Interactive Foam: Touchable and Graspable Augmented Reality for Product Design Simulation

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1 Abstract

Computer Aided Design (CAD) applications have been widely used becoming designers' inevitable tools for expressing and simulating innovative ideas and concepts. Especially during the past ten years, CAD has greatly enhanced the performance of the product development process by "Concurrent Engineering". However, replacing traditional materials and mock-ups with 3D CAD systems, designers are faced with the "intangibility" problem, not being able to physically interact with test products in early stages of design process. In this paper, we introduce a touchable and graspable interface (Interactive Foam) based on Augmented Reality technologies. Using Interactive Foam, blue foam mock-up is seamlessly overlaid by a 3D virtual object, which is rendered with same CAD model used for mock-up production. In order to solve the visibility problem between the reviewer's hand and the virtual object when the hand is occluded by virtual object, we implemented a robust hand detection and separation method. Interactive Foam was tested for interactive design processes of a mug and a cleaning robot. Designers were able to touch and grasp the virtual object changing the material properties interactively.

Keywords: CAD, Design Process, Augmented Reality, Skin Detection, Tangible Interface, Rapid Prototyping
Conference Topics: Virtual Prototyping, CAD applications

2 Introduction

With advances in Computer Graphics and Geometric Modeling technologies, CAD tools have been rapidly spread since 1990's to become designers' inevitable means for expressing and simulating innovative ideas and concepts. As a consequence, 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", performance of designers 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.

2.1 "Intangibility" problem in traditional 3D CAD systems

In the early ages of product design, designers used to sketch ideas in 2D or 3D forms with various wieldy materials such as paper, pencils, markers, plaster, wood, foam boards, styrene foam, and urethane foam. Now, replaced by computer-based CAD systems, designers are faced with the "intangibility" problem. 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 (Fig. 1). For these reasons, inexperienced designers often incorrectly estimate the results of 3D CAD design, repeating mistakes.

To solve the "intangibility" problem, Rapid Prototyping (RP) technologies such as SL(Stereo Lithography), SLS(Selective Laser Sintering), LOM(Laminated Object Manufacturing), 3D printing, and FDM(Fused-Deposition Modeling) have been developed to be used with 3D CAD systems[1]. However, rapid prototyping has some problems for using in early stages of product development. Firstly, due to requirements of

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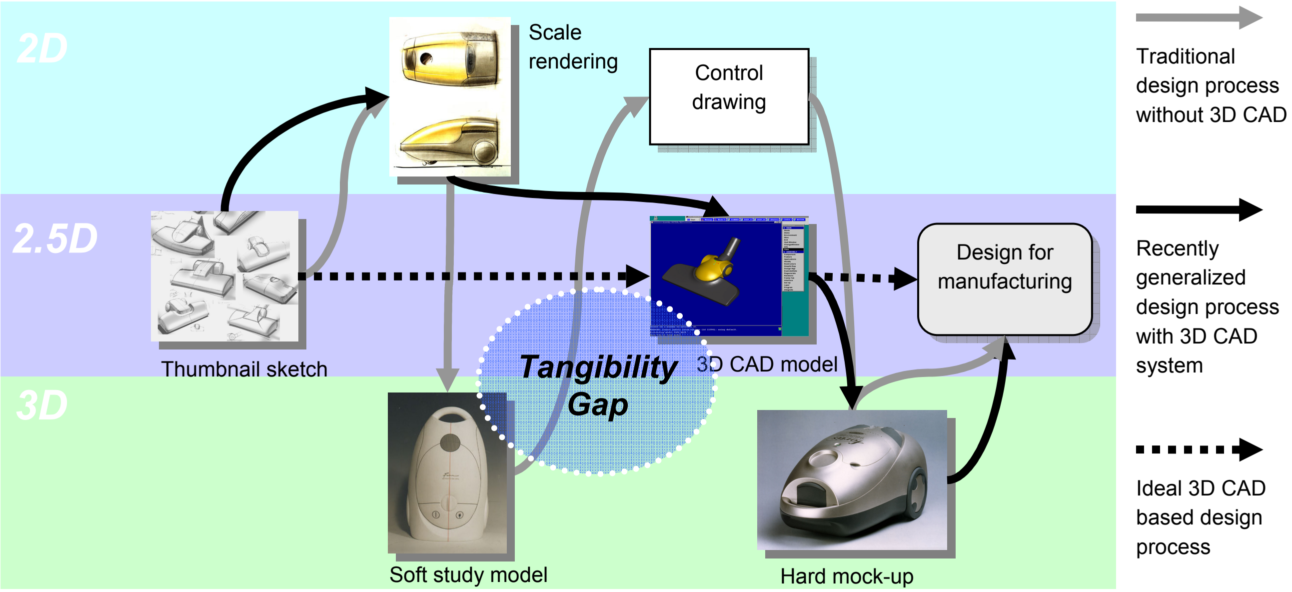

