Augmented Foam: A Tangible Augmented Reality for Product Design

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Abstract

Computer Aided Design applications have become designers' inevitable tools for expressing and simulating innovative ideas and concepts. However, replacing traditional materials and mock-ups with 3D CAD systems, designers are faced with the intangibility problem, unable to physically interact with test products in early stages of design process. As a touchable and graspable interface based on 3D CAD data, we propose Augmented Foam, which applies Augmented Reality technologies to physical blue foams. Using Augmented Foam, a blue foam mock-up is overlaid with a 3D virtual object, which is rendered with the same CAD model used for mock-up production. We presented a method to correct occlusions of the virtual products by user's hand. Augmented Foam was tested for a mug design and a cleaning robot design. Designers were able to inspect and evaluate the design alternatives interactively and efficiently.

1. Introduction

Computer Aided Design (CAD) tools have been rapidly distributed since 1990's to become designers' inevitable means for expressing and simulating innovative ideas and concepts. Traditional processes are being replaced by 3D CAD systems in making thumbnail sketches, soft study models, control drawings, hard mock-ups, etc. As information unit of design tools has been transformed from "atom" to "bit", designers' performance has been greatly improved; most design tasks are now impossible without CAD tools. However, as the environment transforms from physical world to virtual world, designers are faced with emerging intangibility problems. As realistic as it can be, the rendering results on monitors cannot provide realistic tactile feelings of design models as can foam models or other physical prototypes. Furthermore, unlike 2-dimesional scale renderings and 3-dimensioal physical mock-ups, 2.5-dimensional perspective drawings have lost a cue for the perception of absolute size.

For these reasons, inexperienced designers often incorrectly estimate the results of 3D CAD design, repeating similar mistakes. To compensate for the intangibility problem of CAD system, Rapid Prototyping (RP) technologies have been developed [1]. However, RP has some limitations to be used in early stages of industrial design process. Firstly, due to requirements of expense and labor, designers cannot easily test and develop ideas through iterative design-evaluation process. Secondly, because hard materials are used for RP, design products are not easily modifiable as are form mock-ups (e.g., polystyrene foam, polyurethane foam). Thirdly, rapid prototypes are difficult to represent material properties such as colors and textures. For these reasons, most designers using 3D CAD systems experience trial and errors during the product development processes.

In this paper, we introduce Augmented Foam (AF), a tangible Augmented Reality (AR) system, for product design simulations. In AF, a blue foam mock-up is overlaid with a 3D virtual object, which is rendered with the same CAD model used for mock-up production. By hand occlusion correction, virtual products and user's hand are seamlessly synthesized. AF was tested for a mug design and a cleaning robot design. Designers were able to inspect and evaluate the design alternatives interactively and efficiently.

2. Related Research

AR technologies have been used for collaborative design applications [2-5]. In Fata Morgana project [6], designers were able to walk around a newly designed virtual car for inspection and comparisons with others.

Most AR application examples of design work developed up to present are limited to large-scale objects that the designers were not able to grasp and move. In these examples, the information provided was limited to visual information, lacking physical interactions between the observer and the object. However, in many product design processes, physical interaction and tactile information are advantageous, or even critical.

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Lee et al. used Mixed Reality platform for virtual product design [8]. The hand region was separated and inserted into Virtual Environment to enhance reality: their intention was to bring real object (user's hand) into virtual environment, while our intention is to bring virtual object (product) into the real environment. They also used a block as a physical object instead of a mock-up (design product).

Hinckley et al. utilized physical props as a passive-haptic interface in Virtual Environments [16]. However, there were spatial discrepancy between visual interface and haptic interface. Low et al. also allowed for passive-haptic interface for projector-based dioramas [17]. Projectors illuminated on the display surfaces of a synthetic room created using Styrofoam blocks.

Augmented Prototyping used the RP and AR technologies to improve product development process by combining physical and virtual prototyping [7]. Using AR, the colors and textures were overlaid on the parts produced by RP. Designers used HMD's to review the 3D CAD products provided with visual reality and tactile feedback. Among the previous work, Augmented Prototyping is most similar to AF in concepts and employed technologies. However, AF uses CNC-produced foam mock-up, which is available in the early design stages as well as for reviews. AF also resolved the visibility problem of the user's hand with the virtual products to allow for active haptic interactions between the designer and the object with corrected visibility.

