Sketch Based Modeling System

Hideki Aoyama and Hiroki Yamaguchi

Keio University, Department of System Design Engineering
3-14-1 Hiyoshi, Kohoku-ku, Yokohama, Japan
haoyama@sd.keio.ac.jp, yamaguchi@ina.sd.keio.ac.jp

Abstract. In the design process of the external form of a product, sketching is applied for creating and embodying idea. Sketches are able to reflect the aesthetic sense of designers the most easily, making them the most efficient design tool. Sketches can be classified into thumbnail sketches, rough sketches, and rendering sketches according to the embodied idea. Rough sketches are used for developing the idea. In this paper, a system to support the rough sketching process and evaluate the designed product shape using 3D models constructed from the rough sketch is described. This system has a function for extracting and generating sketch lines drawn by a designer, a function for interactively modifying sketch lines, and a function for constructing 3D models from rough sketches. In order to support rough sketching, algorithms which automatically extract/generate the desired sketch-lines are proposed and implemented as a system. A method to construct 3D models form sketch lines is also proposed and implemented as a system.

Keywords: Style design, idea embodiment, 3D model construction, Sketch, Sketch supporting system.

1 Introduction

Circumstances surrounding product development are significantly changing, and it is becoming increasingly difficult to differentiate the functionality and economic efficiency desired with the progress of manufacturing technology. As a result, design is increasingly playing a larger role in the selection of products as awareness of its importance grows.

Various computer aided systems are effectively working for design and manufacturing processes. In design processes, computer aided design systems (CAD systems) are utilized for detail design of functional parts. However, currently used CAD systems have the following problems;

- form definition processes are complex,
- the designed form depends on the primitive shapes of the using CAD system, and
- creativity of idea is obstructed by the complex operations.

Therefore, support performance for appearance design and basic design of 3D-CAD systems is extremely poor. Since the design of the appearance configuration is a creative endeavor which strongly depends on aesthetic sense of designers, it is difficult for designers to make use of this aesthetic sensitivity due to the complicated

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operations of 3D-CAD systems which interfere with the ideas of designers. Design shapes created are thus limited by the capability of 3D-CAD systems, which lead to the need for systems with high operability which do not interfere with the ideas of designers.

In the process of embodying the external form of a product, design is firstly created by sketching. Designers embody the form from the image while they sketch over and over again. Sketches are able to reflect the aesthetic sense of designers the most easily, so they can be said to be the most efficient design tool. Sketches can be classified into thumbnail sketches, idea sketches, rough sketches, and rendering sketches according to the embodied idea level [1]. Among these, rough sketches are sketches which are located midway between thumbnail sketches and rendering sketches and used to develop the idea. After the image which forms the basis of a product is represented in the thumbnail sketches, rough sketches are drawn to advance the idea based on the thumbnail sketches. In the rough sketch process, designers draw many lines for a line expressing a product, and a clear line is finally determined. Drawing rough sketches expands the idea developed in the thumbnail sketches.

In this study, the authors proposes a sketch support system which uses a tablet PC as the input device of sketch lines to automatically extract or generate the desired sketch-lines from information on drawn lines as the rough sketches, and which can also interactively modify extracted or generated lines. In order to evaluate the designed product shape, a system which automatically constructs 3D models from rough sketches is also proposed. The proposed systems: the sketch support system and the 3D model construction system, are implemented and there effectiveness are confirmed by basic experiments.

2 Proposed System

2.1 Background of Proposed System

Figure 1 shows an example of rough sketches drawn by a car designer in the process of embodying the external form from images. As shown in this figure, first, the designer thinks of and develops ideas, and creates the whole shape desired gradually while drawing a one silhouette line which expresses the outline of the car many times over each other. Based on these lines, the designer redraws the thick and wide line for a silhouette line of the whole shape, and decides the designed shape of the car.

Recently, digital sketch systems for drawing sketches on computer directly using a pen tablet and tablet PC are introducing for practical use. Being used digital sketch systems are more convenient than traditional sketching using a paper and a pencil in painting compared to coloring and shading. However, with regard to drawing lines which is the most important process in sketching to advance an idea, the advantages of digitization cannot be applied. When using digital sketch systems, designers advance their ideas while drawing one silhouette line many times and embodying the desired lines while deleting the unwanted lines.

