Interactive Geometric Modeling System based on Practical Engineering Drawings*

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An interactive geometric modeling system based on a new CAD/CAM through processing, combining computer aided drawing and geometric modeling, was developed. In this system, three dimensional data can be produced from the internal data of practical engineering drawings. For an example, its application to FEM analysis is shown.

Key Words: Design Engineering, CAD, CAM, Geometric Modeling, Interactive

1. Introduction

CAD/CAM needs a systematic technique: It must be discussed from the stand points of computer technique, human engineering and design theory. It is difficult to have practical application of such a system unless it is one produced from their combination. CAD/CAM through systematization based on geometric modeling is reasonable as methodology. However it is unlikely that usual geometric modeling systems are produced from the above stand points.

Three dimensional models of object are designed internally in order to combine CAD and CAM without making drawings. In this case, drawings are a kind of external representation produced from the internal model. A designer can obtain its drawings only through geometric modeling (Fig.1(a)). Most of geometric modeling methods proposed at present are based on the above idea, which is to construct the basic shapes of elements, referred to as "primitive" in set operation processing, using some system of analysis. Also in this case, the data are produced through the internal model, which is modified according to the result.

This paper intends to explore whether or not a designer can apply a geometric modeling based on the above-mentioned idea for making drawings to describe an object he has in mind. A conclusion cannot be obtained instantly, since it is dependent on the object in question and the method of geometric modeling. However, for the following reasons, it is unlikely that it has practical applications for many products.

- (a) Drawing, which is simply a representation of 3-D objects on a plane, has a long history.
- (b) Geometric modeling methods usually are

limited in the applicable shape, because they assume some standardization.

- (c) At present, a computer aided drawing system is coming into the stage for practical application.

Through the processing system proposed in this paper, 3-D models can be produced from the internal data of drawings (Fig.1 (b)) through CAD/CAM. Through this system, designers can also perform descriptive drawing and design tasks which are not restricted by the lack of representing ability. Further, computer aided drawing and geometric modeling, which have been studied for different purposes, can be combined. In this paper, a geometric modeling adapted to the above-proposed processing system is described. It has been considered difficult for a computer to translate the data of drawings into three dimensional models, because

- ① Drawing data are not usable for the computer in the production of 3-D shapes.

Fig.1 CAD/CAM through system

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- ② Representational practice is different according to the shape of an object.
- ③ Drawings occasionally lack sufficient information for making 3-D shapes. The authors tried to solve the above problems using man-machine interaction.

In this paper, the description and representation of practical engineering drawings are analysed, and the algorithm for producing a three dimensional shape from the internal data of drawings is discussed (chp.2).

Development of an interactive system is carried out as a reasonable shape modeling process by investigating the role of man and computer (chp.3).

As an example, the through processes of drawing, geometric modeling and finite element modeling, and their mutual independency are explained (chp.4).

This geometric modeling system based on practical engineering drawings is discussed from the point of view mentioned above (chp.5).

Detail of finite element modeling will be reported soon in another paper.

2. Basic Investigation

2.1 Analysis of engineering drawings

It is important to establish the methods for description and representation of practical drawings, considering also a geometric (3-D shape) modeling based on drawings. The analysis of practical drawings obtained in this development is shown below.

- (1) 3-D representation of 2-D figure
In the part and assembly drawings, parts and whole shapes are represented as a set of 2-D figures classified as follows:

- ① A figure showing two planes intersecting at right angles in three dimensions (a projection).
- ② A figure cutting an object in a plane (a cross sections).
- ③ A figure showing the surface of an object on a plane (a development).

The 3-D representation of these 2-D figures is defined by the 2-D shape and the 3-D position. From the stand point of the 2-D description of drawings, they are represented as follows:

- (a) 2-D shape
Lines (continuous line, hidden outline etc. showing linear and arc), dimension lines, dimensions etc.
- (b) 3-D position
Reference lines, the relative position of 2-D figures, cutting plane lines, etc.

- (2) Representation of solid object

From the stand point of the representative form of a solid object on 2-D figures, a solid object is represented as follows:

- ① A 2-D figure can be considered a set of basic surfaces (hereafter referred to as surfaces or constituent surfaces), and 2-D surfaces are generally shown by connective lines.
- ② The 3-D representation of a projection surface is represented by a pair of 2-D shapes projected on two orthogonal planes showing their

relative position in 3-D space. Generally, 2-D shape is shown by a characteristic open line, which defines the 3-D representation of the surface. In the other case, the 3-D surface is a primitive shape element. Hidden lines and the other projections (in a three-view system) are auxiliary to the definition of a 3-D surface.

