Spray Modeling: Augmented Reality Based 3D Modeling Interface for Intuitive and Evolutionary Form Development

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Abstract

We present an intuitive 3D modeling interface for conceptual and evolutionary form development in the early phase of the design process. Through field studies of design modeling projects and physical form-making processes, the "volume spray" concept has been proposed with the metaphor of 3D air brush. The spraying manipulation is used for creating 3D frames, generating 3D volume and finishing integrated shape. The flexible combination of these modes enables quick expression of conceptual 3D ideas. The concept has been implemented as an Augmented Reality based system supporting direct 3D manipulation of virtual models with stereoscopic displays and a 3D tracker. A real air brush with a gun and an air compressor has been used as an interactive input device providing haptic and sound feedback.

Key words: 3D interface, Interactive Modeling, Augmented Reality, Computer Aided Industrial Design, Computer Aided Geometric Modeling

1. Introduction

The rapid iteration of ideation, drawing, modeling and evaluation is very important for developing initial concepts in a product design project. Because designers continuously evolve their formative concepts by deforming expressed images on the process, immediate visualization of their ideas is crucial for the effective evaluation and the active group communication.

Although these steps are closely related with each other, the current 3D modeling interface restricts the designer's creative expression. Current CAD (Computer Aided Design) tools are operated in the 2D display with 2D input devices like a mouse or a keyboard while designers' mental models are in a three-dimensional space. This difference provokes the conflicts between users' mental models and their behavioral patterns [1]. Moreover, the applications are presented with system-oriented data structure. That is to say, users are forced to construct a model from vertices, lines and surfaces. Therefore, it limits their ideation flexibility with this rigid sequence of use.

The goal of this research is to develop an intuitive 3D modeling interface by understanding the 3D form making processes and finding useful metaphors bridging the gap between the designer's mental model and the modeling interface. We employ the benefits of direct 3D manipulation and Augmented Reality to build a more intuitive 3D interface.

2. Related Works

There have been previous researches on 3D modeling interfaces based on the virtual or augmented reality. Researches of these 3D modeling systems have focused on technical experiments of spatial interactions in a computer-mediated environment. For example, [2,3] suggested navigation methods in an immersive VR or AR environment with basic interface of 3D trackers. Other researches have explored diverse methods like gesture [4] or haptic [5] interface to construct a virtual model. But most of them are technology-oriented, which result in lacking the consideration of users' mental model and their usability.

Applications for special use have also been introduced. For example, the "digital tape"[6] is developed from the tape drawing method of automobile design and the "shape tape"[7] adopts flexible tape as an interface medium for creating virtual models. But they mainly focus on specific functions of professional modeling. Sketch-based modeling methods were suggested[8, 9], which value free hand drawing behavior and support automatic translation of 2D sketching into 3D CAD models. Such approaches have fundamental limitations because the complexity of 3D expression requires more information than the 2D line sketches can provide. Therefore there has to be a set of assumptions for such approaches. Simply, it would be difficult to be used in a real model making situations where the modeling methods to be used are unpredictable. And they largely focus on developing algorithms against its usability and effectiveness of usage.

Our approach is to suggest a novel interface metaphor based on the field studies. It is expected that the metaphor would fill the gap between the designer's mental model and the system functions in the 3D modeling process. We focus on the early phase of the design process, where conceptual and evolutionary 3D concept development is considered more important than detailed construction of a pre-defined form.

3. Field Research

The field study was conducted to understand the 3D form making processes in different work contexts. The first part of the field study was conducted in a university course of computer aided industrial design. We observed the use of current 3D modeling project and tried to find out the difficulties and the needs of designers. In the second part, we observed physical form-making processes in a variety of model making workshops such as clay modeling, wood carving and glass crafting. By understanding the tools and methods in these traditional form making processes, insights and metaphors could be generated for a new interface.

3-1. 3D modeling process in CAID

We observed that 3D modeling was type of a simulation of the final outcome in product design. Designers could evaluate the design proposal with a realistic representation of the virtual model. Before creating 3D models, 2D sketching was done to search optimal shapes supporting functional and aesthetic requirements. Students created a series of outline drawings with simple and easy methods. Comparing overlapped images and deforming them little by little, they decided the final shape [Fig.1].