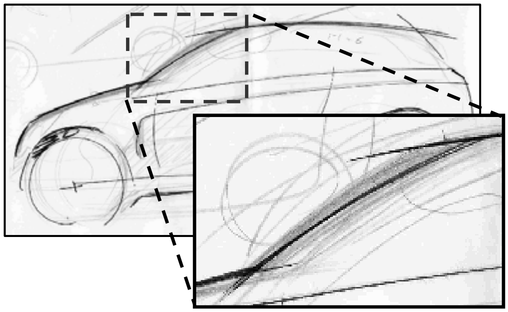


Fig. 1. Example of rough sketch

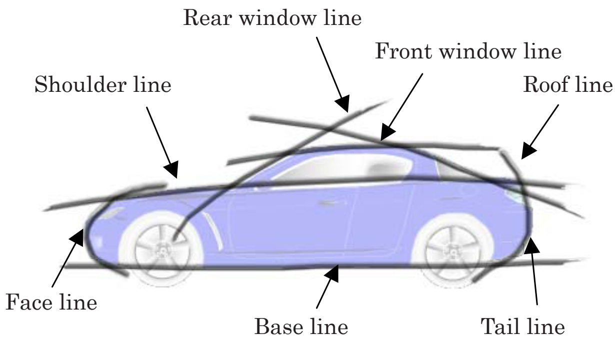


Fig. 2. Silhouette lines expressing car body form

2.2 System Configuration

In view of the above mentioned circumstances, the authors have developed a sketch support system applying the advantages of sketch digitization. This system has a function for extracting and generating sketch lines, function for interactively modifying sketch lines, and function for constructing 3D models from rough sketches. From the information on sketch lines input to the tablet PC, a line is extracted or generated automatically. By overwriting new lines to an extracted or generated line, this line can be modified interactively. In addition, 3D models can be constructed from 2D sketches generated in this way and the design can be evaluated in the 3D form.

2.3 Function for Automatically Extracting and Generating Sketch Lines

Input of Lines. In the initial process of aesthetic design, designers embody their image by drawing the external form of a product using silhouette lines. Silhouette lines express boundaries of brightness on the object when parallel rays are applied. Figure 2 shows the silhouette lines expressing the side shape of a car. In the case, the side car shape is represented by seven silhouette lines.

This system extracts or generates the line for a silhouette line which is drawn as many lines in his/her thinking process by a designer. Upon deciding a silhouette line by extracting or generating, the designer lays a layer, and completes the side shape of a car. When deciding a silhouette line, the line input as scattered points is approximated to a cubic Bezier curve. When a cubic Bezier curve is defined as $Q(t)$, and the control points of $Q(t)$ are defined as $Pi(i = 0 - 3)$, $Q(t)$ can be expressed by the following equation (1).

$$Q(t) = (1-t)^3 P_0 + 3t(1-t)^2 P_1 + 3t^2(1-t)P_2 + t^3 P_3 \quad (1)$$

Extraction and Generation of Lines. To decide the evaluation criteria in the extraction and generation of a line from a number of lines, the authors interviewed car designers and obtained information on how designers feel when sketching; designers feel that they draw a good line when their arm is moving smoothly and that dynamic lines are drawn with momentum.

From the knowledge, pen pressure and drawing speed in drawing lines were incorporated as evaluation standards for the automatic extraction of lines. A line was then extracted based on the following evaluation standards (a) - (c), and a new line was generated from a number of lines in the following way (d).

(a) The line with the least number of sign changes of acceleration between adjacent points at discrete points on an input line is extracted.
(b) The line with the greatest average-pen-pressure is extracted.
(c) The line with least number of sign changes of the difference in pen pressures extracted is extracted.
(d) The line is newly generated by connecting the mean positions of a number of lines smoothly.

The above (a) and (c) are the processing of evaluation standards capturing the designer's feelings that good design lines appear when the designer's arm is moving smoothly. The processes (a) and (b) mean line extraction in which change in velocity and pen pressure in sketching is the least. The above (b) is the processing based on the judgment that a designer will apply more pressure himself/herself when lines are drawn with momentum. The above (d) is based on the judgment that designers will draw the desired sketch lines themselves many times unconsciously while drawing sketch lines over and over again, and this is the process of finding the average of sketch lines drawn.

Figures 3 and 4 are examples of distribution of pen pressure and acceleration when drawing a sketch line. According to the evaluation standards, the result of extraction based on the process (a) is shown as Figure 5.

2.4 Modifying and Fairing Sketch Line

Modification of Sketch Lines. After the line is extracted/generated from many lines by the above processes (a) - (d), the extracted/generated line needs to be modified interactively based on the designer's evaluation. This system can therefore modify the line interactively by adding new lines to a line extracted/generated after a line is extracted/generated from many lines by the above processes (a) - (d). As shown in figure 6(a), when sketch lines are added to an extracted/generated line, a new line is determined as the position average of the extracted/generated line and added lines as shown in figure 6(b). This process is effective for the case that a designer would want to modify an extracted/generated line partly while confirming the shape little and little. In other case, a designer wants to modify a line by validating added lines and connecting them to a line already drawn smoothly as shown in Figure 6(c). This process is also effective for the case that added lines changes from an extracted/generated line to a large degree.

