

## SPATIAL SKETCH SYSTEM FOR CAR STYLING DESIGN

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### ABSTRACT

It is undesirable for car designers to wait long for a physical mockup, or to learn a difficult CAD interface. This paper presents a Spatial Sketch System that provides a sketch-like modeling interface, and realizes 3D drawing for human oriented industrial design, such as car styling. The designer can draw lines and surfaces directly and freely in the canvas of 3D space by operating a pen-type pointing device while viewing a stereoscopic display. The process of modeling consists of two parts: Rough Sketch and Refinement. In the Rough Sketch, the user works his/her ideas out rapidly by drawing free-formed curves and surfaces. This is an expansion of the ordinary 2D sketch into a 3D digital tool, and is useful for the conceptual design that is the first stage of car styling. It provides multi-layered canvases and colored pencils that are selected from a 3D floating menu. An erasing command is performed just as if a real eraser rubs drawn objects out. Then, in the Refinement process, precise tracing of the sketched surfaces completes the refined NURBS model. Functions to assist the user are also implemented. For example, commands of frequent use are selected by simple gestures. For example, a curve is removed when the designer shakes it quickly. This enables faster command selection than that depending on a typical menu-based interface. All commands are saved so that the designer can undo and redo them to rapidly compare alternatives in creative design work.

### 1 INTRODUCTION

Computers are employed more and more in industrial product design because the alternative - the construction of physical mockups - wastes time and money. Currently Computer Aided Design (CAD) systems were used as standard digital tools to construct three-dimensional models. The advantage of a CAD system is that a mathematically well-regulated model can be made, but the common use of three orthographic views isn't intuitive and operations are complicated. It is disadvantageous for conceptual design, which demands the inspirations of designers in the early stage of the design process. It is also difficult to understand stereoscopic impressions with the standard non-stereoscopic CRT display. As a compromise, conventional paper sketches are used for the initial imagination of designers; then CAD and clay or wood mockups are employed for the final evaluation of consistency and quality of products. But designers long for an environment where all design processes can be done consistently using the computer.

Therefore, this paper presents the Spatial Sketch System, which realizes such an environment. The canvas of this system is three-dimensional space: the designer can draw curves and surfaces in space directly using a pointing device just as he/she would use a pencil. Because the intuitive interface mimics a paper sketch, the creative work is never disturbed. And, it is easy to refine the design by trial and error thanks to digital data. Furthermore, by stereoscopic display, it is possible to visualize the car interior design and to evaluate the ease of operation of the cockpit at the same time.

To construct such an integrated environment, it is important to provide not only an intuitive and easy interface, but also the correction of differences of coordinates between the real space and the virtual space. Mismatches between the input device coordinates and the stereoscopically displayed coordinates make the reproduction of the imagined design impossible, because the impression of virtual product made in un-harmonized coordinates will be different from the produced real product. This means that the examination and evaluation, which is the final stage of the design process, can't be done correctly.

So, in this paper, we describe a way of developing a system in two themes. One is how to sketch in space using the Spatial Sketch System, and another is technique to display correct stereoscopic vision to user.

## 2 TOOLS FOR CONCEPTUAL DESIGN

Let's think about the traditional design process. In the first step, the designer sketches his/her ideas on a paper with a pencil, or kneads clay for the creation of a new design. Sketching is able to represent ideas rapidly; therefore many designs can be created quickly. Clay modeling isn't as speedy as sketching, but it is advantages that it can confirm suitability of three-dimension models. At the next stage, these designs are taken in the computer by the scanner or digitizer, and a CAD system refines it. The increase in efficiency of production processes is valued; digital data assist it. If it is digitized once, it may be reused.

There is some research in digitizing the conceptual design directly. For example, SKETCH (Zelevnik, 1996c) and Teddy (Igarashi et al., 1999b) are digital tools, which can sketch in the computer from the beginning. They use a mouse or tablet as the input device instead of a pencil and paper. Therefore, sketching action is digitized immediately. Then, a three-dimensional model is constructed automatically from the two-dimensional sketch action. So, the purpose of these researches is different from our goal a little.

3-Draw (Sachs et al., 1991c) improved the interface of CAD system by using Virtual Reality technology. This system can input a three-dimensional curve directly by using a three-dimensional pointing device instead of a mouse. VLEGO (Kiyokawa et al., 1996a) proposes an easy modeling environment for beginners. It uses a Head Mounted Display and data gloves as the interface, and operation is easy to understand because it imitates LEGO toy blocks. Its main aims are to propose an intuitive and easy interface and to develop the modeling tool by primitive object for beginner (Butterworth et al., 1992; Hashimoto et al., 1999a). Beyond these projects, our system provides an interface that won't disturb the work which needs inspiration, and the stereoscopically display precision which is necessary for the product design examination are taken very seriously.

