3D Modeling Interface with Air Spray: Field Study of 3D Model Making and Prototype Development

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ABSTRACT
This paper presents a novel interface for 3D modeling in augmented reality, aiming at developing a form gradually in the early phase of a product design process. Previous VR/AR based modeling systems have focused largely on geometrical algorithms and system performance issues. From a designers' perspective, this study analyzed the conventional form creating processes and developed a more intuitive and designer-friendly modeling interface. Based on the understanding of various form-making methods and tools, we suggest the concept of "spray modeling" interface, which adopts a real air spray gun as an input device. It allows the user to create a 3D frame and to spray virtual foam around the frame as in a sculpturing process. It also provides coherent sound and air-force feedback. As a metaphoric approach for novel modeling interface, spray modeling is expected to be widely applied to human computer interaction researches beyond design modeling.

Author Keywords
3D Interface, Interactive Modeling, Augmented Reality, Computer Aided Industrial Design, Computer Aided Geometric Modeling

ACM Classification Keywords
H.5.2 [User Interfaces]: Prototyping, D.2.2 [Design Tools and Techniques]: Evolutionary prototyping, H.5.1 [Multimedia Information Systems]: Artificial, augmented, and virtual realities, J.6 [Computer-Aided Engineering]: Computer-aided design (CAD)

INTRODUCTION
Creative ideation and quick expression of conceptual forms are required in the early phase of design process. Design ideas evolve through iterative visualization and embodiment [2, 5], which provokes further ideation and dialogue between members in a design team [18]. As these steps are closely tied with each other, efficient tools and methods for the form making process is important to improve the quality of the final outcome. Designers need intuitive tools that inspire their imagination.

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Current 3D Modeling Interface
Desktop-based computer aided design (CAD) modeling is widely used as model simulation tools. However, they have problems of complex user interface. They are operated in a 2D display with 2D input devices, while designers conceptualize objects in a three-dimensional space. This incurs conflicts between the user's mental model and the system model [4].

Moreover, when using a CAD modeling system, designers are forced to build models from geometric components such as vertex, curves and surface. This modeling sequence is caused by the system-oriented data structure. It is difficult for designers to start modeling in these CAD systems without having the clear picture of the final form.

Alternatively, virtual or augmented reality based three-dimensional modeling systems have been introduced to solve the dimensional difficulties of current user interface in desktop based 3D modeling. However, they are mostly evolved from technology-oriented approach lacking in understanding of the shaping process. Many studies in VR/AR focused on the interface of navigation in constructed VR environment rather than the real-time modeling process, which is more necessary in design work.

The Objective of the study
The objective of this study is to suggest a novel 3D modeling interface, which enable users to think intuitively and express their ideas. Emphasizing the users' mental model and their natural behavior, we ultimately aim at 3D modeling interface for the conceptual design phase of the design process. For the intuitive manipulation of 3D virtual models in space, we use AR environment and reflect the observation from field studies to a concept-modeling interface.

RELATED WORKS
A number of CAD systems and interface methods have been developed since digital technologies have been brought into the design process. [8, 14, 15] adopt free hand sketching behavior for 3D modeling interface. 3D Sketch [14] converts a planar image to a 3D geometric model with corresponding views and sequences of sketch strokes. Teddy[8] automatically generates a spherical 3D geometry

from a sketched image. Qin et al. based on fuzzy knowledge, presuppose an approximate geometric model from a given line sketch [15]. In spite of the consideration for designers' familiarity with sketch interface, these are based on two-dimensional manipulation. The system only deals with box-shaped or closed round forms and requires accurate interpretation of every line stroke, which might be ambiguous in some cases.

[6, 7, 21] extended the line sketches into the three-dimensional space. Digital Tape Drawing[6], which is specially developed for automobile design, allows users to create line curves in all six faces of the cubical space. The curves are assembled into a complete 3D model. Similarly, Shape Tape[7] adopts a flexible band as a physical medium for editing virtual curves which compose the 3D model. These three-dimensional sketching systems introduce a unique interface of their own. However, these methods are more appropriate for the later phase of modeling. Designers tend to start shaping ideation not from line curves but from rough and unclear shapes.

Many studies [3, 13, 20] focus on geometric modeling algorithms. Singh suggested the interactive digital French Curve, which has been used conventionally in high quality 2D drawings or 3D sculptures [20]. It serves as an interactive guide for curve editing, but high dexterity is required to manipulate the intricate curve components. [3, 13] employ a modeling metaphor based on the persuasive principles of model-making process. However, users may find it difficult because these processes usually underlie the actual user interface. While many researches focus on the modeling algorithms, the study of corresponding physical interface is rarely explored.