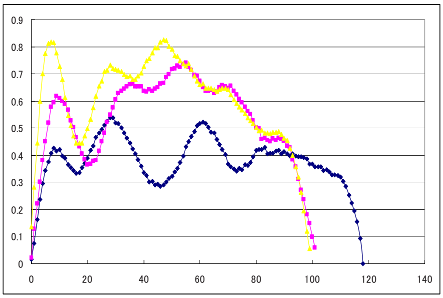


Fig. 3. Distribution of pen pressure

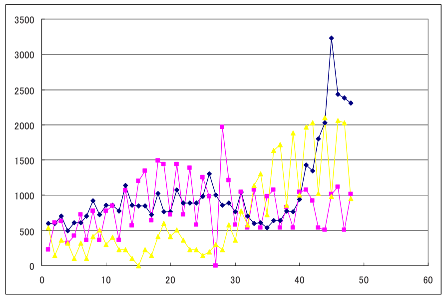
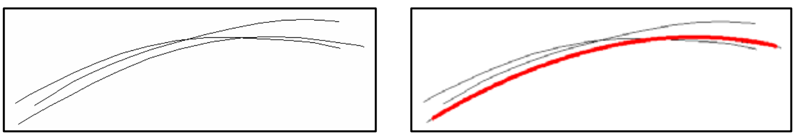


Fig. 4. Distribution of acceleration



(a) Input sketch lines

(b) Result of extraction

Fig. 5. Example of sketch line extraction

Fairing Sketch Line. It is known that designers draw sketches by controlling the curvature of lines unconsciously [2]. Therefore, the aesthetic degree of an extracted and generated sketch line or modified sketch line can be evaluated by curvature distribution which is represented as the curvature logarithm chart. In the chart, the horizontal axis is defined as $\overline{\rho}$ represented in equation (2), and vertical axis is defined as the frequency of appearance $\overline{S}$ represented in equation (3).

$$\overline{\rho} = \log_{10} \frac{\rho}{S_{all}} \tag{2}$$

$$\overline{s} = \log_{10} \frac{s}{S_{all}} \tag{3}$$

where, ρ : curvature, S_{all} : entire length of curve, s : curve length of with ρ .

