Validating Spatial Augmented Reality for Interactive Rapid Prototyping

Shane R. Porter* Michael R. Marner† Ross T. Smith‡ Joanne E. Zucco§ Bruce H. Thomas¶

University of South Australia
Wearable Computer Laboratory

ABSTRACT

This paper investigates the use of Spatial Augmented Reality in the prototyping of new human-machine interfaces, such as control panels or car dashboards. The prototyping system uses projectors to present the visual appearance of controls onto a mock-up of a product. Finger tracking is employed to allow real-time interactions with the controls. This technology can be used to quickly and inexpensively create and evaluate interface prototypes for devices. In the past, evaluating a prototype involved constructing a physical model of the device with working components such as buttons. We have conducted a user study to compare these two methods of prototyping and to validate the use of spatial augmented reality for rapid iterative interface prototyping. Participants of the study were required to press pairs of buttons in sequence and interaction times were measured. The results indicate that while slower, users can interact naturally with projected control panels.

Keywords: Spatial Augmented Reality, Rapid Prototyping, Industrial Design.

Index Terms: H.5.2 [Information Interfaces and Presentation]: Graphical User Interfaces—Input Devices and Strategies; I.3.6 [Computer Graphics]: Methodology and Techniques—Interaction Techniques

1 INTRODUCTION

This paper investigates the use of Spatial Augmented Reality (SAR) for interactive rapid prototyping. SAR allows us to augment physical objects with projected images in order to change their appearance. This technology can be applied to the industrial design domain, where the visual appearance for a prototype can be projected directly onto a simplified physical model of the design.

Our goal is to use this prototyping technology within a design process such as Pugh's Total Design methodology [3]. This methodology consists of six iterative stages: market (user need), product design specification, conceptual design, detail design, manufacture, and sales. We are interested in the detail design stage where decisions are made about the functionality of the prototype. In the past, this involved installing components such as buttons or dials on the prototype to test their placement and functionality. If something needed to be changed with the design, a new functional prototype was developed and evaluated. Our research explores improving this process by using SAR for interactive rapid prototyping.

We have developed a SAR system that is used to make prototypes with interactive virtual components. We track the position of the user's finger which allows us to determine when they are interacting with the components (as shown in Figure 1). We have performed an evaluation that compares this method of interacting with virtual components to interacting with physical components. Participants performed a simple button pressing task with several low-fidelity prototypes which include a box, a car dashboard and a dome. The evaluation has provided quantitative and qualitative data that supports our vision of using SAR for interactive rapid prototyping.

*e-mail:shane.porter@unisa.edu.au
†e-mail:marnermr@cs.unisa.edu.au
‡e-mail:ross@r-smith.net
§e-mail:joanne.zucco@unisa.edu.au
¶e-mail:bruce.thomas@unisa.edu.au

2 BACKGROUND

Augmented reality (AR) has been used in the design process by various industries. The automotive industry has used AR for evaluating the design of a car interior [6]. Regenbrecht et al. [5] has outlined several other uses for the automotive and aerospace industries such as training, assistance during a job, maintenance and design. SAR has also been used in the design process. Augmented Foam Sculpting [2] allows a designer to create virtual 3D models by sculpting foam prototypes. SAR is used to project visualizations onto the foam to aid the designer. WARP [7] also uses SAR to allow designers to experiment with different material properties for a design prototype.

Most of the SAR research is inspired by Shader Lamps [4], which uses calibrated projectors to augment physical objects with projected images in order to change their appearance. Shader Lamps has been extended to support digitally painting onto a physical object with Interactive Shader Lamps [1]. Our SAR technology uses these concepts for our interactive rapid prototyping system.

3 EVALUATION

We constructed physical prototypes and matching SAR versions and compared the results of a task. The task was to press buttons on each of the prototypes. The experiment was a 2 x 3 repeated-measures design. The independent variables examined were interaction method (physical and virtual) and device (box, dashboard

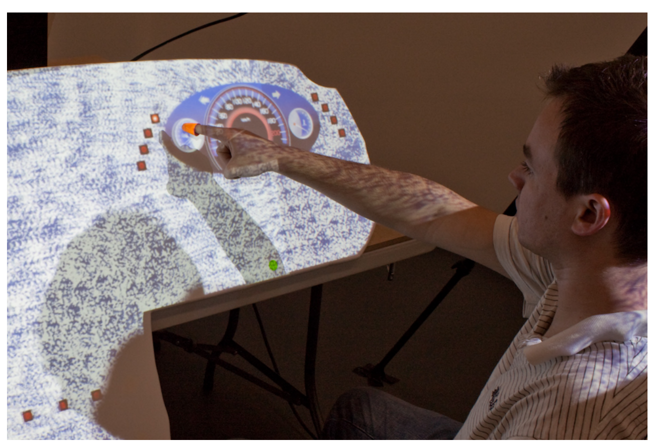

Figure 1: A user interacts with a virtual control panel. The panel is painted white, with the visual appearance and interactive functionality provided by the SAR system.

and dome). The dependent measures were task and button press time.

Results were gathered from 24 participants comprised of students and staff at the University of South Australia and the general public. Of the participants, there were 19 males and 5 females; 2 left handed and 22 right handed; mean age 26.83 years (SD 7.60).

Three control panel designs were developed for the evaluation: a button box, a simplified car dashboard, and a dome. Each control panel contained 16 buttons. For each design, a version with physical buttons and embedded electronics was built, and a matching SAR version was created. Participants wore an orange thimble on their index finger that was tracked to detect button presses for the SAR conditions. The physical prototypes used pushbuttons with embedded LEDs.