- ③ A 2-D cross-section (plane) shows a 3-D shape directly, while the characteristic line (linear) on the other 2-D figure projected on the orthogonal plane defines the 3-D position.
- ④ The basic 3-D surface of a 2-D developed surface (plane, cylinder (cylindrical cone) is represented by a pair of other 2-D figures (as mentioned above). The 3-D representation of a developed surface is represented by a 2-D development, the 3-D basic surface and the indirect relation of their positions. In other cases, this is auxiliary to the definition of the 3-D surface.
- ⑤ A surface composed of sculptured surfaces is generally represented by cross sections. These surfaces are classified as follows:

- (1) A surface represented by a clipped figure.
- (11) A surface constituted by interpolational cross sections lines.
- (111) A surface constituted of intersection lines.

When (11) cannot represent drawings definitively, (111) represents 2-D figures indirectly.

- ⑥ A solid shape is represented by a set of surfaces. The connective condition of each surface is defined by the 3-D shape and position, and the solid condition is represented by the closed part in 3-D space.
- ⑦ The above mentioned 3-D shapes generally correspond to part shapes represented by a set of 2-D figures on a part drawing, which gives dimensions to define part shapes. The relative position of each part shape is represented by a set of 2-D figures on an assembly drawing, which gives dimensions to define their relative positions. A whole shape is defined by each part and its relative position.

2.2 Flow diagram of 3-D shape modeling

The practical representation of engineering drawings is complex. In order to represent them by a computer, we must resolve the following:

- (1) The translation of 2-D information into information by which a computer can make a 3-D shape.
- (2) Development of an algorithm for the generation of 3-D shapes.
- (3) Development of a round-algorithm for classification and unification.

In Fig.2, a flow diagram for the generation of 3-D shapes, based on the analysis of drawings, is shown. However, it is difficult for a computer to treat each process in Fig.2 automatically,

including the process of memorizing the 2-D data of drawings on sheets. The reasons are as follows:

- ① It is difficult for a computer to understand the structure, sense of 2-D figures and the coordinate system which shows the 3-D position.
- ② The sense is clarified by other indirect processes, such as the 3-D generation of 2-D developed surfaces and the 3-D generation of surfaces whose dimensions, etc., are not given directly in the drawings.
- ③ The interpolational surfaces of cross-sections in drawings do not give sufficient information for 3-D shapes.

In our system man's understanding and ability to interpret are put to practical use through interaction with the computer.

3. Development of an Interactive System

3.1 Basic idea

Fig.3 shows the relation between shape models and drawings and the basic idea of 3-D shape generation in this system. Usually in manufacture each part is made from projections, cross-sections and developments represented in part drawings, and the whole structure is made by constructing these parts from assembly drawing. In this system, shape modeling is performed by a simulation of the above process. That is, shape models, classified into surfaces, part shapes and whole shapes, are in the form of a tree structure. Surfaces of the lowest shapes are defined, part shapes are defined by constructing the surfaces, and whole shapes are defined by an assembly of part shapes. Surfaces are defined by construction lines. Usually the con-

Fig.2 Flow diagram of 3-D shape modeling

struction lines are taken from the part drawing. The other 2-D figures showing the same 3-D shape provide other information for the construction of a surface. The coordinate system showing their relative position in space is defined by each 2-D figure, as before. The method of construction is selected according to the type of 2-D surfaces and 3-D shape.

Using Fig.2, each process is explained as follows. In this case, a few modifications are made for man-machine interaction.

3.2 General flow

(1) Input of 2-D figures

① Drawings

(i) Scaling

The scale of the 2-D lines on the graphic display relative to a full-size object is defined by indicating two points on the tablet and inputting the distance between them.

(ii) 2-D lines

Two dimensional figures (containing reference lines, etc.) can be defined by a simulation of drafting. Highly accurate data can be obtained by inputting dimensions directly. Characteristic points, which define a line, are connected automatically with the nearest point or line in a preferential range. The search range is put into the computer as required.

② 2-D figures

The group of lines which constitutes a 2-D figure are defined as a collectively-numbered 2-D figure

③ Coordinate system

In X, Y coordinate system the two axes of 2-D figure are defined separately by picking (processing in micro-computer) the start point and the end point. But in $\theta, R\theta$ coordinate system, the distance between them is input according to scale.

Usually 2-D lines representing a development are defined after developing the basic 3-D surface, which represents the same object in 3-D space, on graphic display (refer to (ii), (b), ① in

Fig.3 Structure of 3-D shape models and drawings

construction). In this case, the coordinate axes and 2-D figures are defined automatically.

A developed 2-D figure on coordinate system is taken out, and moved to a fixed 2-D position after developing the basic 3-D surface.