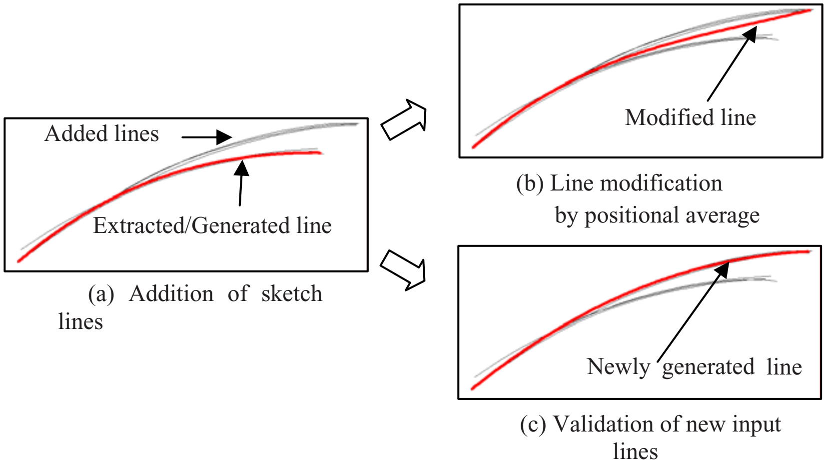


Fig. 6. Modification of sketch lines

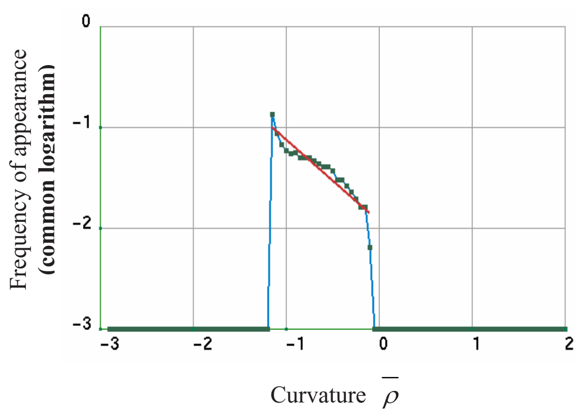
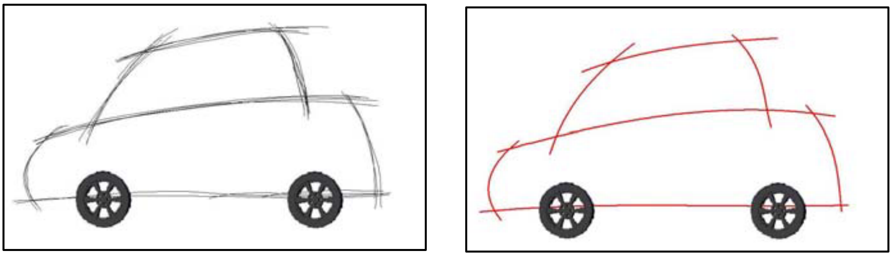


Fig. 7. Curvature logarithm chart

Figure 7 shows an example of the curvature logarithm chart. The chart shows the relationship between curvature and the length rate for curvature and represents the rhythm of curvature. A curve with a uniform curvature rhythm is called a rhythm curve which shows the linear property in the chart. A rhythm curve is seen on industrial products admired for design and beautiful natural objects. A sketch line drawn by a designer is evaluated from the view points of curvature distribution and the faired line can be generated by making the line the linear property in the chart.

2.5 Implementation Results of System

Figure 8(a) shows the rough sketch of the side view of a car drawn on a tablet PC. This figure 8(b) shows the results of extracting and generating each silhouette line



(a)Input sketch lines (b)Extracted or generated lines

Fig. 8. Extraction and generation of sketch line

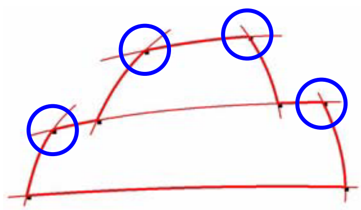


Fig. 9. Positions of connecting curves

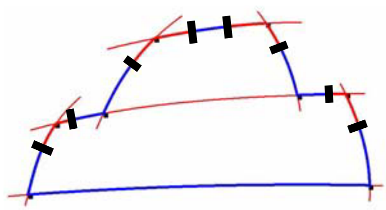


Fig. 10. Division of basic lines

according to the evaluation criteria for sketch lines described above. These extracted/generated lines can be modified respectively.

2.6 Definition of Connecting Lines

As shown in figure 2, the side view sketch of a car drawn with the basic lines seems to be angulated wholly due to positional continuity only at the connected points of the basic lines. In order to connect the basic lines with higher-dimensional continuity, connecting lines should be constructed between the basic lines at the four points as shown in Figure 9.

In order to make connecting lines, the basic lines are divided at constructed spaces as shown in Figure 10. Then, the connecting lines are constructed in the spaces. To construct the connecting lines with higher-dimensional continuity between the basic lines defined by cubic Bezier curves, the lines defined by the control elements [3] and the control points are used.

When two Bezier curves $A(t)$ and $B(t)$ are connected smoothly, formulas (4) and (5) must be established.

$$\frac{dA(1)}{ds_1} = \frac{dB(0)}{ds_2} \tag{4}$$

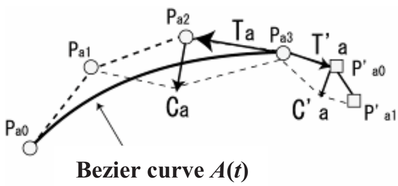


Fig. 11. Tangent vectors and curvature vectors in curve *A(t)*

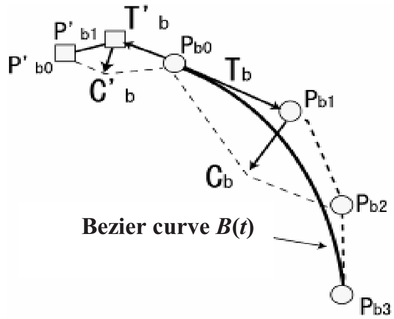


Fig. 12. Tangent vectors and curvature vectors in curve *B(t)*

$$\frac{d^2 A(1)}{ds_1{}^2} = \frac{d^2 B(0)}{ds_2{}^2} \tag{5}$$

where, s_1 : arc length of the curve $A(t)$, and s_2 : arc length of the curve $B(t)$.