There have been researches on VR/AR-based 3D CAD systems. 3DRAW [16] is a virtual line-sketching system using 3D tracking pointers. Surface Drawing [17] enables a direct hand-manipulation of a virtual model by generating surfaces with gesture recognition gloves. It supports freeform surfaces with natural and intuitive interface, but it needs more active feedback to guide accurate spatial interaction. Virtual Sculpting[12] adopts sculpting methods with haptic feedback using a PHANTON™ device, but its approach mainly aims at system implementation without considering the creative aspects of design ideation.

FIELD STUDY

We conducted a field study of various modeling works to understand formative principles and to get inspiration for interface concepts. The concerning area of observation ranges from practical design modeling to artistic craft such as clay modeling, wood carving and glass craft. 3D CAD modeling process was also investigated to find out the problems involved in using existing CAD systems.

3D Modeling Process in a CAID Course

We observed the 3D CAD modeling process in an undergraduate course of Computer Aided Industrial Design (CAID) in KAIST with Students who had practiced Alias Studio Tools™ for a month.

Before creating 3D models in the computer, they underwent sketching to search an optimal shape estimating functional and aesthetic requirements. They created a series of outline drawings repeatedly. After deciding a rough shape, they started CAD modeling from a simple mass of 3D geometry and continued adding details on it (see Figure 1). Several model variations were compared and iteratively refined until the final shape was determined. In this course, it was found that sketching and modeling were not effectively linked. Ignoring the details on the sketches, students often improvised for detail modification in 3D models. It might be because the realistic visualization in CAD modeling helped for a more active concept development.

Typical modeling functions, such as *extrude, loft, or sweep*, which define the shape of profiles and then pass them through a linear path, were frequently used (see Figure 2). These methods support the creation of an initial mass, on which additional details would be added or subtracted. It is appropriate for organic and free-form modeling but demands well organized form-construction planning before modeling. The expression and modeling method were heavily dependent on the methods of the CAD software. Consequently, the modeling results tended to be similar among students because they all used similar functions.

Students had much trouble in dealing with the *Boolean* operation, which is used for assembling, intersecting or subtracting separately generated surfaces. The function involved quite a complicate operation. Users had to pre-calculate the output before expressing conceptual ideas. We observed that this limitation prevented active form experiments and that students did not make the most use of the CAID tool for their ideation.

Design Model-Making

Designers also use physical materials to simulate or develop their conceptual ideas. Depending on the characteristics of each modeling process, appropriate methods and tools have been devised. Paper or cardboard is widely employed at first steps, because they are simple and easy to deal with.

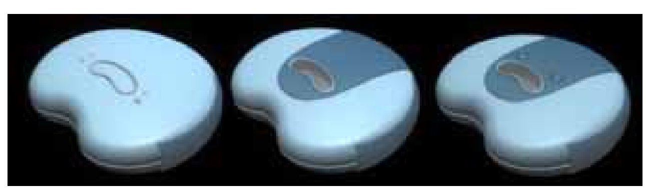

Figure 1. Adding details on 3D model

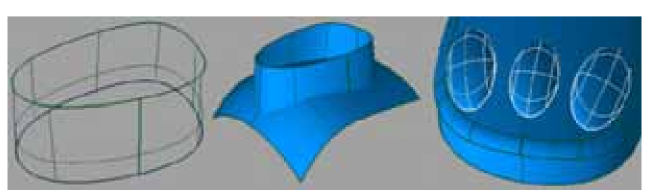

Figure 2. Surface modeling method (sweep, Boolean) [1]

More feasible materials like expanded resin, clay or wood support effective solid model making. At later steps, surface processing is generally used, because highly realistic appearance is necessary to examine design features before going into production.

Thermoforming modeling

Thermoforming of plastic material is a popular method to present smooth surface of design models. While this is used for delicate finishing rather than for creative ideation, it offers useful process and methods, which can be borrowed at the stage of early idea expression. A model-maker first prepares a basic wooden form. Then s/he covers it with a heated plastic plane that is easily deformed due to its thermoplastic feature. After the plastic plane is spread along the surface of the basic solid model, it cools down and hardens to the deformed shape (see Figure 3-1). Several separate parts fabricated in this way can be assembled into a whole shape. The method of generating a smooth surface based on the initial solid form can be linked to the step of refining and it can also be applied to develop a given form by deforming the surface.