- (2) The definition of constituent surfaces (wireframe, rotative and translative solids)

① 3-D lines

Lines are defined before the definition of a surface. 2-D lines are defined by the input of drawings (refer to (1), ①, (ii)). The lines defined in this stage are classified as follows:

- (i) Line of interpolation between 3-D surfaces.
- (ii) Line of interpolation between 3-D cross-sections.
- (iii) Line of intersection between 3-D surfaces.

These are generated by picking the characteristic points and lines of a 3-D figure on graphic display. A line of interpolation is generated by a row of points. The line of intersection is generated by picking the basic surface and the cutting surface. In this system, lines of intersection can be generated by combining planes, cylinders, revolving surfaces, and sculptured surfaces; kind of lines of interpolation generated are linear, arc, spline. Cross section will be illustrated.

② Constituent lines on both sides of a surface

Lines which constitute a surface are defined by picking the lines of 2-D or 3-D figure on a graphic display. In this case, the function of dividing a line is used frequently. In a substantive model, distinguishing between outline and connective lines (refer to 3.3), on both sides of a surface is done by picking the outlines consecutively. In a wire-frame model such as a cross-section, constituent lines are picked freely, or randomly. The translation of revolving surfaces can be accomplished by inputting the rotative and translative quantities of each axis. In addition, after the definition of the surface ③ located on the surface it can also be done.

Fig.4 Construction method by projection

③ Construction, type of surface

Construction lines of a 2-D figure are translated to 3-D (part) coordinate space. In this case, they are connected with 3-D lines which are already generated within a given range. Construction methods are divided into two main classes. Each class is divided into small groups depending on the form represented.

(i) Projection method (Fig.4)

The projection method is used when the relation of a 3-D position to 2-D constituent lines and other 2-D figures required for construction is represented in a global coordinate system. This method is used to generate the cutting surface (line) of a cylindrical body (surface) which is based on 2-D constituent lines. Depending on the type of cutting surface, this is classified as follows:

(a) Plane

A plane can be constructed by picking three pairs of characteristic points on 2-D constituent lines and the other 2-D figure.

(b) Cylinder (plane)

A cylinder can be constructed by picking the arc (linear) line of the other 2-D figure.

(c) Cylindrical surface

A cylindrical surface can be constructed by a row of arc lines (or a spline) of the other 2-D figure. (a) can be constructed by obtaining indefinite coordinates of three different points from the other figure. The plane can be constructed only if the other corresponding points are not represented directly, and the coordinates are defined on other figures, such as abbreviated figure.

(ii) Insert method (in Fig.5)

The insert method is used when 2-D constituent lines are represented in the local coordinate system. When the other figures represented in the global coordinate system are a 2-D projection and a 3-D figure, this method can be divided into two classes, as follows:

Fig.5 Construction method by insertion

(a) Cross-section

A cross-section can be constructed by picking two pairs of characteristic points on 2-D constituent lines and other 2-D figure.

(b) Development

This method is divided into two classes according to the position of the 2-D constituent lines relative to the 3-D basic surface. These two classes are:

(i) Plane

A plane can be constructed in a fixed position by picking three pairs of characteristic points on 2-D constituent lines from the 3-D figure.

(ii) Cylinders, including revolving surfaces (containing circular cones and spherical surfaces) and sculptured surfaces

These can be inserted in a fixed position of the 3-D basic surface.

When a 3-D shape is defined from a 3-D figure on graphic display, the type of surface (plane, cylinder, revolving surface, sculptured surface) is input. The type of sculptured surface is classified according to its interpolation function.

A surface is numbered by automatic counting and memorized by the computer.

(3) Definition of part shapes

A group of surfaces which constitute a part shape are defined as a collectively-numbered part shape.

(4) Definition of a whole shape

Each part shape defined in different coordinate systems of the same 3-D space is translated into a (whole) coordinate system by picking three pairs of characteristic points on the graphic display.

3.3 Internal representation

Fig.6 explains the definition in relation to a line and a surface. A line is defined by the type and row of numbered points. Points connected with other lines, except those above them, are defined as connective points. A surface is defined according to its type and outlines. Lines connected with the other surfaces, except those above outlines, are defined as connective lines. Part shape is defined by surfaces.

A whole 3-D shape is represented by a set of points, lines, surfaces and part shapes, and the connective relation is represented by the same points, lines and surfaces.

Fig.6 Definition of line and surface

2-D figures are represented by a set of points, lines and 2-D figures. 2-D figure is a row of lines, which does not have type (eg. a projection) and connective lines. 2-D figures do not have part 2-D figures (corresponding to part shape) and assembly 2-D figures (corresponding to whole shape) on account of man-machine interaction.

2-D figures and 3-D shapes data (in the form of data structure as in Fig.6) are labelled and filed independently.