When $p_{a0} \sim p_{a3}$ are defined as the control points of the curve $A(t)$, and $p_{b0} \sim p_{b3}$ are defined as the control points of the curve $B(t)$, equations (6) and (7) are established according to precondition equations (4) and (5).

$$T_a = s \cdot T'_a \tag{6}$$

$$C_a = s^2 \cdot C'_a \tag{7}$$

where, s is the proportion of arc lengths of the curves $A(t)$ and $B(t)$, T_a and T'_a are the tangent vectors, and C_a and C'_a are the curvature vectors at connecting point as shown in figure 11. The control elements P'_{a0} and P'_{a1} of the curve $B(t)$ can be then derived.

In the same way, the following equation is also established in the case of the curve $B(t)$. s is the proportion of the arc lengths of the curves $A(t)$ and $B(t)$, and T_b and T'_b are the tangent vectors, and C_b and C'_b are the curvature vectors at connecting point as shown in Figure 12. Thus, the elements of control points P'_{b0} and P'_{b1} can be calculated.

Thus, control points p_{t0} and p_{t1} are derived according to the four elements of the control points.

$$p_{t0} = (1-t) \cdot P'_{a0} + t \cdot P'_{b0} \tag{8}$$

$$p_{t1} = (1-t) \cdot P'_{a1} + t \cdot P'_{b1} \tag{9}$$

Therefore, a smooth connecting curve $C(t)$ between the curve $A(t)$ and the curve $B(t)$ can be expressed by equation (10).

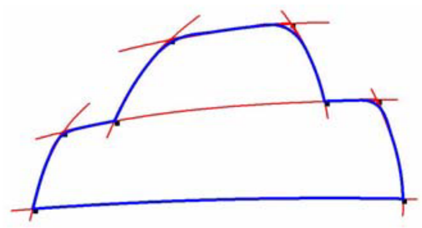


Fig. 13. Basic lines with smooth connecting lines

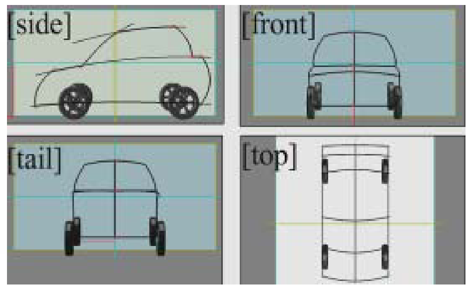


Fig. 14. Example of sketches to construct 3D model

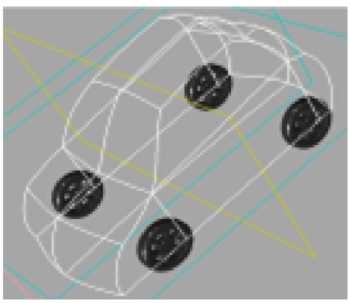


Fig. 15. Constructed 3D model represented as wire frame

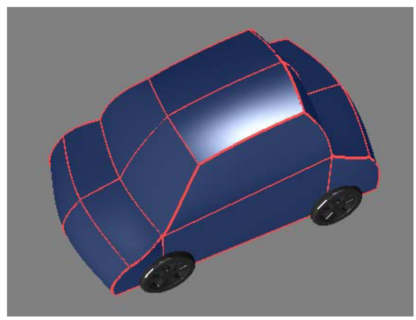


Fig. 16. Constructed 3D model represented as surface model

$$C(t) = (1-t)^3 \cdot P_{a3} + 3(1-t)^2 \cdot t \cdot p_{t0} + 3(1-t) \cdot t^2 \cdot p_{t1} + t^3 \cdot P_{b0} \quad (10)$$

Figure 13 shows the basic curves with smooth connecting curves. The roundness at the connecting points can be changed by the parameters of the connecting curves.

2.7 3D Modeling System

In order to construct the 3D models from 2D sketches, it is essential to decide the target object of design and determine the constraint conditions on modeling. In this paper, the target object of design is assumed to be a car body and the side view sketch consists of seven silhouette lines. The front view, top view, and back view are also drawn with silhouette lines which correspond to seven basic lines of the side view as shown in figure 14.

A system to automatically construct the 3D model from the sketches drawn with silhouette lines of the side view, front view, top view, and back view as shown in figure 14 was developed. Figures 15 shows the 3D wire frame model constructed from the sketches shown in figure 14. And figure 16 shows the 3D surface model of this with cubic Bezier surfaces.

3 Conclusions

In this study, in the aim to support creating process of form design, a digital sketch system which supports the process of rough sketching was developed. The developed system can automatically extract and generate the desired lines from rough sketch lines drawn on a tablet PC and can modify the lines interactively by adding new lines to the extracted/generated lines. In addition, in order to evaluate the design form, a system which constructs 3D models from 2D information generated in this sketch system was also developed.

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