Fig. 1 sketch of overlapped outlines

Meantime, the 3D modeling process started from a rough mass and was continuously modified in terms of details, examining formal principles. The comparison of different alternatives and the iterative refinement were essential for determining the final shape [Fig. 2].

Fig. 2 3D model of detail modification

In the CAID course, a surface modeling application (Alias Studio Tools) was used to construct all 3D geometry. It supported many functions to construct organic and free-form shapes but demanded complex form-construction planning before starting the modeling. The functions such as extrude, loft, sweep and Boolean operations were the most frequently used ones. Users were required to plan the final form in advance of the modeling due to the inflexible sequence of creating vertices, curves, surfaces, and modifications. It seemed to interrupt the free ideation and rapid expression in the design process.

3.2. Physical form-making works

We observed the work patterns and tools in physical form-making workshops of clay modeling, wood carving and glass crafting. We expected that the observation of the form-making methods and tools would provide an effective manipulation concept, which can be extended to VR environment.

Clay modeling

The clay modeling was the cyclic manipulation of attaching and detaching clay. The viscosity of the material made such manipulation possible. The use of a wire frame as an initial guide was an important and unique approach in this workshop. It guided further modifications with recorded construction history. By slightly bending the wire frame, an artist can modify the whole shape as the clay around the frame follows the change [Fig. 3].

Fig. 3 clay modeling

The viscosity of clay allowed quick sketch on the model and easy modifications by rubbing the surface. This “sketch on the surface” considered to be easy and effective for active modification and form development. We observed that an artist repeatedly mark and erase sketches on the clay model by rubbing for experimenting their ideas.

Wood carving

At the woodworking workshop, artists employed a number of tools, such as chisel and knives to carve the model. They were used differently depending on the purpose of modeling. The artists were trained to intuitively select the right tools among many others for delicate modeling. Repetitively cutting small pieces was required to construct a desired shape. The sketch for modification was also marked directly on the model [Fig. 4]. However, we noticed that the artist was more careful to carry out physical carving comparing to the case of clay modeling. It might be because cutting is irreversible with wood.

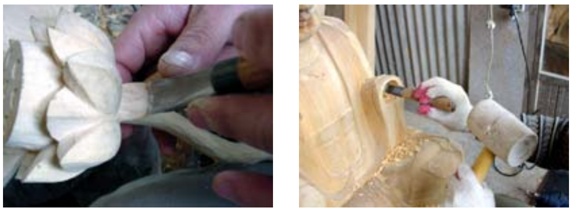

Fig. 4 wood carving

Glass crafting

When crafting glass, the artist deforms the shape by transferring the material's chemical states. As s/he heats certain parts of the glass surface, the area changes to liquid then easily expands as s/he blows breath to it [Fig. 5]. It is also similar with the surface modeling application and effectively expresses the deformation of surface. In this work, the clear division of both hands' role was exhibited. One mainly controls the deformation with nippers or by itself, while the other one continuously rotates the model with type of lathe [Fig. 5].

Fig. 5 glass craft

In the observation of the physical form-making works, one of the important findings was that continuous developing and iterative evolution of the modeling process was essential. Artists construct the model with continuous handling such as rubbing or cutting. Unlike the CAD modeling which starts with a detailed planning of the construction, the accumulation of repetitive simple changes determines the final shape. It enables to confirm the results of deforming or modifying right after the manipulation. And the operation is so iterative that artists freely express their formative ideas, directly see the results and easily modify them.

It was also uncovered that the modeling process heavily depends on the characteristics of the materials used. For example, in the clay modeling process, the characteristics of clay allows quick sketches on the model and easy modification by rubbing the surface [Fig.3]. Also in woodcarving, one can carve the model with various tools like chisel and knifes along the guidance marked on the model [Fig.4].

3.3. Directions and insights for a new interface

The field study shows that every model-making work has its unique characteristics according to the methods, tools and materials. Table 1 shows the checklist for concept development derived from the field study. As diverse form-making works take various processes according to their material features, pertinent process for design modeling should be considered prior to defining an interface concept; particularly emphasizing on the expressive ideation with proper combination of its visualization.

Continuous form development and flexible mass modification should be included as relevant solutions under the whole process. The process should support simple and easy model construction methods which enable continuous form development. And the ideation could be activated based on the iterative modifications and effective expressions of the models.

