INTERNATIONAL DESIGN CONFERENCE - DESIGN 2004
Dubrovnik, May 18 - 21, 2004.

QUALITATIVE COMPARISON OF VIRTUAL AND AUGMENTED PROTOTYPING OF HANDHELD PRODUCTS

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Keywords: augmented reality, design support, interactive concept testing, prototyping

1. Introduction

In recent years, powerful computer aided design engineering tools have been introduced to realize so-called Virtual Prototypes: digital displays of the product in a simulated environment, offering various evaluation and modification means. However, virtual prototyping of physical products will not always produce a representative experience. For example, Kuuti et al. [2001] describe the limitations of concept testing with a screen-based 3D browser: 1) product is not shown in its intended context but floating in the air, 2) users easily get lost in 3D space (navigation), 3) the sense of scale and the ability to test physical ergonomics is difficult yet impossible. Similar shortcomings can be found in Bochenek et al. [2001], in which the performance of four different VR displays – head mounted displays, Fake Space Boom, stereoscopic screen, and monoscopic 2D screen based VR - is compared in a design review setting. Often, the monoscopic monitor-based systems performed best and were preferred by the subjects. Furthermore, it was observed that the overwhelming technology introduced a positive bias towards judging the actual design

The concept of Augmented Prototyping combines Rapid Prototyping techniques to obtain 3D physical objects (e.g. Stereolithography, CNC milling), with Augmented Reality systems [Verlinden et al., 2003a]. The aim is to establish a high sense of engagement in the design process, supporting both exploration and presentation. We have documented some successful explorations with the shader lamps technique [Raskar and Low, 2001], spanning from the design of cars [Verlinden et al., 2003a] to interiors [Verlinden et al., 2004] and handheld devices[Verlinden et al., 2003b]. With this technique, 3D perspective images are projected directly on the object. The mapping of virtual 3D object and projected image depends on the viewer's location, shape of the physical object/screen, and the projector parameters. If there is a direct correspondence between virtual object and physical surface, the projector can be treated as the inverse of a pinhole camera. This reduces the complexity of the pre-distortion to a simple projection matrix. In that case, standard 3D rendering systems can be employed.

A software architecture was devised labelled WARP (Workbench for Augmented Rapid Prototyping), see Figure 1. Previous systems based on this architecture allows the projection of several details, materials, and colours on physical models; different 2D and 3D locatio5n tracking devices were employed to interact with the prototype. In considering the case studies and prior research systems, four different design support types for augmented prototyping have been identified: 1) component layout, 2) material and colour selection, 3) interaction prototyping, and 4) engineering simulation. Although we hypothesize that augmented prototyping has a large potential within the field of industrial design, a number of issues remain uncovered. Main concern is determining the added value of such prototyping means.

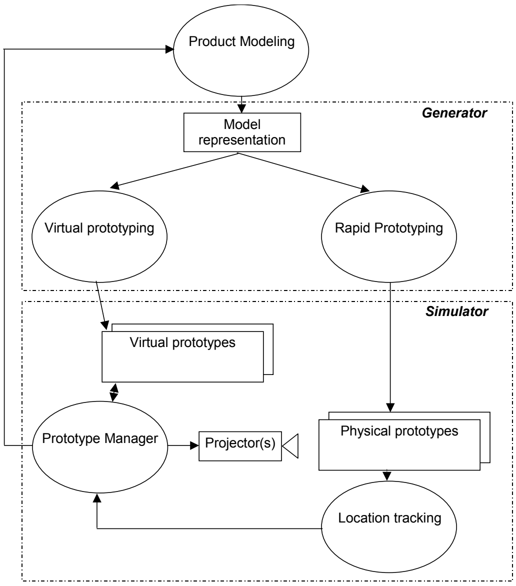

Figure 1. WARP simulation architecture

We assume that, apart from manufacturing time and costs, the sense of engagement represents a strong indicator of this added value. Yet it is not entirely clear how this can be measured objectively. Bochenek et al. [2001] provides an interesting assessment of prototyping means during Design Reviews, using metrics as the number of design errors found, the time to track errors down, and the time to create solutions for these. A similar approach is used in this article to compare the performance of virtual and augmented prototyping. This is done by a design review experiment of a handheld voice recorder.