Spray coloring

Spray coloring is done at the final step to complete a physical design model. Connected with an air compressor, a spray gun gives out paints together with compressed air. Then the pigments are set on the surface of the completed model. Spray coloring offers useful methods that can be applied to the refinement of rough models. The structure of a spray gun and its gesturing manipulation provide a valuable concept for spatial interaction in 3D modeling.

Spraying distance and angle are mainly related to the surface size and shape of an object. Varying the amount of air and paint can determine the texture expression of a surface. For example, if a user sets the device to give out much paint and little air, then the surface will seem to be corroded with particle clots. These factors can be flexibly adjusted with controllers and valves on the spray gun.

The spatial gesture of an expert model maker is quite dexterous along the targeting surface of an object. They use both hands; the main one for spraying and the other one for fixing the objects. As it is not facile even for them to make delicate gestures in empty space, the spraying pattern is almost always simple and repetitive. They just make up-and-down or right-and-left moves within a short range. The role of fixing and rotating the object serves as the guidance for spraying gestures previously mentioned, turning the object to its surface that is to be sprayed (Figure 3-2).

Physical Form-Making in Craft Works

Traditional physical form-making works have their original processes and tools. We analyzed each work in order to understand formative processes and to develop user-friendly interface concepts, reflecting familiar working behaviors.

Clay modeling

Clay modeling undergoes through attaching and detaching clay benefited from the material's viscosity. A wire or wood is often used for constructing an initial frame. The overall form develops based on the initial frames and then by bending them slightly, an artist can deform the entire shape as the clay around the frame follows the change (see Figure 3-3).

The viscosity of clay also allows quick sketch on the model and easy modification by rubbing the surface. This "sketch on the surface" is an easy and effective interface for active modification and form development. We observed that an artist easily repeatedly marked and erased sketches on the model by rubbing the surface. This flexible process of sketching directly on the surface influences active formative experiments.

Wood carving

Compared to clay modeling, wood carving is more appropriate for detail expression than active ideation. The process consists of repetitive small cuttings and they are accumulated to create a desired shape. Artists employ various tools like chisel and knives to carve a detailed shape. They select the right tool among many for a specific type of cutting (Figure 3-4).

The sketch for modification is often drawn directly on the model. However, the artist was more careful to carry out actual carving compared to the case of clay modeling, because cutting is irreversible in wood working. This means that formative ideation is largely influenced by the process and material of modeling. Additionally, experts say that considering the type of wood is important because of the tactile feeling when carving. This implies that delicate feedback is crucial when controlling carving wood.

Glass craft

Unlike the previous modeling or carving, glass craft does

Figure 3. Physical model-making works
3-1.thermoforming modeling, 3-2.spray coloring, 3-3.clay modeling, 3-4.wood carving, 3-5.glass craft (from left to right)

not directly handle the whole solid but is based on surface deformation. An artist deforms the shape by changing the material's chemical state. As s/he heats certain parts of the glass surface, the area changes to liquid and then can be expanded as s/he blows into it (Figure 3-5). Separate simple shapes can also be assembled flexibly by heating the area to be attached.

This modeling method is similar to that of thermoforming modeling and spray coloring because it all goes through a deformation of a given surface. Therefore it can also be of reference to refining interaction in the later steps of modeling. Additionally, division of roles between two hands was exhibited. One hand mainly deforms the surface by pulling or pressing the surface with devices while the other continuously rotates the model with a kind of a portable lathe.

INITIAL FINDINGS AND INSIGHTS

The field study shows that every kind of model-making process has its own characteristics according to the methods, tools and materials. We can apply these methods and tools selectively to a novel concept of 3D modeling interface, considering the objective to support the early stages of design modeling.

Through observation of the CAD modeling course and design model-making works, we identified that it is desirable to support both flexible ideation and effective visualization in product design modeling because the realistic representation influences the user's perception. Consequently it helps active ideation for the form development as well as making the process more flexible. For example, although clay modeling is the most flexible to make and change the shape, it is not efficient in expressing detail due to the difficulties in delicate cutting and surface polishing. For ideal design modeling, which allows both active ideation and effective expression of these ideas, the interface can be devised through a reasonable combination of each modeling method.

We derived applicable concepts from various model-making works and then categorized them according to the procedural characteristics. Table 1 shows 3D modeling interface concepts developed from the observation of each physical model-making method.

Based on this approach, we summarize the guidelines of 3D modeling interface concept for an initial conclusion of field studies.