The next issue to consider is the manipulation, especially the direct handling of virtual model. We noticed that the feeling of direct contact with the model is essential for iterative form evaluation. If it is applied to Augmented Reality, a corresponding feedback should be considered to help the spatial interaction. Designers' behavioral patterns or the use of two hands might be additionally considered.

Table 1. The Guideline for Concept Development

Process	Continuous Form Evaluation
	Iterative Modification
	Effective Visualization
Interface	Direct Handling of Modeling
	Feedback for Spatial Interaction
	Reflecting Habitual Behavior

4. Proposed Concept and Implementation

4.1. The concept

From the field studies, particularly from the observations of the sculpturing and the glass modeling process, we developed a concept of volume spray modeling. The concept uses the spray metaphor because it is a familiar manipulation method in our everyday life. Specifically the spraying airbrush is a traditional tool in the design field, which emits paints with the air flow. We adopted the airbrush as an interface device, which is not only for borrowing the spraying manipulation analogy but also for providing press-responsive air feedback and sound effect. Another supplementary benefit is that designers are already accustomed to the device from conventional art work.

We attached a 3D tracker to the airbrush and made use of it for 3D sketching of wire frame in the provided space, spraying virtual volume, and spraying virtual air blow to smoothen the shape. The airbrush input device plays the role of connecting the physical manipulation to the virtual modeling in the augmented workplace [Fig. 6].

The user holds the airbrush in the space and adjusts the amount of the virtual volume to be sprayed by pressing the controller on it. The sensors are equipped to capture the controls of the spray device [Fig. 7]. The input values from the sensors are used for the virtual modeling interaction. And the user feels the responsive airy feedback from the manipulation of the air compressor-connected spray device.

Fig. 6 concept of spray modeling
in the augmented workplace

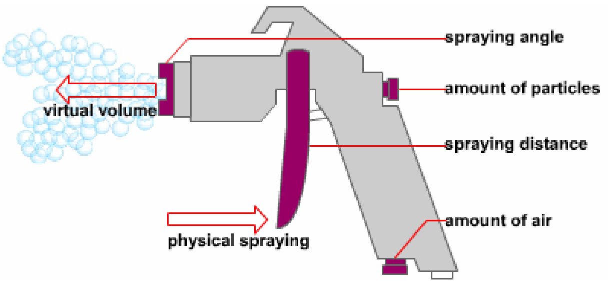

Fig. 7 spraying device manipulation

4.2. Modeling process

The spray modeling process consists of three modes with fundamental spraying interface: 3D frame drawing, volume spraying, and air spraying for smoothening [Fig. 7].

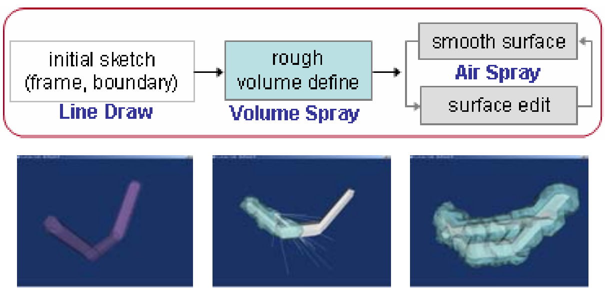

Fig. 7 process for spray modeling

According to this process, the user draws the initial frames as a guide for further forms. Next, s/he adds some volume around them by spraying particles. He would smoothen the surface occasionally. This process is accomplished iteratively to allow continuous form evolution. Each modes of modeling process is described below.

- Line Drawing: It is for generating 3D guide lines or curves by tracking movement of the input device in the space. In this mode, the frame is drawn following the trace of a tracker attached device. With this method, the initial rough ideas can be easily expressed.

- Volume Spraying: It is for defining volume with point cloud visualization. In this mode, the particles sprayed from the device are attached to the nearest frames or gathered around previous generated particles. Repeating this volume spraying continuously, a user can develop a form as s/ he intends to.

- Air Spraying: It is for editing surfaces of constructed model. In this mode, smooth surface is generated covering the roughly sprayed volume or the existing surface is edited more smoothly. Through this mode, a user can refine the modeling shape and its visual expression.

