INVESTIGATION ON THE USE OF ILLUMINATED CLAY IN AUTOMOTIVE STYLING

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ABSTRACT: Recent advances in mixed reality systems show a great potential for design, in particular projection-based augmented reality. This article documents an explorative study that was carried out to investigate functional and technical requirements of augmented prototyping in automotive design. A clay model of a car (1:5) was scanned and then a simple video projector system was used to illuminate the car. The system was evaluated by automotive design students and teachers. Initial reactions were positive, although the envisaged application did not match their demands. Furthermore, a series of technical challenges should be faced before this approach can be widely applied.

KEYWORDS: Augmented Prototyping, automotive design, clay modeling, tangible user interfaces, embodied interaction.

1. INTRODUCTION

In the last decennium, many useful computer-based applications have been developed for styling. This article reports on an explorative study that combines virtual and physical prototyping – called augmented prototyping - for automotive design.

Although there exist a vast amount of literature regarding virtual modeling of cars, not much has been reported on the inclusion of mixed reality systems, which have completely different characteristics and problems. Our main contribution is to map these, based on a qualitative study. Based on earlier experiences, we hypothesized that the incorporation of augmented reality displays in traditional clay sculpting could have an added value. Furthermore, we wanted to explore the scenario of communicating concept models. After development and implementation of the poof of concept, we were very curious to evaluate it with automotive design experts.

2. BACKGROUNDS

Two main fields have been used in this study: automotive clay modeling and the concept of augmented prototyping. Each will be briefly explained in the following sections.

2.2. 3D Automotive Styling

Since the 1930-ies, clay models (on both reduced and full scale) are commonly used as a malleable physical tool. They allow car designers (or stylists) to present and model the geometry of the car body. From Tovey [1997], a number of important steps of the automotive design process can be extracted. At two management intervention points, clay models are used: during the model presentation in week 7 (scale 1:4 or 3:8), and more in week 18 in full scale. In automotive design textbooks like Hoadley [2002], a detailed description is given on the required tools and skills for physical sculpting. In essence, a wooden or foam core is constructed and a 15 cm layer of special styling clay is clad on top of it. Modern variants of this clay (supplied by for example Chavant, Eberhart Faber, and Kolb) are actually wax-based products that soften when heated above 50°C. After the clay has been applied, the rough shape of the car is carefully implemented by using so-called measuring bridges and contour plots. Automated CNC milling machines are often used for this process. Subsequently, manual sculpting is performed, supported by a wide variety of scraping tools. When the geometric modeling has finished, the clay models can be covered with a stretchy plastic film called dinoc that can be sprayed with automotive paints. The result is almost indistinguishable from a real car.

In the last decennium, many useful computer-based applications have been developed for bridging styling and engineering disciplines. Virtual prototyping also establishes a direct link between modeling and simulation, which is very important in such complex products. In practice, differing approaches to the styling process exist [Tovey, 2000]. Some use physical models in all steps; others have abandoned these craftsmanship's techniques in favor of computer-based 3D graphics displays (e.g. CAVEs and Virtual Workbenches). Little empirical research has been performed on the effectiveness of individual approaches [Tovey, 2000].

2.1. Augmented Prototyping

A recent approach is not to abandon the physical prototyping, but to extend it with digital imagery, called Augmented Reality (AR). Several augmentation techniques could be found in Milgram and Koshino's reality-virtuality continuum [1994], ranging from video-based AR and See-through Head Mounted Displays to tangible computing. Of particular interest is projection-based Augmented Reality. In this case, digital images are projected directly on physical objects. This allows multiple independent users and haptic interaction. All physiological depth cues are supported without the need for mediating devices [Stevens, 2001].