Direct Sketching on Models

We found that the integration of ideation and its expression are crucial for intuitive modeling and that they are supported by 3D sketching directly on the surface of physical models. Though the planar 2D sketch is a quick and simple method, it is not appropriate in physical or 3D CAD modeling because the ideation is dissociated from a 3D model. Direct manipulation of the real model can

Methods	Applicable interface concept
Clay modeling	• frame construction • additive modeling • rubbing, indenting • sketch on the surface
Wood carving	• detailing for by cutting out • using various carving knives • sketch on the surface
Glass craft	• blowing surface • two-hand manipulation • assembling by heating
Thermoforming	• surface deformation • use of basic form • assembling separate parts
Spray coloring	• spraying particle • attaching particles on surface • spraying gesture in space • two-hand manipulation

Table 1. Physical model-making methods and their applicable interface concepts

support both intuitive interaction and immediate perception of form developing process through corresponding tactile feeling on the model surface as well as its visual changes.

The form should be created, modified and expressed in direct relation with a 3D model in space. The perception and the expression activate each other through iterative influence.

Simple and Repetitive Manipulation

The form develops through continuous evolution from an initial shape in physical modeling. The manipulation is almost simple and repetitive like adding, cutting, or rubbing. They are different from specified commands of CAD modeling, such as sweep, loft or extrude. The deformation is carried out by the accumulation of continuous small changes. Therefore it is important to suggest manipulation as simple and consistent as possible for intuitive modeling.

Additionally, two-hand interaction should be considered with the main one for modeling manipulation and the subsidiary one for positioning the model in space. With the help of this assistant positioning, only the main hand has to consider simple manipulations like adding or cutting.

Combination of Molding and Carving

Molding is an additive form-making method, in which additional mass is attached to previous ones. It is deeply related with the viscosity or adhesion of the main materials. While it supports constructive formation and iterative evolution, the shape tends to be too blobby as in the case of clay modeling. Therefore, the additive modeling method is appropriate for generating basic shapes in the early modeling stage. Once the basic shape is formed, some regulated modification should be followed to refine the form. Additionally, the use of frame construction serves as a guide when creating the whole shape, which can be deformed as a whole.

On the other hand, carving is a subtractive process of cutting away the materials. It supports quite detailed and exact expression on the rigid material. However, it is not appropriate for big deformation because cutting changes little by little. It also requires delicate tactile feedback of cutting manipulation. In physical modeling, the process is irreversible. Thus an artist is restricted from freely expressing an idea on the real model. Therefore it is more appropriate for later phase of detailing than for initial form development.

According to their own characteristics, each method can be selectively employed to the new 3D modeling interface. A reasonable combination of modeling and carving needs to be considered.

Proper Tools Reflecting the Whole Process

It is observed that various features of methods and the use of tools are deeply interrelated with each other. Rasp or rake in clay modeling and carving knives or chisels in woodworking cannot be separated from their whole process. The tool enables the manipulation to be easy and simple with the efficient structure fitted for a given method. Therefore we can affirm the importance of manipulating tools and insist the need of devising a proper tool, as a new input device that is agreeable to spatial manipulation for 3D modeling interface.

Moreover, desirable tools should not only reflect the whole modeling process and method with its effective usability but also inspire modeling ideation with interesting and familiar interface. Users can perceive the virtual model by interacting with the device. The feedback from the device itself is also important because it is the only physical interface in virtual modeling.

SPRAY MODELING: A NOVEL 3D MODELING INTERFACE

Based on the findings and implications from the field study, we propose the concept of ‘Spray Modeling’, to spray virtual foam in space. We use a real spray gun as a 3D modeling input device and the interaction between this physical manipulation and the virtual model is performed in an augmented reality environment. Spraying provides suitable feedback with sound and air force. The process of frame construction and volume addition is seamlessly combined with this spraying interface.

Spray modeling addresses the requirements explained in the initial findings of physical model making works. It supports direct sketching on the model with its augmented reality based direct manipulation of virtual models. The process of form development, by spraying particles and making attachments, makes modeling interaction simple and repetitive without complexity. Also it goes through a reasonable modeling process, combining spraying as an additive modeling step in the early phase and surface deformation as modifying or detailing steps. The use of a spray gun serves as an effective user interface with air-force feedback, reflecting the whole modeling process and interaction.

Concept Development

The concept of spray modeling was derived from a combination of the process of clay modeling and the manipulation of spraying. To satisfy both active ideation and effective expression, we reinterpreted traditional clay modeling into device-mediated virtual modeling. We focused on a spray device as an interesting interface for spatial interaction because it is used similarly in practice. Therefore its traditional behavioral use and gesture are expected to be a familiar reference to spatial interaction of virtual models. The concept of settling down particles on the model can be reasonably applied to adding volume to the initial model.