3. Design Process using Augmented Foam

Augmented Foam incorporates AR technologies with widely used blue foam, which is inexpensive, easy to cut, and can be produced by CNC (Computer Numerical Control) in a short period of time. Using AF, blue foam mock-up is overlaid with a 3D virtual object, which is rendered with the same CAD model used for mock-up production (Fig. 1). The visibility problem between the virtual product and the user's hand was also solved. With corrected visibility, the proposed AF provides integrated interface of visibility and tangibility.

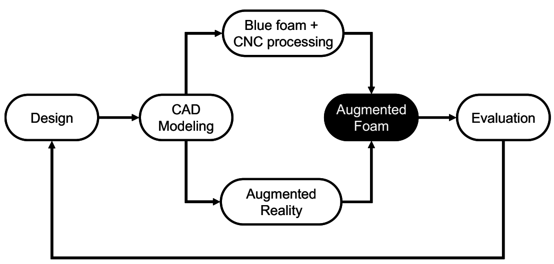

Figure 1. The Concept of Augmented Foam

3.1. Strengths of Augmented Foam

AF is differentiated from other AR instances or RP products in the following aspects.

- Haptic presence: AF allows users to grasp and touch virtual products for efficient evaluation.
- Natural visual presence: By using physical mock-ups, AF provides shadows and reflectance in the real environment.
- Easy modification: In AF, the colors and textures of the object can be easily modified, and detailed shapes can be expressed through user-interface programs.
- Interactivity: AF allows designers to interactively find optimal attributes (e.g., size and position) of detail design items such as buttons.

3.2. Mock-up Production

AF was designed to construct a physical foam mock-up from a 3D CAD data and overlay the 3D model of the same data on the mock-up. For example, a mug model was constructed using Rhinoceros 3.0 (Fig. 2 left), then converted to STL format. Foam mock-ups were produced by CNC from blue Urethane foam (Fig. 2 right). CNC-produced foam mock-ups were painted in dark blue to simplify hand-region detection. Lastly, an artificial marker was installed on the mock-up for visual tracking (Fig. 3-b1).

3.3. Tracking

Artificial visual markers were used to register virtual objects on the foam mock-up. For visual marker tracking, we used ARToolKit2.65 library [9]. For video capture and display, an IEEE 1394 web camera (iBOT) and a video see-through HMD of SVGA-resolution (I-Visor DH-4400VPD) were used respectively. CAD data of STL format (same format that was used for CNC production) was also used for virtual overlay.

3.4. Hand Visibility Correction

For hand visibility correction, hand region needs to be separated from the background. Wu et al. implemented user's finger tracking using a single camera for a virtual

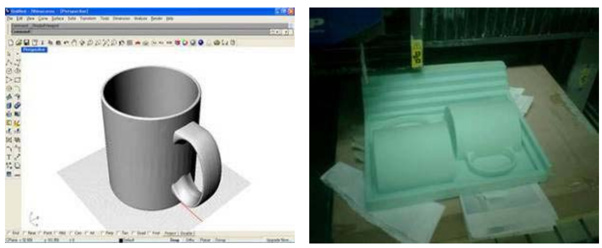

Figure 2. Process of constructing Augmented Foam: 3D CAD modeling (left) and CNC-produced foam mock-up (right)

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3D blackboard application. Skin region was detected using color predicate, which is a histogram-like structure [10]. However, the detected skin region seemed to be coarse. Malik et al. proposed a method for detecting a hand over top of the pattern to render the hand over the top of the virtual object in an AR implementation [11]. They used a simple image subtraction method, fixing the camera pose. Lee et al. used pyramid method for rendering real human hands in Virtual Environments [8].

Comparisons of RGB value combinations have demonstrated no worse results than other methods in skin region detection [13]. Wark et al. exploited that simple thresholding method with R/G ratio detected skin-like colors effectively [14]. We have tested several previous methods of skin color detection to find that the method of Peer et al. [15] had desired performance. Although it is reported that color space transformation didn't seem to make noticeable difference in skin color detection [12], illumination condition did affect on the skin region detection. In our implementation, we simplified the method of Peer et al. by removing redundant comparisons and applied dynamic thresholds instead of static thresholds to reduce the effect of illumination condition. Equations are summarized in the following.

$$if\,(r > \tau_r \wedge g > \tau_g \wedge b > \tau_b \wedge r > g + \delta_g \wedge r > g + \delta_g)$$
$$then \quad skin - region$$

where r, g, b and, τ_r, τ_g, τ_b are color values and dynamic thresholds for red, green, and blue components, and δ_g, δ_b are dynamic difference thresholds of green and blue from red color. These threshold values were dynamically calculated to be proportional to the overall intensity: e.g., $\tau_r = 95 \times (\sum v / \sum 255)$ where v is the intensity of a pixel, assuming maximum intensity is 255.