Figure 1: Change of product design process by introducing 3D CAD system

expense and labor, designers cannot easily test and develop ideas through iterative "design-evaluation" process. Secondly, because hard materials are used for rapid prototyping, design products are not easily modifiable as are form mock-ups (e.g., Styrofoam, urethane foam). Thirdly, rapid prototypes are difficult to represent material properties such as color and texture.

For these reasons, tangibility is not easily accessible with 3D CAD systems, and most designers experience trial and errors during the product development processes.

2.2 Interactive foam: Incorporating tangible Interaction with 3D CAD model

Human tends to explore the surface of an object and comprehend realistic feelings of the size, volume, and roughness of the object through Active touch [2]. At design alternative evaluation stage, designers investigate objects by meticulously touching and sensing them, because visual information itself is insufficient. To provide sufficient information to the designers, a new design tool should allow for tactile (tangible) information, while maintaining the strengths of convenient 3D CAD systems.

We propose the employment of Augmented Reality (AR) technologies, which can be used to synthesize the real and the virtual objects. With blue foam, which is favored by most designers, AR may provide "tangibility" to a 3D CAD model. Blue foam made of urethane is inexpensive, easy to cut, and can be produced by CNC (Computer Numerical Control) in a short amount of time, and hence used in many design studios for design result test. In this paper, we introduce a touchable and graspable interface, where blue foam mock-up is overlaid by 3D virtual models using Augmented Reality technologies. We call this interface "Interactive Foam".

2.3 Needs for solving visibility problem in Interactive Foam

The biggest challenge of implementing Interactive Foam is the visibility problem: the occlusions between the real environment and the virtual models are difficult to be correctly displayed. For example, when a designer touches a blue foam mock-up, virtual object which overlays the blue foam also overlays the designer's hand, and hence the designer's hand on the foam becomes occluded. In this case, the conflict between the visual and tactile information debases the designer's feeling of immersion. Because the interaction is carried out with designer's hands and foam mock-up, we focused on the occlusion problem between the virtual object and user's hand in Augmented Environments.

In this paper, we proposed a new product design simulation technology using AR technologies to overlay virtual models on a widely used material, blue foam. The visibility problem between the virtual model and the user's hand is solved by robustly detecting the hand regions. With corrected visibility, the proposed Interactive Foam provides visible and tangible interface.

3. Related Work

3.1 AR technology applied in design process

Augmented Reality, providing magical feeling of immersion, has been one of the most attractive research topics in the human computer interaction and computer graphics fields since early 1990's. Thanks to advances in hardware devices, tracking technologies, and display technologies, AR implementations are available on commercial off-the-shelf desktop and notebook computer systems. AR has been employed in various application areas, one of which is design process.

AR, as an interaction tool between users and the computer system, has been used for Collaborative design applications [3][4][5][6]. Ahlers et.al[3] and Schumann et.al[4] proposed the use of AR technologies to support remote collaboration in performing tasks such as equipment placement. AR technologies have also been used for collaborative design tasks in collocated situations [5][6]: MagicMeeting system [5] was developed to evaluate design results of automobiles; BUILT-IT system [6] was used for cooperative urban planning. In Fata Morgana project[7], designers were able to walk around a newly designed virtual car to inspect and compare with others.

AR application examples of design process 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. In many product design processes, physical interaction and tactile information are advantageous, even crucial.