The basic light model and illumination issues are presented in Raskar and Low [2001], see Figure 1. . Each virtual point V has to be mapped to a point M on the display surface by intersecting the ray connecting the user location and V. The corresponding pixel P in the projected image is then calculated based on the projector parameters (its field of view, location and orientation). An important observation is that casting an image on a physical object is complementary to constructing a perspective image from a virtual object by a pinhole camera. If the physical shape has the same geometry as the virtual, no special algorithms are required to pre- distort the computer image: a simple 3D perspective transformation (represented by a 4 by 4 matrix) is sufficient. Bandyopadhyay et al. [2001] extend this concept with dynamic tracking and interactive painting. Some of the setups have incorporated clay or plasticine as its medium, most notably the Illuminating clay setup by Piper et al. [2002]. There, a Minolta Vivid 3D scanner was used to continuously scan the clay surface while a projector displayed geographical information on the same surface. Other malleable materials that have been used include sand and glass beads [Ratti et al., 2004]

The application of projection-based AR display techniques in design have been explored by several research groups, most notably at MIT MediaLab (key researcher: Hiroshi Ishii), Mitsubishi Electronics Research Laboratory (Ramesh Raskar), Fraunhofer institutes (Andre Stork and Oliver Bimber). At Delft, we have developed a number of projection-based AR systems to support design, labeled augmented prototyping. This technique also includes physical

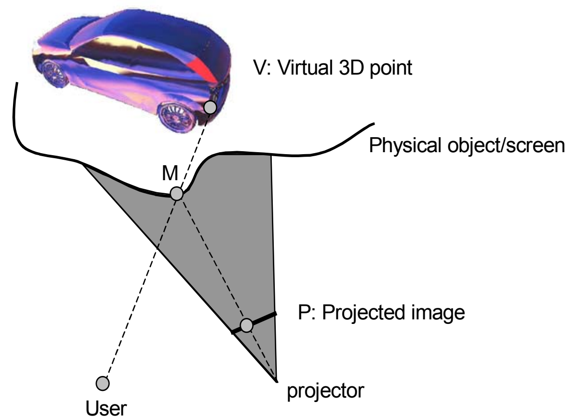

Figure 1 Relationship between projected image and physical object [Raskar and Low, 2001].

model making with RP techniques [Verlinden 2003]. Four different design support types for augmented prototyping have been identified: 1) component layout, 2) material and color selection, 3) interaction prototyping, and 4) engineering simulation. The opportunities in automotive 3D modeling would be i) to skip extensive painting and finishing by simply projecting materials/textures/colors on the body, ii) to be able to explore different detailed components like headlights, and iii) to add extra data and media to create a convincing presentation.

3. PROOF OF CONCEPT

In exploring the capabilities and technical issues of the clay-based augmented prototyping, we selected a design from a local automotive styling class. This class was specifically focused on clay modeling and was attended by senior Industrial Design Engineering students. It was our objective to convert the clay model to a fully blown augmented prototype in a short time, based on in-house technologies. The design we adopted was made by Mr. Jacco Lammers, a redesign of the Fiat Multipla (see sketches at Figure 2). A 1:5 scale clay model of the body – measuring 80 by 40

Figure 2 Sketches of the selected car design (courtesy of J.Lammers).

Figure 3 Car model (scale 1:5).

centimeters - was made in about 3 weeks. The model was not very detailed and no finish had been applied (see Figure 3).

3.1. System development

The creation process of the augmented prototype is depicted in Figure 4 and included 3D scanning, software development, and adjustment of the physical model. A Minolta Vivid 700 scanner was used to scan the physical model. Seven scans from different viewpoints were necessary, which were combined and simplified in the scanning software (i.e. the number of polygons were reduced. The scan was then imported into Kinetix' 3D Studio