Figure 8 shows an example process of modeling a simple game pad. First, the user draws the initial frames and sprays some volume around them. Then by blowing air on the rough volume, desired surface can be generated. For creating more accurate details, s/he repeats the process of guide sketch, volume spray and surface edition.

Fig. 8 usage scenario for modeling a game pad
(from top left, every image shows
the continuous process of form development
targeting the final image of bottom right)

4.3. Modeling interaction

The spray modeling interface and process are supported by the augmented reality system, in which users' physical manipulation and the virtual model are interactively combined. Figure 9 shows that the stereo display and an air spraying device are integrated into the system.

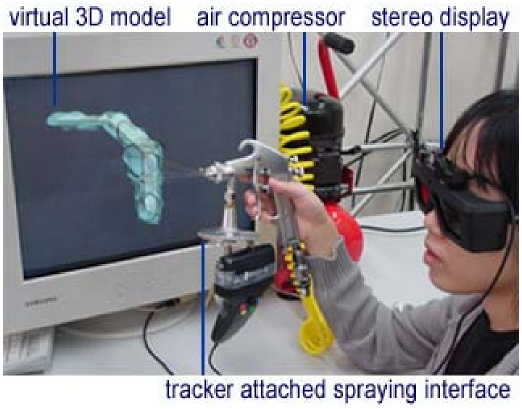

Fig. 9 system configuration

In the AR system, the stereoscopic display enables the user to overlay virtual models onto the real spraying device. By tracking the users' view point, the parallax display controls the virtual model to be followed according to the users' movement. It allows the virtual model to be handled with a more realistic perception.

For more natural navigation in the augmented reality environment, it might be a crucial process to map the location of the physical input device and that of the virtual model. Though the 3D model is presented as a plausible stereo image, a kind of visual indicator to guide the device manipulation relevant to the virtual model is necessary. We added a spray region indicator [Figure 10] from the device before the actual spraying action. Users can pre-measure where and how much the virtual volume would be sprayed with a slight press of the spray gun and then they may decide to proceed or not.

4.4. System implementation

To build the hardware, we used the CrystalEyes™ for the active stereo display system and the 3D tracker (IS-900 PC™). Users can see through with the glasses but when a stereo image from the monitor is seen, the virtual image could be overlaid onto the real scene. The tracker had two markers. One marker was attached to the stereo glasses. The real-time 3D movement data from this marker was used to calculate interactive 3D view of the virtual model. The other marker was attached onto the airbrush to detect the position and the orientation in real time.

The software was implemented with the Visualization Toolkit [12] in the Visual Studio.Net environment. As object-oriented 3D computer graphic software, the VTK supports a wide variety of visualization algorithms and advanced modeling techniques like implicit modeling and mesh smoothing. The real airbrush connected with an air compressor was used for control and to give feedback.

The actual spraying effect can be mapped onto the virtual volume generating model shown in Figure 10. The position and orientation of a spray gun is detected by the 3D tracker which is attached to the device. Then a virtual plane perpendicular to the direction of spraying is calculated at a certain distance (D). On this virtual plane, some random points are selected around the intersection point within a defined range (R). Connecting these points and the virtual positioning of the spray gun, the emitting lines are determined. As each line emits a certain amount of foam to this direction, the sprayed volume is settled on the position where each emitting line meets another existing surface or a frame. If one line has several points of intersection, only the nearest one from the starting point is selected. The point data is constructed to a volumetric mass with a vtk class, *vtkGaussianSplatter*, which injects input points into a structured point dataset. As each point is injected, it "splats' or distributes values to neighboring voxels in the structured point dataset.