3.2 Virtual overlay techniques on physical prototype

In some previous researches, virtual models were overlaid on physical objects in order to provide realistic material experience. Shader Lamps were used to project inherent material properties (color, texture, etc.) in order to reproduce realistic appearance of the original object [8]. Projectors were used to illuminate on white-colored neutral objects. Augmented Prototyping used the RP and AR technologies to improve product development process by combining physical and virtual prototyping [9]. 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. Lee et al. used Mixed Reality platform for virtual product design [10]. The hand region was separated and inserted into Virtual Environment to enhance reality.

Among the previous work, Augmented Prototyping is similar to Interactive Foam in concepts and employed technologies. However, Interactive Foam uses CNC-produced foam mock-up, which is available in the early design stages as well as for reviews. Interactive Foam 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. Mixed Reality platform of Lee et al. is also similar, however, in their platform everything except for the user's hand was virtual: their intention was to bring real object (user's hand) into virtual environment, and our intention is to bring virtual object (product) into the real environment for product evaluation in the user's real environment.

3.3 Hand Occlusion Problems in Virtual / Augmented Environments

Hand and / or finger detection may contribute to interaction with 3D Virtual or Augmented Environments. Wu et al. implemented user's finger tracking using a single camera for a virtual 3D blackboard application. Skin region was detected using color predicate, which is a histogram-like structure [13]. However, the detected skin region seemed to be coarse, which might be enough for finger position determination. In our application, the goal was to correctly display skin region, and hence elaborate detection was required. 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 [12]. They used a simple image subtraction method, fixing the camera pose. Their method is not applicable to Interactive Foam where all of the camera, the foam mock-up, and user's hand may change poses in the augmented environment.

4. Implementation of Interactive Foam

4.1. Key concepts

Interactive Foam is differentiated from other AR instances in that it allows for haptic presence to the users through physical interactions. Interactive Foam also allows for natural visual presence through shadows and reflectance in the real environment. In Interactive Foam, the color and texture of the object can be easily modified, and detailed shapes can be expressed through user-interface programs. In addition, designers may change the size and position of detail design such as decorative textures and buttons to find optimal parameters interactively.

4.2. Making foam mock-up from 3D CAD data

Interactive Foam 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. In our implementation, object models were 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 skin-color detection. Lastly, an artificial marker was installed on the mock-up for visual tracking (Fig. 3-b1).

4.3. Integration of physical foam and virtual overlay

Artificial visual markers were used to register virtual objects on the foam mock-up. For visual marker tracking, which is required for virtual object overlay, we used ARToolKit2.65 library [11]. For video capture and display, an IEEE 1394 web camera (iBOT) and a video see-through HMD of SVGA-resolution were used respectively. CAD data of STL format (same format that was used for CNC production) was also used for virtual overlay. Due to visibility problem, general-purpose AR technologies cannot be used for physical interactions with real / virtual objects. In our research, the hand regions were separated from the background using robust skin-detection algorithm as described in the following section.

4.4. Solution for hand occlusion problem

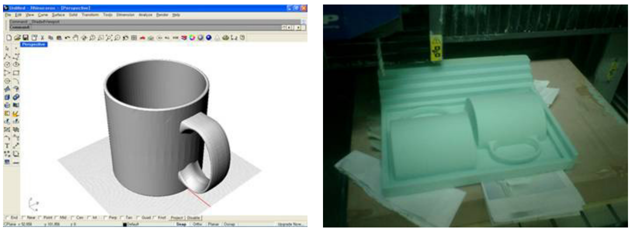

Figure 2: Process of constructing Interactive Foam, (left) 3D CAD modeling, (right) CNC-produced foam mock-up

To detect user's hand from a real environment image, the skin regions need to be identified from the background. To be less affected by illumination conditions, HSV color space is often used instead of RGB color space. However, color space transformation doesn't seem to make noticeable difference in skin color detection [16]. Comparisons of RGB value combinations have demonstrated no worse results than other methods in skin region detection [15]. Wark et al. exploited that simple thresholding method with R/G ratio detected skin-like colors effectively [17]. We have tested several previous methods of skin color detection to empirically find a method with desired performance. In our implementation, we employed a method similar to that of Peer et al [14]. Our skin region detection algorithm is summarized in the following.