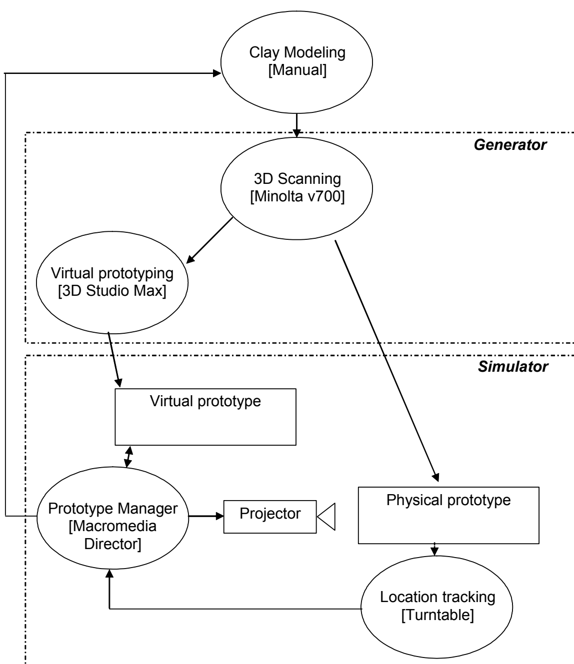

Figure 4 Prototyping workflow in the experiment.

Max for further editing. This editing consisted of removing unwanted floating polygons/vertices, adding surfaces and objects where needed, creating surfaces for texture mapping and adding texture mapping coordinates to these surfaces. The surfaces which would be used to render components in-place were created by selecting the appropriate polygons on the model and using them to create a new surface, positioned slightly above the original polygons. The UVW mapping modifier was then used to create texture mapping coordinates on the new surfaces.

As expected, preliminary tests showed that it was almost impossible to project imagery on brown clay - only fluorescent, saturated colors could be rendered as intended. The physical model was painted with simple household white latex and wheels were made from wood.

Figure 5 The component selection menu.

3.2 Dialogue

To display and interact with the augmented prototype, a user interface was implemented in Macromedia Director. A simple turntable allows rotation of the model, which is registered by a simple encoder that automatically updates the angle of the virtual 3D model. More details of this setup can be found in [Verlinden et al., 2003].

As the primary objective was to establish a proof of concept, only limited functionality was implemented. In the clay modeling stage the basic shape is already defined. We assumed that the augmentation could best provide for component selection and color studies. , in the Prototype Manager software a menu allowed the user to select these components, see Figure 5. After a careful study of literature, the following design parameters were selected: shape of the windows, headlights,

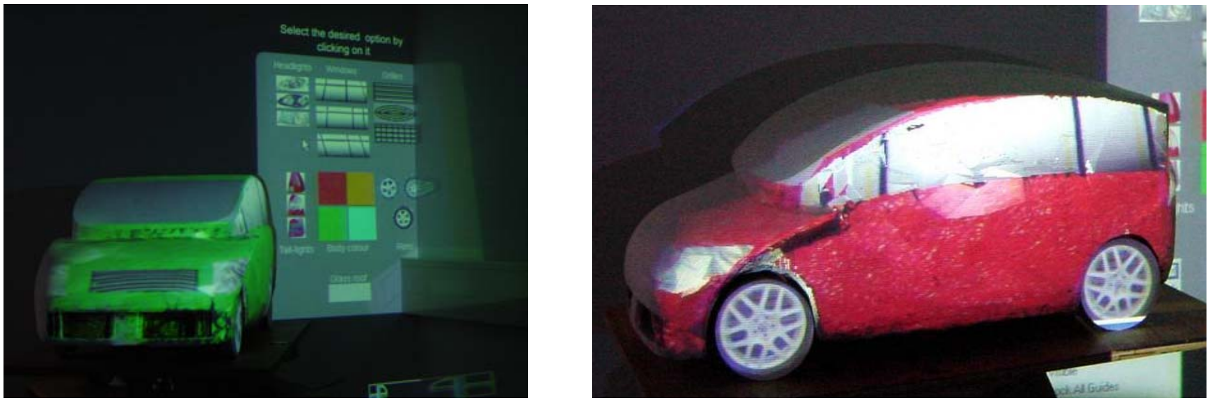

Figure 6 Snapshots of the illuminated clay car.

tail lights, grilles, contour lines and accents on the body, and finally wheels (rims). All of these can be related to areas on the scanned 3D model. For each, a collection of bitmaps was made. A regular computer mouse was employed to control the menu. Snapshots of the system in action are showed in Figure 6.