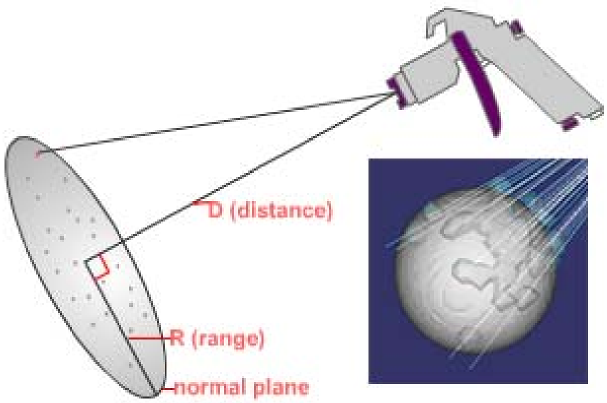

Fig. 10 interaction for spray modeling

5. Discussion and Conclusion

In this study, we observed various form-making fields to understand the modeling process, specific methods and tools. Based on the findings from them, we suggested a conceptual 3D modeling interface, the volume spray modeling. It aims to support evolutionary formative ideation and visualization in the early phase of the design process. We expect that this quick and easy modeling interface helps designers to concentrate more on the concept itself saving the effort to learn the tools. It will also enable the active communication between designers and developers or between designers and general users in the conceptual design process.

Through the preliminary subjective evaluation, we observed that the modeling process with three-mode combinations was quite iterative and that it helps the procedure of continuous ideation. Particularly, the frame drawing at the first step allows the ambiguous concept development that could be further refined. However the flexible mode conversion and the simpler 3D navigation need to be supplemented for more reasonable manipulation. If a real bendable wire is used as a physical frame, whose deformation could be captured as virtual data, the volume spray around it and the application of construction history would become more facile.

Additionally, the adoption of spray gun as a physical input device makes the 3D modeling interface more realistic and effective. The sound and the responsive air force from spraying manipulation provided plausible feedback. And the users feel familiar with the airbrush as a traditional design tool. Through the analogy of their use to 3D modeling, they can take advantage of the device structure to flexibly deal with combined modes of modeling process-drawing frames and spraying volumes. And it provokes the further possible application of air force feedback in the VR/AR based spatial interactions.

There are some issues to be addressed in the metaphor and the developed system for more detailed user evaluation. The presented surface of a modeled volume is rather rough because of the processing load. For more precise user evaluation and practical usage, more effective point modeling algorithm should be incorporated with the interface concept. The real and the virtual coordination also should be more accurately integrated for the direct handling of the virtual models. And the manipulation of detail modeling such as sketching on the surface and mass modifying should be considered in the future work. Applications of air force feedback in spatial interactions would be further investigated.

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References

1. Donald A. Norman, “The Design of Everyday Things”, 2002, Cambridge MA, MIT Press
2. Emanuel Sachs, David Stoops, Andrew Roberts. 3-DRAW: A Tool for Designing 3D Shapes. IEEE 1991, vol.11, issue 6. IEEE Computer Society Press
3. Zsolt Szalavari and Michael Gervautz, “Using the Personal Interaction Panel for 3D Interaction”, Eurographics1997
4. Steven Schkolne, Michael Pruett, Peter Schroder. Surface drawing: creating organic 3D shapes with the hand and tangible tools. CHI 2001, ACM Press
5. Yan-Hong Lu, Wei-The Wang, Wei-The Wang, Rung-Huei Liang, Ming Ouhyoung, “Virtual Sculptor: A Feature Preserving Haptic Modeling System”, ACM2002
6. Tovi Grossman, Ravin Balakrishnan, Gordon Kurtenbach, George Fitzmaurice, Azam Khan, Bill Buxton. Creating principal 3D curves with digital tape drawing. CHI 2002, ACM Press
7. Tovi Grossman, Ravin Balakrishnan, Karan Singh. An interface for creating and manipulating curves using a high degree-of-freedom curve input device. CHI 2003, ACM Press
8. Steve Tsang, Ravin Balakrishnan, Karan Singh, Abhishek Ranjan. A suggestive interface for image guided 3D sketching. CHI 2004, ACM Press
9. Qin S., Wright D., Jirdanov I. From on-line sketching to 2D and 3D geometry: a system based on fuzzy knowledge. CAD 2000, vol.31, no.14. Elsevier Science
10. Jun Mitani, Hiromasa Suzuki, Fumihiko Kimura. 3D Sketch: Sketch-Based Model Reconstruction and Rendering. From geometric modeling to shape modeling 2002, Kluwer Academic Publishers, Norwell, MA, USA.
11. Takeo Igarashi, Satoshi Matsuoka, Hidehiko Tanaka. Teddy: A Sketching Interface for 3D Freeform Design. SIGGRAPH 1999
12. Kitware, Inc. The Visualization Toolkit http://public.kitware.com/VTK/