Key Features

Physical interface and feedback

The use of a real spray gun is the essence of spray modeling interface. It does not only serve as a familiar interface but also provides effective feedback with air force and sound. This sensory feedback will activate modeling ideation as well as enhance the realistic perception of the spraying distance and the amount of air. There are several controllers attached to a spray gun and they can be used to change the spraying distance, emitting angle, amount of air and paint. These factors can be flexibly adjusted to make various spraying effects.

Spraying and attaching particles

Spray modeling reduces several difficulties of virtual modeling in space. Even if users spray particles slightly away from the aimed position, particles will attach to the ones that are already positioned. Considering the difficulties of delicate gesture in space, this virtual modeling interface enables users to control the device in simple repetitive spraying gestures, moving the device up-and-down or right-and-left within a short range, just like expert model makers.

Frame guidance for form development

As in clay modeling, the process of frame construction allows active expression of rough concepts and its continuous development. Users can also iteratively evolve the initial form by deforming the overall frames and then comparing various alternatives. Moreover, through the use of real wire as a physical reference to virtual frame, which is overlaid in real space, spatial modeling becomes easier.

Organic form modeling

This spray modeling process and manipulation is more suitable for modeling organic forms, which are difficult to form with typical functions such as “extrude” or “sweep”. In this modeling process, free-form expression and smooth assembling of separate parts are supported intuitively because it keeps the simple and repetitive methods of additive modeling.

Modeling Process

Spray modeling is composed of three modes; 1) 3D frame construction, 2) volume spraying and 3) surface smoothening. This combination of modes is selectively used for intuitive expression of rough forms and its evolutionary development. According to this process, a user draws the initial frames as a guide for further volume spraying. Next, s/he adds volume around them by spraying particles. Occasionally s/he refines the model through surface smoothening. This process is done iteratively and continuously until the desired form is achieved.

3D frame construction

As we found that basic frames are built with linear wire or wood in the beginning of clay modeling, the user starts modeling by 3D frame construction. The frame is constructed with real materials, such as wires or a set of joints, and can be ambiguous in the beginning. Ideally the shape of the real frame should be recognized in real time. In our system, the user has to replicate the frame.

The physical frame may not only serve as a form developing mediations in initial modeling process, but also as an effective spatial reference of virtual manipulation, if overlaid by corresponding stereoscopic image of virtual model. Since the physical object adds realistic perception to the 3D model, it is helpful in spraying virtual particles, reducing the difficulties of accurate positioning in space.

Volume spraying

Once the frame is created, the user sprays virtual particles around the constructed frame to add volume. This process is proper for continuous development of forms and for comparing the gradual changes with the previous form.

In this mode of volume spraying, the virtual particles coming from the spray gun are attached to the nearest frames or previously generated particles of a 3D model. Otherwise, it is ignored. The changing image is updated on the real and virtual frame in 3D space with stereo display.

Surface smoothening

Once the form development with the particles is done, the surface needs to be polished smoothly. This is achieved by spraying finer particles to fill the gaps between each other and then pressing on the surface to smoothen it.

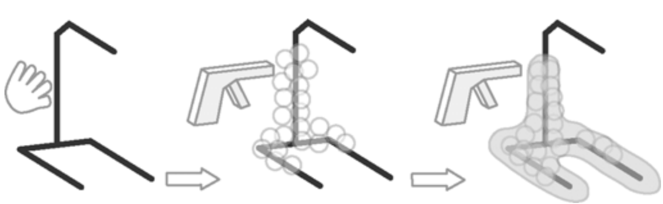

Figure 4. Spray modeling process
1) 3D frame construction, 2) volume spray, 3) surface smoothen