4. EVALUATION

A heuristic evaluation was performed on the resulting system. In a number of sessions were attended by the automotive design tutor, the students, and a group of CAD researchers. A simple meeting room was used that could be easily darkened. The projector was located approximately 3 meters away from the turntable. Our main objective was to test the outcome of the proof of concept and to validate whether the system could be successfully employed to create convincing presentations and to support component selection.

In each session, a short introduction was given on the backgrounds of the automotive design process and the objectives of the project. Then the system was demonstrated, allowing the participants to work with the system themselves as well. Finally, a semi-structured interview was held to collect opinions, suggestions and comments. Interview topics included clay sculpting, the experimental setup, and other opportunities for augmented prototyping.

All sessions lasted approximately 35 minutes; the interview/discussion took the longest. The effect of rotating the turntable surprised most people at first, yet they found it natural to operate it. As the system was demonstrated prior to the participants used it themselves, no serious user interface problems occurred. This is also due to the limited functionality that the system offered.

The participants judged the illuminated clay to be useful in automotive design. However, it will not replace the presentation of a finished, painted model. Such models offer a much higher degree of detailing and material properties, well worth the labor. The projections could be used to add dynamic information in its periphery. Instead, the car styling tutor and students suggested other opportunities for augmentation:

- Zebra striping possibilities for surface continuity testing during sculpting.
- Being able to sketch on the 3D surfaces, preferably directly on the clay model with some sort of virtual paintbrush tool. This could be used to set the styling lines and relevant contours. Some tests were done on the spot, using a 2D drawing application (Adobe Photoshop).
- ‘Interactive sculpting’: use the scanner and projector configuration as a sculpting assistant by projecting physical changes that have to be made manually, in essence using the projection as a guide.

5. ISSUES IN ILLUMINATED STYLING CLAY

Although the proof of concept was quite successful, a number of problems emerged in the implementation and use of the system.

5.1 Optical Scanning of Styling Clay

The styling clay used in automotive design is a brown substance with a reflective surface. Black paper tape or paint is often used to draw on it. These characteristics create difficulties in optical scanning. In industry, contact-based scanners are employed which do not depend on the visual properties of the surface, yet optical or other non-contact scanners have a much higher scanning rates and are preferred in this particular situation. As already mentioned in section 3.1, the illumination suffers the same problem. Although there are color correction remedies possible for projecting onto a colored surface [Bimber et al., 2005], the color brown with a high reflective component is the least susceptible for this strategy. This leads to two alternative solutions, i) using white or light colored styling clays instead or ii) include a manual step for painting the model white before scanning in the prototyping workflow. To our knowledge, only one Japanese clay manufacturer offers automotive styling clay in white. Similar materials like plasticine could be used but have completely different material properties which are less suited for shaping and finishing car bodies.

5.2 Projector Resolution

A state of the art XGA (1024x768 pixels).video projector was used for the installation, which delivered a poor level of detail on the car body. As a selection menu was also projected on the side, only a limited area could be used for projection on the physical model, approximately 400 by 250 pixels. As the side view of the car defines the maximum envelope, each projected pixel measured 2 x 6 mm or 13 Dots per inch (DPI) horizontally and 4 DPI vertically. Each pixel then corresponds to an area of 10x30 mm of the actual car design. The visual presentation of a hand-painted model surpasses this by far. Of course, skipping the menu could lead to a higher resolution – possibly halving the area that corresponds with one pixel.