A press of a virtual button was detected when a user moved their finger within a certain distance of the virtual button's position. To avoid accidental button presses, a de-bouncing algorithm was used. The software needed to detect five collisions with a button for it to be pressed. This caused a delay of 0.16 seconds while each button press was detected. The position of the tracked finger could also be lost if it moved too fast due to the frame rate of the cameras.

The evaluation consisted of six conditions, one for each control panel. The procedure for each condition was identical and consisted of the participant pressing a flashing button and then an illuminated button; this was repeated 32 times with a two second break between each button pair. The order of control panels was randomized for each participant to compensate for any learning effects. All participants received the same button pairs, but in a different order. Data collection at each control panel took approximately 3 minutes.

The time between button presses was recorded for each button pair, as was the total time taken to complete each condition. The operation of each condition was automated by a control program. Following the session, participants completed a questionnaire asking about their experience operating each of the prototypes.

4 Results

4.1 Quantitative Results

The total task time was recorded from the first button press and finished on the last. This time included a two second delay between each pair of buttons. The mean total time across all six conditions was 152.04s (SD 38.41). The physical control panels had a mean total time of 121.33s (SD 11.60), while the virtual control panels had a mean total time of 182.74s (SD 30.41).

Using Analysis of Variance (ANOVA) we determined there was a significant effect of interaction method on total task time, $F(1,23) = 234.65$, $p < 0.05$. The results showed that total task time was not significantly affected by device, $F(2,46) = 2.26$, $p > 0.05$. There was no significant interaction effect between interaction method and device on total task time, $F(2,46) = 3.12$, $p > 0.05$.

The time between button presses was recorded for each button pair. The mean button pair time across all control panel configurations was 0.94 seconds (SD 0.47). For physical control panel configurations, the mean button pair time was 0.53 seconds (SD 0.11). The mean button pair time for virtual control panel configurations was 1.35 seconds (SD 0.31).

Using ANOVA we also determined there was a significant effect of interaction method on mean button pair time, $F(1,21) = 263.49$, $p < 0.05$. The results showed that mean button pair time was not significantly affected by device, $F(2,42) = 0.42$, $p > 0.05$. There was no significant interaction effect between interaction method and device on mean button pair time, $F(2,42) = 2.97$, $p > 0.05$.

4.2 Qualitative Results

The user study participants were asked several questions to gauge their experience when interacting with the prototypes. Responses for each question were on a 5 point Likert scale. Four of the questions were asked for all of the devices, and an additional three questions were asked only for the virtual devices. A final question asked if our system would be useful for interactive rapid prototyping.

The participants indicated that in all six conditions it was easy to identify the buttons, tell which button needed to be pressed, and that the lighting conditions were satisfactory. As supported by quantitative data, the participants felt the physical devices were quick to detect which buttons were pressed.

About two thirds of the participants felt the passive haptics were sufficient for the tasks required of them, and around one third reported that not having a physical button affected their interactions. Most participants indicated that the shadows caused by the projectors did not adversely affect their actions. In addition, many participants felt that SAR provided a good visual representation of each physical device.

Twenty one participants agreed (a score of 4 or 5) that this technology would be useful as a design tool in question 8. There were no professional designers in the group of participants, but we see this response as an indication of support for using SAR technology in the interactive rapid prototyping process.

5 Discussion

The results show that interactions with virtual buttons are slower compared to prototypes with physical buttons. However, since the system is still usable, we feel that this small difference is acceptable. The questionnaire showed that the users were able to understand what they were trying to interact with and the quantitative results showed that they could interact with the virtual buttons in a timely manner. The virtual components are interactive, which means that they can be reconfigured into different arrangements by a designer. In addition, the design of the prototype can be evaluated for usability, functionality, and appearance since users are able to understand what they are interacting with.

We have presented a method of using SAR in the design process for re-configurable interactive rapid prototyping. The SAR system allows designers to place virtual components onto a physical prototype for evaluating the design. The technique for interacting with these virtual components has been evaluated. The performance of the virtual controls is currently slower compared to the physical controls. However, the system is still interactive and users are able to understand what they are trying to interact with. This shows that our SAR system can be used for interactive rapid prototyping.

References

[1] D. Bandyopadhyay, R. Raskar, and H. Fuchs. Dynamic shader lamps: Painting on movable objects. In *IEEE and ACM International Symposium on Mixed and Augmented Reality*, pages 207–216, 2001.

[2] M. R. Marner and B. H. Thomas. Augmented foam sculpting for capturing 3D models. In *IEEE Symposium on 3D User Interfaces*, Waltham Massachusetts, USA, 2010.

[3] S. Pugh. *Total Design: integrated methods for successful product engineering*. Addison-Wesley, 1991.

[4] R. Raskar, G. Welch, K. Low, and D. Bandyopadhyay. Shader lamps: Animating real objects with Image-Based illumination. In *Rendering Techniques 2001: Proceedings of the Eurographics*, pages 89–102, 2001.

[5] H. Regenbrecht, G. Baratoff, and W. Wilke. Augmented reality projects in automotive and aerospace industry. *IEEE Computer Graphics and Applications*, 25(6):48–56, 2005.

[6] H. Salzmann and B. Froehlich. The two-user seating buck: Enabling face-to-face discusssions of novel car interface concepts. In *Proceedings of the IEEE Conference on Virtual Reality*, pages 8–12, 2008.

[7] J. Verlinden, A. de Smit, A. Peeters, and M. van Gelderen. Development of a flexible augmented prototyping system. *Journal of WSCG*, 2003.