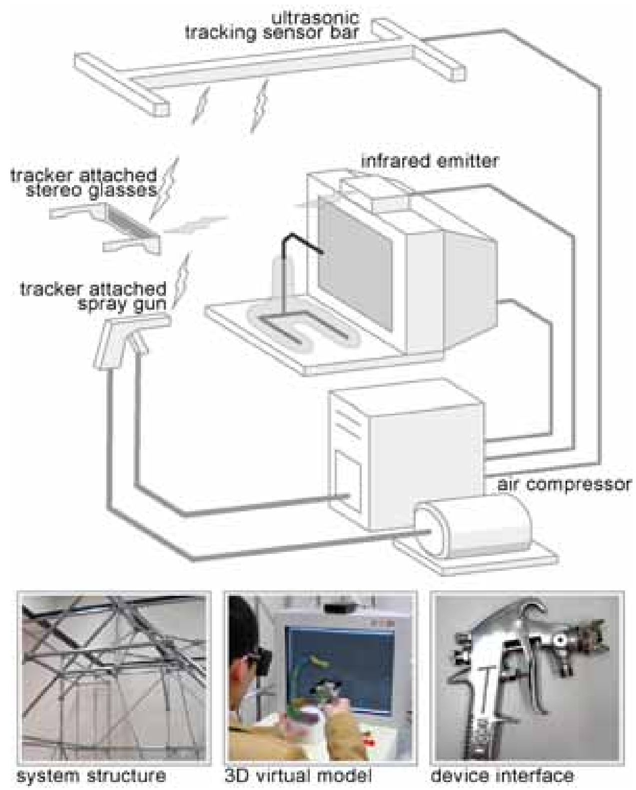

Figure 5. Augmented reality based system for spray-modeling

In this mode of surface smoothening, the separate particles that compose a model can be integrated into a solid form and create a smooth surface with relevant algorithms. It is somewhat similar to heating and melting the particles together. This mode can be applied further in modification of the form by condensing or melting more particles on it.

Implementation

To support direct manipulation of virtual model, we set up a stereoscopic display with a tracking device. Users' physical manipulation of the tracking device and its corresponding 3D data to virtual models had to be accurately positioned. An augmented reality based system was established as shown in Figure.5.

System structure

The system consists of a stereoscopic display system with active stereo glasses (CrystalEyes™ and a monitor), and a 3D tracking system (IS-900 PC™, ultrasonic sensor bar, a wand tracker and a head tracker). The software was implemented with the VisualizationToolkit (VTK) in Visual Studio.Net environment. The 3D tracker and sensors to detect the user's physical control are connected to a real spray gun. A real spray gun with air compressor is used as an interactive input device providing air-force feedback and a simple wire is placed in front of the monitor as frame guidance, overlaid by the virtual model.

Registration

Registration, the accurate positioning of virtual model in the real world, was one of the key technical challenges. To determine the position and scale of the virtual model in the real world, we used binocular parallax technique [19]. Basic camera parameters, the separation distance between eyes and the view plane where the resulting images will be viewed are the primary factors of stereo rendering. By controlling the eye angle in VTK, we realized the suitable three-dimensionality of display according to the focal point.

In prototype implementation, we combined a CrystalEyes™ and a NTSC monitor into stereo viewing hardware considering the cost-effectiveness and feasibility.

We set the focal point at the center of the monitor plane by employing the space in front of the monitor as working area. 3D model is assumed to be created around this point and users are supposed to look approximately at this point. The users' head position and orientation are tracked with 6DOF (Degree of Freedom) head tracker and the separation distance between the eyes is given as a constant value of 8cm. The tracked values are used to get the view up vector and the viewing direction. While controlling the eye angle in VTK, we realized the suitable three-dimensionality of display according to the varying focal point. With these factors, the user's view is updated in real-time according to the user's movement. Additionally, the amount of parallax generated can be controlled by adjusting the distance between focal points and users' head position(see Figure 6).

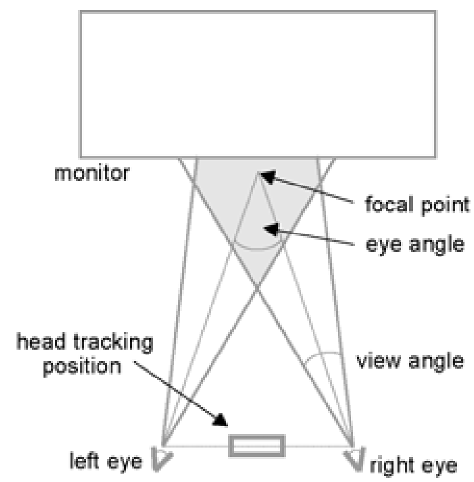

Figure 6. Stereo rendering and binocular parallax

Calculationm model for spraying

As a user manipulates a physical spray gun, the virtual particles are emitted in the augmented space. The spraying effect can be simulated with the model shown in Figure 7. The 3D tracker that is attached to the gun detects the position and orientation of a spray gun, and a virtual plane perpendicular to the direction of spraying is calculated at a certain distance, which is determined by the strength of pulling. On this virtual plane, some random points are selected around the intersection point within a defined range, which is determined by the spray angle. Connecting these random points and the virtual position of a spray gun, the emission paths are determined. The density of emission defines the number of emitting lines within a given area. Supposing each line emits a particle in its linear direction, the sprayed particle is settled on the position where it meets other existing surfaces or frames. If one line has several points of intersection, the nearest one from the starting point is selected.