2. Voice recorder prototypes

To explore the opportunities of evaluating interactive behaviour with augmented prototyping, we developed a prototype of a simple voice recorder. This product type represents a growing collection of mobile products that include a screen and buttons; in their development, prototypes play an important role in optimizing both physical and cognitive ergonomic aspects. The handheld device had rather large dimensions (11 x 7 x 2 cm), and contained speaker, microphone, power switch, and a small screen at the front. On the right side were three buttons for control. It only offered a limited set of functions: recording, playing, navigating, and removing spoken messages.

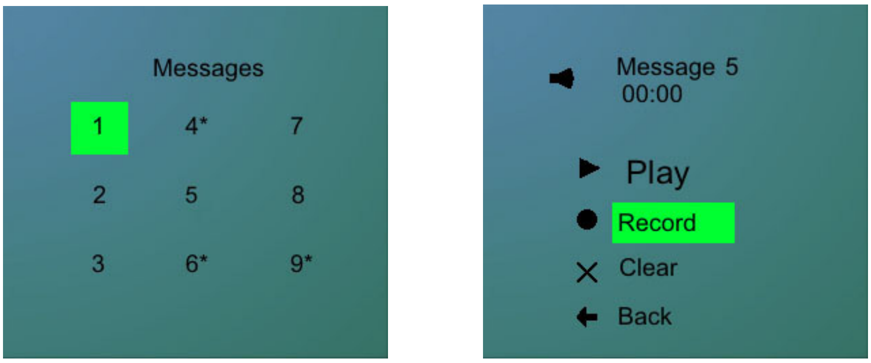

Figure 2. screens of the voice recorder: main menu (left) and submenu (right)

The operation of the recorder was divided on two screens (Figure 2): a main menu displays nine message slots, which can be empty or filled (the latter indicated by an asterisk). When a message slot was selected, a message submenu offered playing/recording/clearing the message. Some annoyances were introduced, as a filled message slot should have been cleared before another message could be recorded. Furthermore, the submenu offered no possibility to navigate directly to a previous/next message.

For the Augmented Prototyping setup, a wooden model was made by hand and mounted on top of a Microscribe 3D tracker (see Figure 3). This tracking technology offers fast and accurate tracking. The software part of the interface was built in Open Inventor. It basically renders a single texture mapped polygon (representing the product's screen) and updates its position and orientation based on the tracker. Separate screenshots were produced for the most probable situations – which resulted in over 40 gif files (of the >100 combinations). A state-machine was implemented to manage these throughout the dialogue. This module was also responsible for playing the pre-recorded audio messages (actual recording of sound was not supported and was faked during the tests). The buttons on the physical mock-up were simulated; a Wizard of Oz setup was used, in which an observer monitored the actions of a user and updated the state machine accordingly. To guarantee correct illumination among the complete action radius of the Microscribe, the projector was located at a 2 meters distance. This resulted in a low resolution of the bitmapped polygon (200x200 pixels at most).

As a reference condition, a traditional 2D version was created with Macromedia Director. This presents front and side views, and the user could interact by clicking on the buttons on the side view and the red button on the front view.

Figure 3. Voice recorder system (left) and projection (middle) and 2D screen model (right)

3. Assessment method: design review experiment

In the product assessment sessions, the subjects were given a short introduction and then a number of assignments that they had to perform. Included were the following tasks: searching for particular messages, recording new ones, and having to cope with memory full exceptions.

Table 1. Questionnaire contents (translated from Dutch)

Q1	Can you hold the voice recorder comfortable in your hand?
Q2	Is the control/operation of the voice recorder understandable?
Q3	Are the buttons logically placed if you would control the real product?
Q4	Can you imagine how the actual product will be like?
Q5	Is the display legible?
Q6	Do you think the prototype is a good replica of the real product?
Q7	Does the prototype offer enough information for a decision to buy the product?

As described in the previous section, the design included some user unfriendly navigation techniques. The amount of errors was monitored and timing aspects were analysed (everything was captured on video). After the assignments, a questionnaire was given, included questions concerning comfort, understandability, legibility, and significance of the prototyping method (see table 1). All responses were scored on a 5 point scale and each question also included a field to add some comments regarding that aspect. Finally, we asked the subjects to estimate the dimensions of the product.