$R>95$ and $G>40$ and $B>20$ and

$R>G+15$ and $R>B+15$

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

5. Experiments and Results

We tested Interactive Foam for a mug design. The difference of general-purpose AR and Interactive Foam is demonstrated in product design simulation processes (Fig. 3). In the general-purpose AR, such as ARToolKit examples, because 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, for lacking shadow effect, etc. As a contrast, Interactive Foam enhances visual presence by providing shadows and reflections (Fig. 3-b3).

Interactive Foam with hand visibility correction demonstrates 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. With corrected hand visibility, the designers are provided with enhanced visual presence while exploring, touching, and grasping the product. As in Fig. 3-b4 and b6, various

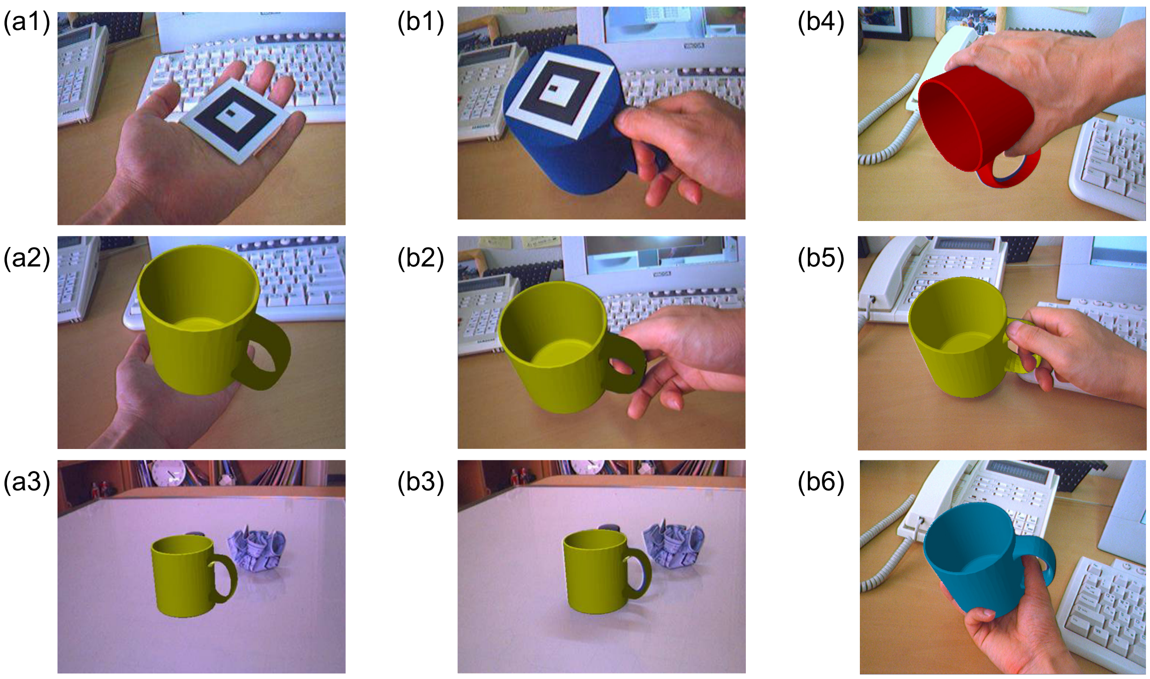

Figure 3: General-purpose AR (a1~a3) and Interactive Foam (b1~b4):
(a1) Plane marker (a2) Virtual overlay on a plane marker (a3) Virtual overlay on a table
(b1) Interactive Foam without virtual overlay
(b2) Interactive Foam with virtual overlay (visibility problem)
(b3) Interactive Foam on a table
(b4~b6)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

aesthetic perceptions can be simulated by changing the properties of the product and grasping poses.

We tested usability of Interactive Foam for appearance and user interface design test of a cleaning robot model (Fig. 4). Interactive Foam 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 panel to find the strength and weakness of each choice. Designers were also able to thoroughly test user behaviors of touching and manipulating the products

Fig. 4 Appearance and interface test of a cleaning robot

6. Conclusions and Future Work

We designed and implemented Interactive Foam, a touchable and graspable Augmented Reality. The usability was tested through a mug and a cleaning robot design example. As expected, Interactive Foam provided visual reality and tactile feedback, elevating feeling of immersion through multi-sense stimuli.

We found that 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. We also investigate to develop a skin detection algorithm that is less affected by illumination conditions.

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