The sensor connected to the spray gun can provide the sense of real manipulation of the virtual model. As the trigger of a spray gun is pulled, the virtual particles are emitted and they construct a volumetric 3D model. The distance of emission is determined by the pulling strength on the trigger. The emitting range, the radius of individual particles, and their density can also be controlled just as one would manipulate them on a normal spray gun (Figure 7).

For the surface smoothing effect, several VTK classes were tested to reconstruct a surface from the unit particles. *Guassiansplatter* integrates all the separate points into a whole mass after calculating their relationship with all neighboring points. *SurfaceResconstruction* is also a similar class which transfers separate position data into a surface or a solid as a whole. Since these classes are basic functions provided in VTK, physical manipulations of users such as rubbing and indenting the surface are not taken into account. With such detailed surface control which enables the refining as well as the deformation of surfaces, users can try out various formative experiments. Algorithms should be studied further for more feasible modeling which supports a detailed controlling of the surface.

We implanted this concept in prototype by combining the processes of physical frame construction of normal wire and of virtual 3D frame drawing over it. Instead of

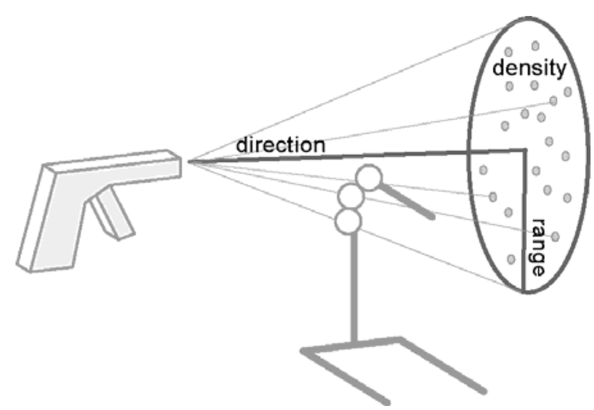

Figure 7. Mathematical model for the virtual interaction

connecting wire deformation to digital data, users themselves are to draw virtual frames according to the wire by themselves. As they indicate a certain position with the input device, sequential points are generated and the lines connecting these points all together form the whole 3D frame in space.

Interaction

As described above, an augmented reality based modeling interface is implemented as an interactive prototype. Based on this configuration, more detailed user interaction is conceived for an intuitive and usable manipulation.

Mode Conversion

Spray modeling is composed of three processes of 3D frame construction, volume spraying and surface smoothening. All is performed with one device manipulation and we should consider both the flexible conversion and the separation of modes. We can relate the change of modes with the manipulation of controllers on the device. For example, the users can toggle the three modes by rotating the valve set in front of the gun.

Visual Interface (Indicator)

This spray modeling mainly focused on reducing the difficulties of virtual modeling in 3D space. Spraying virtual particles and attaching them to previous ones based on the parallax stereo display overlaid on the physical frame lessen the difficulties of accurate positioning. In addition to these considerations, a visual indication of the spraying direction also can be helpful in controlling spatial interaction. With a slight touch of the trigger, each emitting path starting from the device is highlighted, indicating the ultimate direction and the density of spraying. With this visual interface, users can determine whether or not s/he should accept the spraying conditions.

Hand Interaction

Flexible use of two hands may influence effective modeling interaction. Generally the roles of hands can be divided into the main role of manipulation and the assisting role of positioning the virtual models. In the current prototype, we used a fixed virtual model with motion parallax stereo display and therefore, movement of the virtual model was not considered. However, for a more interactive manipulation, we can suggest free movement of the virtual model with a subsidiary hand.

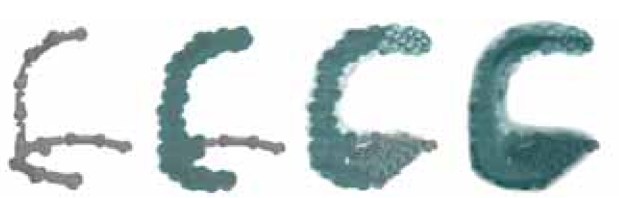

Figure 8. Modeling scenario for shaping a lighting device

Case Study and Evaluation

We conducted a case study for modeling a lighting device with spray modeling prototype within industrial design students at KAIST.