## 3 SPATIAL SKETCH SYSTEM

### 3.1 Overview

The Spatial Sketch System provides a direct drawing and manipulation environment in three-dimensions. The user holds a pen-type six-degree-of-freedom device by the magnetic sensor in his/her favored hand, and a 3D mouse to assist operation in another hand. Clicking and dragging of the pen-type device brings about various operations.

The procedure of modeling is divided into two steps of the Rough Sketch mode and the Clean Up mode. Rough Sketch is an expansion of two-dimensional sketching, and user can sketch freely in space. Clean Up is a function to make a more steady shape. A three-dimensional model of NURBS curves and surfaces is generated based on the rough sketch.

The stereo images generated by the graphics workstation are projected on a large-sized screen from the rear, and the user perceives objects stereoscopically by wearing liquid crystal shuttered glasses (Cruz-Neira et al., 1993). A magnetic sensor installed on the user's head measures the relative position of the user's eye-points. The virtual objects can be observed from various directions because the stereo image changes corresponding to the movement of the eye-points in real time. The relative position of the eye-points and the sensor is measured each time the system starts, because this changes for every use. We define the eye-points as the center of the pupil upon the eyelid for convenience. And a measuring instrument, with a precision of 0.5mm, has previously measured the inter-pupil distance of every user. Figure 1 shows an overview of the system.

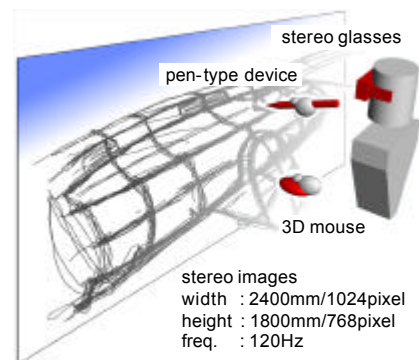


Figure 1. Overview of the system

### 3.2 Rough Sketch Mode

The Rough Sketch is separated into the Line Sketch and the Surface Sketch. The function of the Line Sketch is that the user can draw three-dimensional lines in space. When he/she drags the pen-type device, it traces virtual lines. This is useful to make a rough shape or skeleton. Incidentally, in this operation, if sufficient points can't be gotten due to fast motion, the resulting lines will not be smooth. Current devices can't trace the movement of the hand in satisfactory time resolution. So, it is interpolated by a B-spline curve.

The Surface Sketch can draw surfaces instead of lines, which have a direction and size. This function makes it possible to design a surface more intuitively. The sketch on the paper can't express this. The direction of surface follows the direction of the pen in drawing, and the velocity of the pen decides its size.

The Rough Sketch has other functions. It can change colors and line width, and it can sketch in different layers. Clicking the 3D icon, which floats in space, sets these up. And, it is possible to erase lines or surfaces by using the Eraser. An example of the Line Sketch and the Surface Sketch is shown in Figure 2.

### 3.3 Clean Up Mode

After the initial idea is expressed in the Rough Sketch mode, the refined model is made by the Clean Up mode like a CAD system. This system is based on surface modeling. So, the NURBS curve and surface are the basis of the virtual model. To generate a curve, the user sets up the feature point by clicking points, referring to the rough sketch, and by double-clicking on the last point: the points become a curve, which passes through those points smoothly.



Figure 2. Example of the Rough Sketch

Surfaces are generated by combining curves. When you click on the curve of the number decided respectively after selecting of the function, like the T-Type Surface, from the floating menu, it is done. To generate a swept surface, select the function from the menu, and drag a basis curve. Then the surface is made by two curves of the path and the basis curve.

Even in Clean Up mode one can change properties of objects such as colors or width, just as in Rough Sketch mode. And, it is possible to edit the objects freely. For example, clicking on a curve or surface produces a handle, and dragging of this makes it possible to resize and rotate the shape. Additionally, dragging of a passage point and a control point edits the object in real time. Moreover, objects are moved by direct dragging, and are copied and deleted by gestures.

### 3.4 Command Switching

Gesture (not the 3D menu) selects the mode (Rough Sketch and Clean Up) and the tool (Sketch and Eraser). Gestures can work more speedily than menus. Because, when you use a menu, you have to move the pen to a menu, and then look for the command you desire, and finally restart your work after these troublesome steps. But, a gesture can do all this in one action. And, command switching of the Generate Curve and Select Object in the Clean Up mode is changed automatically by the user's action for the same reason. Figure 3 illustrates the flow of mode switching.

