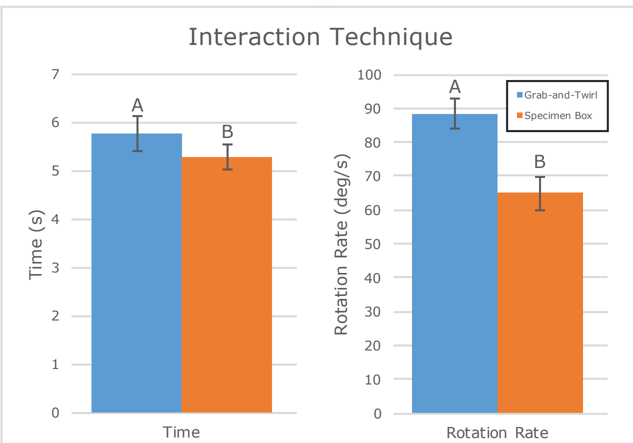

Figure 3: Time and rotation rate for each interaction technique.

We used a six-sided CAVE-type system to perform the experiment. We created a face counting task inspired on the "Stroop Effect". The Stroop effect is created when there is a mismatch (incongruency) between the text and the of color of the ink (see figure 2. The study design had three within-subjects independent variables – interaction technique (IT–Specimen Box–SB, Grab-and-Twirl–GT), difficulty level (congruent, congruent+distractors, incongruent) and trial number (12). The study used 20 participants.

4 Results

Time for task completion was significantly lower with SB ($\mu_{SB} = 5.28$, $\mu_{GT} = 5.77$, $F_{1,18} = 5.53, p < .05$) and rotation rate was significantly lower with SB ($\mu_{SB} = 64.79$, $\mu_{GT} = 88.34$, $F_{1,18} = 22.16, p < .0001$) (figure 3). Although there was no main effect of ordering, there was a significant interaction of ordering and IT for time ($F_{1,18} = 16.177, p < .005$) (figure 4). Pairwise comparisons show that when GT was performed first, it took significantly more time than SB ($p < .0001$). However, there were no significant differences between GT and SB when SB was performed first ($p = .253$). Fourteen participants (70%) preferred GT over SB. Additionally 14 subjects commented that the box was too heavy.

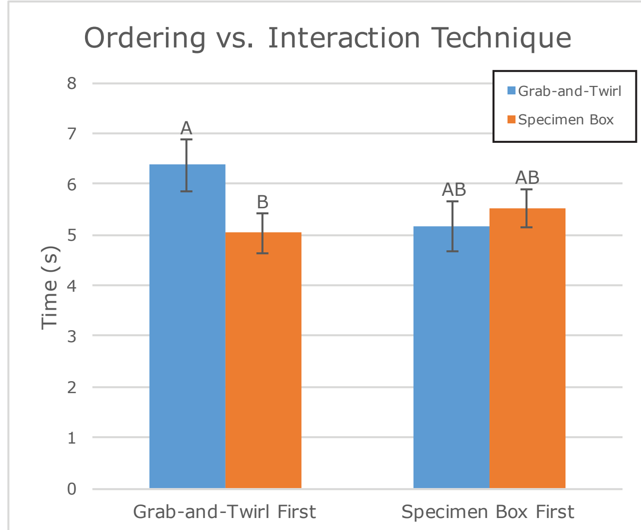

Figure 4: Interaction effect of ordering with interaction technique for time.

5 Discussion

The Specimen Box technique was significantly faster than Grab-and-Twirl for our specific task. The tactile nature of Specimen Box may have provided positional accuracy, so that the user would not overshoot or have to redo intended operations. Another hypothesis is that the tactile nature of the box allowed the user to intuitively (perhaps through proprioception), know what face of the inner target box they were looking at. The interaction between ordering and IT may indicate that performing the tasks initially with a more natural technique caused participants to improve their performance with the less intuitive Grab-and-Twirl.

6 Conclusion and Future Work

Specimen Box opens up exciting future possibilities for bringing a tangible interface into reach for those utilizing world-fixed display systems. While possessing limitations such as box weight, visual distortions (from refraction), and reflection on the box walls, our results showed that the Specimen Box technique allowed user's to achieve better performance in a cognitively loaded task compared to an existing bi-manual technique (Grab-and-Twirl).

While the goal of this work was the description and initial evaluation of a new technique, it should ideally be considered against the broad array of interaction techniques available to users of world-fixed VR displays. Specifically the Specimen Box technique should be compared to the virtual hand interaction technique.

References

[1] L. D. Cutler, B. Fröhlich, and P. Hanrahan. Two-handed direct manipulation on the responsive workbench. In *Proceedings of the 1997 symposium on Interactive 3D graphics*, pages 107–114. ACM, 1997.

[2] L. Encarnação, O. Bimber, D. Schmalstieg, and S. Chandler. A translucent sketchpad for the virtual table exploring motion-based gesture recognition. In *Computer Graphics Forum*, volume 18, pages 277–286. Wiley Online Library, 1999.

[3] B. E. Insko. *Passive haptics significantly enhances virtual environments*. PhD thesis, University of North Carolina at Chapel Hill, 2001.

[4] K. Kim, M. Z. Rosenthal, D. J. Zielinski, and R. Brady. Effects of virtual environment platforms on emotional responses. *Computer methods and programs in biomedicine*, 113(3):882–893, 2014.

[5] D. J. Zielinski, D. Nankivil, and R. Kopper. Specimen box: A tangible interaction technique for world-fixed virtual reality displays. In *2017 IEEE Symposium on 3D User Interfaces (3DUI)*. IEEE, 2017.