In many situations, detected skin region boundaries were rough, causing negative visual effects. To smooth boundary regions, we performed edge-detection (horizontal / vertical / diagonal) to detect boundary regions, and applied a smoothing filter along the boundary.

4. Experiments and Results

We tested AF for a mug design. The advantages of AF are demonstrated in product design simulation processes (Fig. 3). In the general-purpose AR, where plane markers are used without a mock-up, the virtual objects (mug and its grasp) are not touchable (Fig. 3 a1-a3). As can be seen in Fig. 3-a3, the virtual object has floating effect, isolated from the real environment. As a contrast, AF enhances visual presence by providing shadows, etc (Fig. 3-b3).

AF with hand visibility correction demonstrates

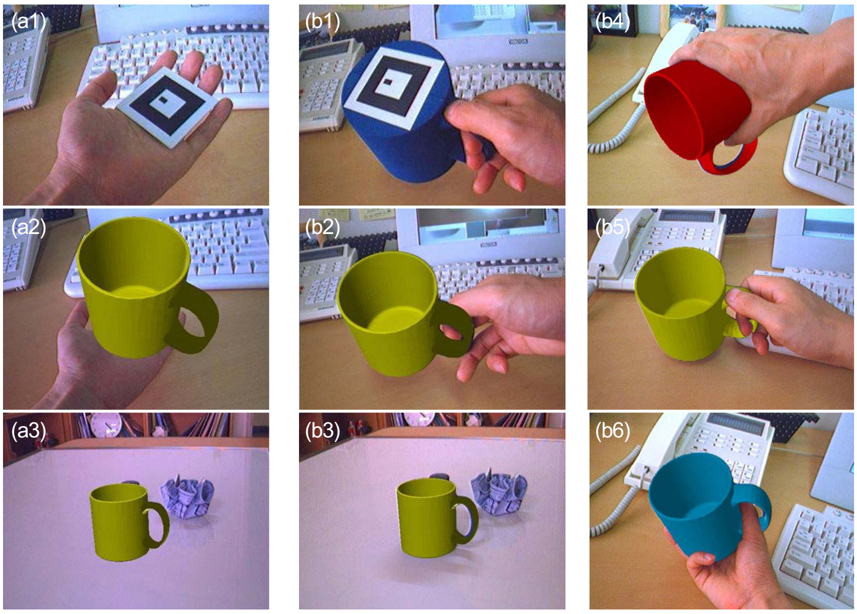

Figure 3. General-purpose AR (a1~a3) and Augmented Foam (b1~b6): (a1) Plane marker (a2) Virtual overlay on a plane marker (a3) Virtual overlay on a table, (b1) Augmented Foam without virtual overlay, (b2) Augmented Foam with virtual overlay (visibility problem), (b3) Augmented Foam on a table, (b4~b6) Augmented Foam with corrected hand visibility (various color cups)

noticeable enhanced visual presence. In Fig. 3-b2, the reviewer's hand is occluded by the virtual overlay of the mug object, while in Fig. 3-b5, the hand and the virtual object are seamlessly synthesized. As shown in Fig. 3-b4 and b6, designers could simulate various aesthetic perceptions through changing the properties of the product, while touching and grasping the design result.

We used AF for appearance and user interface design test of a cleaning robot model (Fig. 4). AF provided the basis for evaluating the positions and sizes of the control panels of the cleaning robot. Designers could evaluate the product by rapidly replacing and comparing other design alternatives of control. Designers were also able to thoroughly test user behaviors of touching and manipulating the products

We measured the graphics performance by rendering an object with more than 70,000 triangles. The frame rate was about 14.5 frames per second in the case of AF with skin detection algorithm.

Figure 4. Appearance and Interface Test of a Cleaning Robot

5. Conclusions

We designed and implemented Augmented Foam, a tangible Augmented Reality, which can help designers make high-fidelity prototypes for their design ideas very rapidly. The usefulness was tested through a cleaning robot design example. As expected, AF provided visual reality and tangible interface, elevating the feeling of immersion through multi-sense stimuli and spatial interaction between designers and design results.
We observed situations when the marker-based object tracking failed by hand occlusion or became unstable in slanted views. We expect to improve object tracking by CAD-based natural feature tracking, which might be occlusion-tolerant and more stable.

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