Participants showed curiosity about the new interface and caught on easily on handling the device due to it's familiarity with the spray gun.

They showed a positive attitude towards the proposed modeling process of frame construction and additive spraying. Virtual and physical frames supported active expression and development of ambiguous ideas, and users used this function in various customized ways. They made several linear wires and twisted them to create a polygon type frame rather than linear frame because they found that the wider frame surface the easier it was to spray particles.

Currently, the presented surface is rather coarse because of the limited performance of surface editing with the provided VTK classes. Thus the algorithmic solution should be developed further to support a refined expression. Detailing and modifying functions such as deleting, carving and rubbing should also be considered with technical solutions for a more complete modeling process.

In relation to surface refining, the concept of a masking guide may be additionally suggested for finely finished expression. In real spray coloring, experts use masking tapes to prevent some parts of the surface from being colored. Likewise, in this virtual volume spraying, it might be helpful to make use of such masking to hide certain areas from being sprayed. It will be required especially to express orderly geometric surfaces for a final design result.

DISCUSSION

As a metaphoric approach to explore this concept interface, we reinterpreted familiar real world modeling behavior and its physical characteristics into an augmented reality based experimental interaction. The spray-modeling interface is suggested as a possibility out of various modeling concepts and we expect it to be linked to a wide range of applications and human computer interaction researches as well as CAD modeling itself. In particular, the adoption of a spray gun as a physical input device can be applied to various applications with air force feedback for VR/AR based spatial interaction. Also the simple interaction of spraying many unit particles at a time can be modified flexibly according to different contexts of use. Some interesting application ideas are discussed below.

Air haptic I/O device

The possibility of air force feedback was discovered as we focused on the conceptual modeling device, an air spray gun. Distinguished from prevalent mechanic haptic feedback, air force feedback is simple yet effective. Moreover, connected with a compressed air source, it generates diverse tangible feelings according to the device structure. Delicate feelings can be simulated through corresponding air responsive feedback such as emission, suction, rotation or vibration. Due to this direct feedback from the device, the interaction of input and output can be tied into a single I/O device for spatial interaction.

Game interaction device

The air spraying interaction can be extended to interactive game devices. As computer graphics and virtual simulation technology varies, users expect more immersive and realistic experience in interactive games. Currently the vibration feedback is popularly used as effects of car-bumps or explosions, but they are rather passive and difficult to control the strength. However, air force can be applied in more dynamic user interactions like shooting balls in football games or throwing darts, where the control of pressure and its feedback are closely related.

Creative art education

Generating complex forms with repetitive simple units is a fundamental way of modeling as described in the spray-modeling concept. Similarly, this method can also play a role in developing children's cognitive capacity through creative art education like stacking blocks or paper folding. For example, children may construct a tree shape with repetitive nail shaped unit and this expression can enhance children's understanding of the relation between different shapes in the world. Moreover, applied in virtual or augmented reality, unit-spraying manipulation can be translated into a more interesting expression, with functions that are impossible in the real world. Since the particles can be deformed according to their spraying path or user's motion, it has unlimited possibility in expressive computing art and education.

CONCLUSION

This study started with the objective to support intuitive and evolutionary design modeling. We observed and analyzed various model making fields to understand their process and methods to get inspiration for a new modeling interface concept. Based on the understanding of various model-making methods, we suggested "spray modeling" as a designer-friendly CAD modeling interface in an augmented environment.

We used a real spray gun as an interactive input device and suggested relevant interface concepts like flexible modeling process and physical feedback of air-force. During interface concept-development, we took novelty into consideration as well as efficiency of task performance, because formative ideation should be done in a creative way. Though this experimental concept is not feasibly implemented, the interactive prototype was proved to be quite inspiring, inciting users' active reaction. For its feasible realization, further technical implementation is required to improve the performance of the spray modeling system.

The physical frame manipulation, which is directly linked to the virtual 3D frame shape and to the overall volume deformation around the frame, should be realized for a more intuitive and evolutionary 3D modeling. The surface refining function also should be improved for realistic expression and active idea development. These technical considerations will enhance the possibilities of spray modeling as a natural modeling interface with its reasonable process.

Additionally, the metaphoric approach that retranslates real world action into augmented reality based interaction engenders many interesting application concepts in various areas besides 3D CAD modeling. In particular, the air force feedback can be applied to a novel haptic interface and effective I/O device for spatial interaction. The spraying manipulation can be applied in interactive games and creative art. These ideas are expected to be an inspiring start point for human computer interaction researches.

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