In consideration of the command use frequency, frequently invoked operations are controlled by gesture or action suitable for quick switching, while commands, which have many variations, or function uses a menu. Each implementation is explained in the following.

#### Switching between the Rough Sketch mode and the Clean Up mode

Click near your shoulder with your dominant hand, at most 10cm in front of your eyes.

#### Switching between the Sketch Tool and the Eraser

Click near your shoulder with your non-dominant hand.

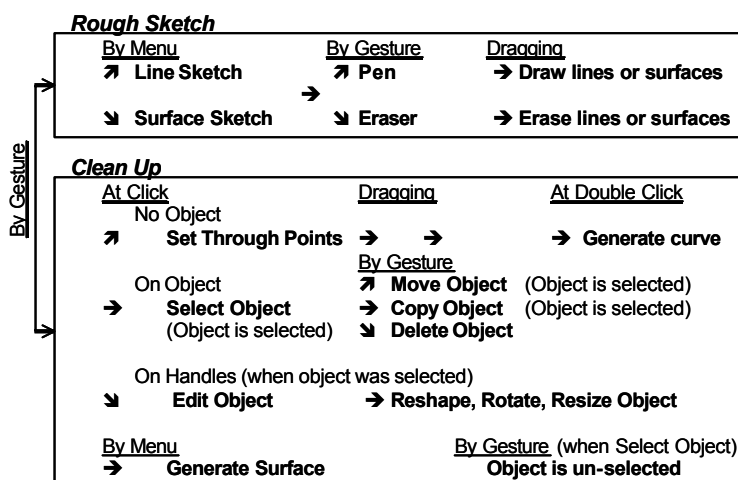


Figure 3. Flow of the mode switching

Action in the Clean Up mode

In this mode, the command invoked depends on where you click. When you click where there is no object, the Generate Curve command starts. After clicking passing points, double-click on the last point. When you click on an object, the command is Select Object. You can move or copy a selected object by dragging without a break. While in this mode, handles control the rotation, size and shape of the object. When you drag them, the object is rotated, resized and reshaped. Quit this mode by clicking near your shoulder with your non-dominant hand.

Judgment of Move, Copy and Delete Object

To distinguish between these commands, the system analyzes the stroke when the user drags the object. The object moves when it is simply dragged. When a loop is drawn in the beginning of dragging, the object is copied to the place where the button is released. Moreover, when the object is dragged with a shaking motion, it means to delete object. For the recognition of gesture, angles between each stroke are used (See Figure 4; Lipscomb, 1991a; Rubine, 1991b).

**3.5 Other Functions**

The system has other functions to assist design. We introduce these functions in this subsection.

Control of the Work Space

A 3D mouse controls the scale, location, and rotation of the workspace. For example, the workspace of 1/2 scale can be used for the rough sketch, and then it is returned to actual size in the evaluation stage. The ability to rotate designed objects and view them from various angles is useful.

Undo and Redo

Because all the sketching commands are completely remembered, you can undo and redo at any times. It is possible to resume it later by saving it in the file, too. These functions are assigned to buttons on the 3D mouse, and not to menus or gestures, since they are used so frequently.

Mirror

Cars are largely symmetrical. Therefore, it is convenient when lines are drawn if the opposite side mirrors the original at the same time. This mode is toggled by menu.

Indication of Guide Lines and Structures

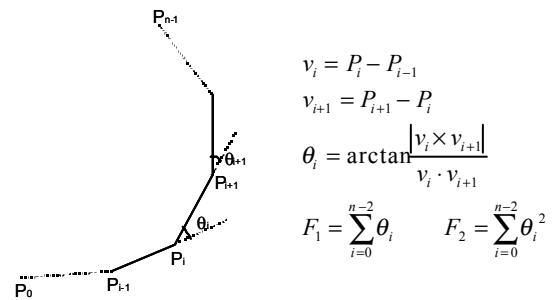
Indicating a guideline and fitting an object to it facilitate the design of more precise shapes. And a problem in design can be made easy to look for by indicating the structure, which is known to limit the design in advance, such as an air conditioner unit.

**4 BUILDING OF VIRTUAL WORKSPACE FOR DESIGNING**

Theoretically, when the system can measure various necessary parameters for rendering stereo images without measurement errors in real time, it will give the user a correct stereoscopic effect. Actually, however, it is unavoidable that measurement contains some errors. And, the virtual world obviously has a few cubic effects than the real world. So, even if correct stereo images were rendered, it wouldn't be assured whether people could perceive a cubic effect properly.

To make a comfortable design environment, the correction of differences of coordinates between the input device and the stereoscopic display is required. In other words, we need fuse the two worlds.