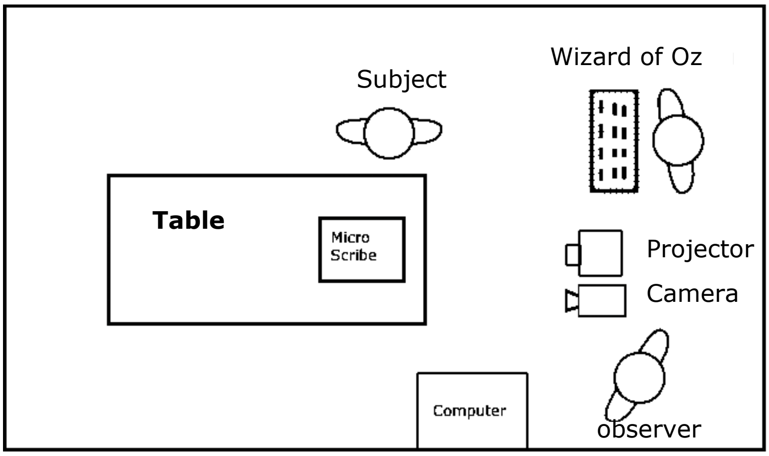

Figure 4. Snapshot of the 2D screen prototype of the voice recorder

All tests were performed in the same dimmed room. In the augmented condition, the layout was as in Figure 4, with one observer and one Wizard of Oz operator. The screen condition was accomplished in a regular PC setup and two observers.

4. Results

In total, 9 subjects participated. All senior design students and staff members, five used the standard screen prototype, four the augmented setup. The time to finish the assignments didn't differ much among the test group (all around 9 minutes).

The following distinctions could be made between the two conditions: with the traditional 2D screen prototypes, subjects tend to click on product's display instead of the buttons (as if it had a touch screen), this happened only once with the augmented prototype. Furthermore, two of the five remarked that the voice they hear are not their own voices (none did in the augmented condition). Of the augmented condition, the legibility was considered sufficient, but lower than the screen. In particular, asterisks in the main menu (Figure 2) were perceived less quickly.

During the sessions, many remarks were made regarding the design. Many subjects remarked that the red power button was confusing; this can also be noted as it was occasionally pushed by accident in both conditions. The unfriendly features - the illogical navigation and the inability to record a message without clearing it first - are mentioned during the task execution by 2 subjects in each condition. As for the physical ergonomics, two of the screen users remark that the design only supports right-handed people. Similar, but more detailed remarks were made by the subjects of the augmented condition, e.g. three indicated that the placements of the buttons on the side should be improved, as it was difficult to control them by thumb while holding the product in their hand. Another observation that identified a higher sense of engagement was that one subject in the augmented condition brings the physical model closer to his mouth while recording.

Unfortunately, the employment of the Microscribe tracker introduced some extra strain. It had a limited movement envelope with 5 instead of 6 degrees of freedom. Furthermore, it added weight and inertia, which did not always result in comfortable circumstances. Arm and wrest posture was sometimes tense. To establish an optimal projection, subjects were sitting on the right side of the model (see Figure 4); one person commented that sitting on the left side would have been better. Furthermore, we could perceive noticeable delays in update speed when the physical mock-up was swiftly moved or turned. Surprisingly, this was due to the latency in the LCD-based projector.

The Wizard of Oz operator sometimes had difficulties to monitor button clicks of the side panel – especially when the subjects were pressing the buttons rapidly. Another limitation was introduced by the fact that not all screen textures were made, which meant that the subjects could not freely interact with the augmented prototype, but were limited to the dialogue sequences of the assignments.