We must note that the field of view of the video projector is also a limiting factor in getting as much pixels as possible in a small region. Optical extension lenses can be purchased to reduce the field of view, allowing the projector to be located further away. A radically different solution is the iLamps concept [Raskar et al., 2003], which encompasses a tracked hand-held projector which can be moved and directed in any point much like a flashlight. This allows an unlimited level of detail at the required spot. In some pre-tests that we made we found out that the projector could not be equipped with a standard Flock of Birds 3D magnetic tracker due to interference. Other tracking techniques should be used for this paradigm.

Of course, multiple projectors could be used to concurrently light up the whole model, as for example documented in [Raskar and Low, 2001] and [Verlinden, 2004].

5.3 Tracking accuracy

The employed turntable system was originally made for a smaller model, approximately 4 times as small as the clay model (10x22x10 cm versus 40x80x40 cm). The rotation precision was approximately 1.8 degrees, which means a maximum projection error of about 13 mm (versus 3 mm on the smaller one). This was noticed during development and evaluation, yet did not seem to bother the users too much, as the user had direct control of this rotation and filled in the “gaps”. Of course, it would be better to have an improved accuracy which is less than the projector resolution on the model. Alignment of the virtual and physical model was done by hand in a simple calibration routine; an automatic procedure would of course be preferable.

5.4 Interaction and Functionality

Except the operation of the turntable, all interaction in the proof of concept was performed with a traditional computer mouse. Of course, spatial tools should be used instead, allowing co-located interaction with the artifact model. In another publication [Verlinden et al., 2004], we have defined user interface guidelines for augmented prototyping. In this clay-based domain the following of these guidelines need special attention i) explicit support of capturing the modeling process (e.g. interaction histories and management of alternatives), ii) interactions with virtual-only (projected) entities should be avoided, iii) the product’s context should be included or at least acknowledged in the modeling environment (e.g. usage environment, engineering, marketing). As the act of automotive styling encompasses more than specifying the car body shape, the augmented prototype should be put in its context. Challenging relationships could be rendered between geometry, collages, sketches, and the engineering aspects (for example projecting internal details on the body.

As discussed in the evaluation, other functions should be considered as well, including in-place sketching (as presented in [Bandyopadhyay et al., 2002]), switching between alternatives, and material/texture/color exploration. Animations can be used to increase the expressive content of the model, as the cartoon diorama metaphor of Raskar et al [2002].

6. CONCLUSION AND FURTHER WORK

In a small timeframe, we implemented a proof of concept of projector-based Augmented Reality in automotive design. We anticipated that the most useful application would be projecting materials/textures/colors on the body, and offering the exploration of different components as headlights. It could be very influential in finishing the physical models, at present a laborious and time-consuming process. We could use an existing and representative clay model on reduced scale; it was scanned and a simple configuration application was implemented.

The evaluation showed positive results, automotive design students and tutors reacted enthusiastically to the possibilities that were offered, yet the system did not offer much added value to the envisaged scenario. According to the consulted users, illuminated clay is more suitable in earlier phases, to support modeling instead of evaluation or decision making. Issues that need consideration include the inherent brown reflective clay, the projector resolution and tracker accuracy as well as interaction and functionality.

Solutions have been documented to improve the usability of all-digital automotive design systems, e.g. digital tape drawing and the portfolio wall [Buxton et al., 2000] and virtual slicks [Hummels and Overbeeke, 1998]. Even though designers have proficient spatial reasoning capacities, we still see the need for physical modeling in the early phases of automotive design. As an embodied interface, it offers both tangible and social/collaborative cues [Dourish, 2001]. Empirical evidence shows that haptic and tangible cues of projection-based AR are superior to its peers, offering a more convincing insight in a complex three-dimensional shape [Stevens, 2002]. Furthermore, there exist developments to combine manual and computer/CNC clay-based modeling to accommodate the qualities of both and to alleviate time-consuming operations [Vergeest et al., 2004]. The augmented prototyping approach could be easily combined with this.

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