This system realizes this high precision fusion. Figure 5 shows the flow of it. The following explains that flow.



At the stroke in 0.7 seconds from the beginning

```

if F2 > 6000°
    then DELETE
if F1 > 330° and 20° < average(theta) < 60°
    then COPY
else
    MOVE
    
```

Figure 4. The basis concept for gesture recognition

### 4.1 Proper Use of the Position-Detecting Sensors

The optical sensor is high precision, 0.51mm in this system, but when objects conceal the sensor, it is impossible to measure, and in any case it is difficult to measure in real time by current devices. In contrast, the magnetic sensor can measure in such a situation. However, it is known that there is a problem: a magnetic source in the neighborhood may reduce its precision (Muller, 1997).

Our necessary precision is several millimeters, and so an error on the order of centimeters is inadequate. Therefore, an optical sensor is combined with a magnetic one to combine their advantages with this system. The magnetic sensor measures the eye-points and pen, because these measurements of position and direction are required in real time. The optical sensor is used for the registration of the real world and the virtual world, and for correction of magnetic sensor's coordinates, since these must be precise.

### 4.2 Distortion Correction of the Magnetic Sensor

At the first step, the position of pen and eye-points as measured by the magnetic sensor in real time are transformed into real space coordinates. Here we regard the coordinates measured by the optical sensor as the real space coordinates because this sensor has few distortions. For transformation between coordinate systems, a 4x4 matrix is used (A). The making of this matrix requires the following steps.

First, several positions in space are measured with both the optical sensor and the magnetic one. Next, a matrix, which outputs the position of the optical sensor's coordinates from the input of the magnetic coordinates, is calculated by a least squares method. The two correction matrices, A1 for the eye-points, and A2 for pen tracking, are calculated separately for the improvement of precision, because the regions of their working spaces are different. Matrix A1 is calculated by sampling 60 points in the range of the width 350mmxheight 250mmxdepth 300mm around the center of the eye-points. Matrix A2 is calculated by measuring another 90 points in the range of the width 500mmxheight 500mmxdepth 300mm, which is the working space of the pen. Finally, these two matrices are mixed, resulting in matrix A. The Figure 6 shows the mixing algorithm.

The effectiveness of these two matrices is shown in Table 1 and Figure 7. Here, the errors are calculated as the difference between the position, as measured by magnetic sensor and transformed by each matrix, and the predicted position in real coordinates. In the case of using only one matrix, the error exceeds 7mm. But by using a mixed matrix, errors decrease to about 3mm.

### 4.3 Matching with the Virtual Space Coordinates

The main use of the system is designing car interiors. Therefore, only the position of the seat is set in both the coordinates of the real space and the virtual space. So, we use it to find corresponding coordinates. With actual measuring, the screen is measured, instead of the seat, because it is easier. The screen is decided uniquely as a relative position from the seat. The matrix B that transforms both of the real space and virtual one is defined based on the screen position as follows (B).

First, we define the virtual coordinates as the orthonormal coordinates: the origin is the center of the screen, and the X, Y, Z-axes are the normal, horizontal, vertical direction with respect to the screen. Here, the projection screen is the plane X=0. Next, a grid with a 100mm step is synthesized by computer graphics and projected on the screen, and the optical sensor measures this. This sets the Y-axis and Z-axis of the virtual coordinates. Then, X-axis is computed as the

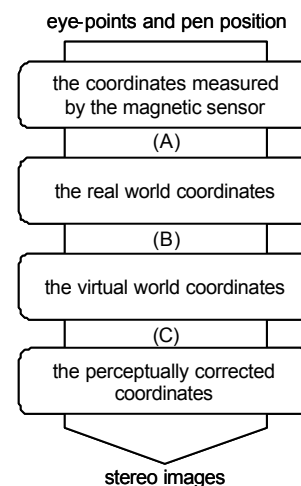
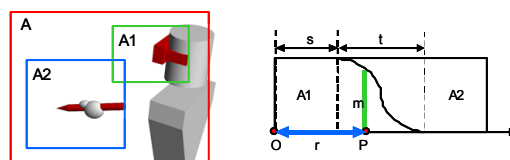


Figure 5. Flow of the registration



The transformation matrix A is,

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if r<=s
    then A=A1
if s<r<s+t
    then A=m·A1+(1-m)·A2
if r>=s+t
    then A=A2
    
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where m is the ratio for mixing of two matrices,

$$m = \frac{1}{2} \left\{ 1 + \cos \left( \pi \frac{r-s}{t} \right) \right\}$$

r is the distance between the position of the sensor P and the origin of the magnetic field source O.