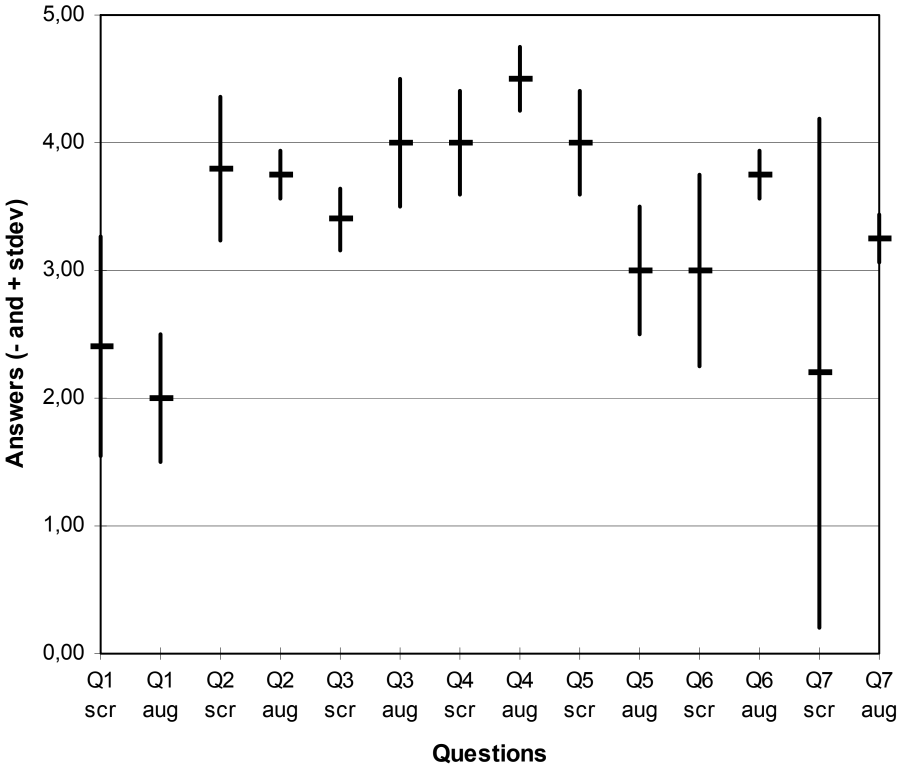

Figure 5. Questionnaire results (scr=screen, aug=augmented)

In regarding the results from the questionnaire, subjects of the augmented condition are more confident in their remarks regarding comfort (Q1). Specific remarks are given on the placement of the buttons at the side (which are hard to reach while holding the product). For understandability, both conditions get equal results (Q2), but the deviation is much smaller in the augmented condition. The same is the case for the placement of the buttons (Q3). Whether it is representative for the actual product (Q4), is valued a bit higher for the augmented condition, without a significant difference. For legibility (Q5), the traditional screen is valued better– as stated earlier, the resolution of the augmented condition is much less and it suffered considerable calibration problems, yet this didn't seem to bother the subjects. In the augmented condition, subjects were more confident that the prototype provided sufficient information to decide on purchasing the actual product (Q7). In all cases, remarks in augmented condition are more detailed and more concrete especially concerning Q1, Q2, Q5 and Q6. At question 4 (representative of the real product), remarks of the screen condition are positive while the augmented condition yields negative ones; this seemingly contradicts with the score. At question 7 (sufficient information for purchasing), more remarks are made in the screen condition - all negative. Regarding the estimations of the dimensions, no big differences could be found among the subjects. The augmented condition showed slightly less variation, yet this particular characteristic is probably more depending on the personal talent to estimate absolute sizes than on the of kind of prototype.

5. Conclusions

In the case of testing the interaction of the voice recorder, more design flaws were found in the augmented condition than with a standard 2D screen prototype. Although not statistically sound, it indicates that this augmentation method excelled in presenting both physical and cognitive aspects of interacting with the artefact.

Based on these findings, we will devise a quantitative study to find more evidence and factors that influence the sense of engagement of such prototypes. The combination of observation and questionnaires can be optimized. Physiological parameters (such as heart rate) might be also interesting to include in further testing.

Some technological problems that require further study include 1) the employment of the Microscribe tracker and body posture, 2) projector's lag time, 3) legibility of the projection on relatively small surfaces, and 4) the calibration procedure. Furthermore, tracking the interaction of the buttons posed serious challenges to the Wizard of Oz operator. Devices like Phidgets [Greenberg and Fitchett, 2001], which encompass general-purpose sensors and actuators, could be employed to support such fine-grained interactions. For example, the iStuff architecture offers a wireless phidgets that include sliders, knobs and buzzers [Ballagas et al., 2003]. The use of static bitmaps should be replaced by a more flexible solution, for example by using the continuous capturing a standard screen region. This would enable designers to use their standard 2D prototyping tools as Macromedia Director, while additional software module renders the captured screen in a 3D environment.

Acknowledgement

This research has been performed as part of the Integrated Concept Advancement (ICA) project, at the Delft University of Technology.

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