s is the effective radius of matrix A1. (s=250mm)

t is the range which mixes matrix A1 and A2. (t=100mm)

Figure 6. Making of transformation matrix

	region		
	near eye	near pen	all
A1 only	1.612	10.692	7.534
A2 only	13.368	3.816	7.138
A	1.612	3.799	3.038

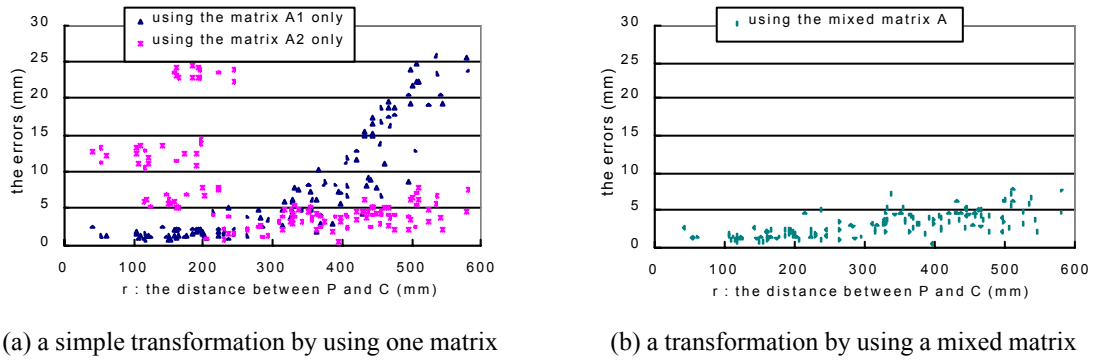


Figure 7. The effectiveness of the using mixed matrix A

exterior product of these two vectors. Finally, we can make the 4×4 matrix of only rotation and translation.

**4.4 Stereo Images with the Consideration of Perceptual Character**

If the above measurements were performed without errors, the user would perceive a correct stereoscopic effect. But, in fact, the user cannot perceive properly, because measurement errors are inevitable, so the perceptual character in the virtual world is unusual (Lampton et al., 1995; Nagata, 1996b; Utsumi et al., 1994).

We investigated the difference of depth perception in such stereoscopic displays in the past, and we proposed a correction technique in a previous paper (Yoshida et al., 1999c). By using it, the coordinates are transformed into stereo images coordinates with the consideration of perceptual characteristic at the end (C).

This is performed by modification of both the eye-points and the screen position in the stereoscopic calculation. The optimal amount of modification is decided using sample values of depth differences. Because of this correction, the difference of depth between the pen and the virtual object decreases to within 3mm, on average.

**5 CONCLUSIONS AND FUTURE WORK**

This paper has presented the Spatial Sketch System, which can sketch in three-dimensional space directly. Our system's aim is the use in industrial products design from the initial stage to the final stage. So, we introduced modeling procedures for conceptual design works at the first half. Then, we proposed a technique to make the coordinates measured in real time correspond to the coordinates displayed on the computer, and to render stereo images in consideration of the perceptual character in the stereoscopic display. Our system is able to design more intuitively than the standard CAD system, and it is more useful than the two-dimensional sketch because it uses digital data from the beginning. And, the environment, which the difference between the pen-type device and the virtual objects is within about 5mm, could be realized finally.

At the end, the example of sketch made in our system is shown in Figure 8 when some designers used the system experimentally. As a result of this trial use, we received high evaluations from the designers about the usability and possibility of the spatial sketch.

We would now like to go on to develop this system by adding more commands and to search for use as a CAD system that has the new interface. And the point in the interface parts is open to further discussion. For example, the accuracy of reorganization wasn't satisfactory in this algorithm, so operation by gesture might not be able to work as well as intended. In our future work, we need to improve it, or replace it with another interface, such as voice recognition.

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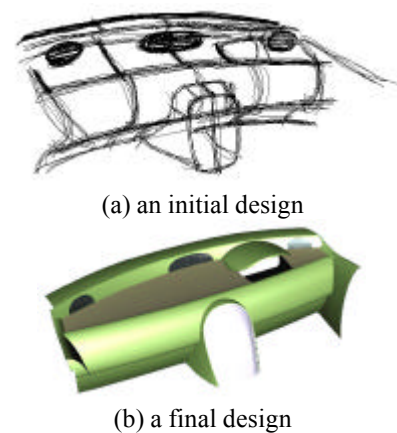


Figure 8. Example of sketch by designer in the trial use

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refining this paper. Finally, we would like to express our sincere gratitude to Dean and Professor Teruo Fukumura at Chukyo University for his considerable support.

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