4. Application

This system is practically applicable to the data generation of FEM analysis. Applications are explained (with hard copies) as follows:

(1) Application to hydraulic power shovel arm

Fig.7 shows the system's application to a hydraulic power shovel arm. (a) shows 2-D figures produced from the internal data of practical engineering drawings. 2-D figures in (a) are modified for plate and shell element analysis by the offset function. (b) shows a 3-D shape model, constituted by surface and solid model. Result of finite element mesh division for a 2-D block (surface) and the block inserted in a 3-D shape model are shown in (c). (d) shows a part of a finite element model. Each node and element are renumbered using the connective relation of surfaces.

(2) Application to spiral pump casing

Fig.8 shows an application to spiral pump casing. (a) shows examples of 2-D figures in conceptual design. Making a 3-D shape model in (b), the construction of cross-sections, the definition of interpolation lines (linear) and sculptured surfaces are performed. An intersection line, composed of a basic surface and a cutting surface, is shown. The information on the basic surface is not represented directly on practical drawings. The necessary lines are added in (a). (c) shows a part of a finite element model. (3) Application to steam turbine valve casing

Fig.9 shows the application to steam turbine valve casing. (a) shows examples of 2-D figures. (b) shows a 3-D shape model composed of fillets, etc. The fillets in (b) cannot be generated by rotation of cross-sections. Since each cross section shape changes along the circumference, the dimensions are not represented directly and the interpolation lines of sections must be defined on the other surfaces connected with fillets. In this case, the information (lines) used to generate the basic 3-D surfaces, from which the interpolation lines can be made, is added to the 2-D figure on practical drawings. (c) shows a finite element model and a basic shape model for automatic finite element mesh division.

5. Discussion

5.1 Man-machine interaction

In man-machine interaction, man's role is to translate the visual information represented on a drawing or

graphic display into the input information for the computer using the process of recognizing, searching, judging and forming a hypothesis. The necessary conditions to this are as follows:

(1) The input information can be found easily.

(a) 2-D figures

(b) 3-D shape model

(c) Finite element division

(d) Finite element model

Fig.7 Application to a hydraulic power shovel arm

(a) 2-D figures

(b) 3-D shape model

(c) Finite element model

Fig.8 Application to a spiral pump casing

- (2) The information can be input easily into the computer.

In this system, a designer, who can understand a drawing and imagine a 3-D object, can find needed data and input them into the computer easily. He can eliminate, add to or modify them as he sees fit. The input method is used only (a) to pick characteristic points and lines represented on a graphic display in the generation of 3-D shapes, and (b) for the input of simulation drawings by a designer. The input command "menu", the guidance of commands and parameters and the graphic representation device make this easy.

5.2 Representative ability of 3-D shape

Figs.10 and 11 show examples of basic modeling processes in this system. In this system, 3-D shapes can be generated from 2-D figures (a projection cross-section or development) by set operation and mapping processes (Figs.10 and 11, respectively). However, in drawings the processes in Figs.10 and 11 are limited by the description of the drawing.

For an example, the description of a drawing is not usually done with spline. 2-D development may be limited to planes, cylinders and cylindrical cones, while the development of rotating surfaces (except rotating cylindrical cones) and sculptured surfaces is not done. Also, combinations of processes are limited. That is, a 3-D shape generated through expansion and/or free combination of processes in Figs.10 and 11 represents the applicable range of this geometric modeling algorithm. The merit of this modeling is that it enables the generation of sculptured surfaces (Fig.10(a)(b)) in an arbitrary position in

space (Fig.11(c)). This would be difficult to do using primitive ideas of geometric modeling.

A shape generated through the combination of processes in Fig.10(a), (c) (corresponding to primitives) and (d) may indicate the limit of geometric modeling using primitive ideas.

5.3 Computer processing of drawings

Considering the normal capacity of computers, an automatic generation of 3-D shapes from the internal data of drawings cannot be done effectively. It can be done only by using man's ability to recognize 3-D shapes. In the modeling algorithm of this system, man's job can be reduced if the processing ability (eq.speed, memory) is improved. By filing the data of commands and parameters in the generation process, a 3-D object can be obtained automatically, whenever the dimensions are changed, by using the command-trace function.

6. Conclusions

An interactive geometric modeling system, based on a new CAD/CAM processing system combining computer aided drawing and geometric modeling, was developed. In this system, 3-D shape model data can be produced from the internal data of practical engineering drawings using man-machine interaction. The chief features of this system are as follows:

- (1) A designer can put descriptive drawings into the computer and generate a 3-D shape easily as long as he can understand the drawing.
- (2) The 3-D shape generated is wireframe, surface, solid, and the representable range is wide.

Fig.9 Application to a steam turbine valve casing

Fig.10 Set operating process

Fig.11 Mapping process

- (3) The processes of drawing and generation of 3-D shape model are mutually independent. Each process can be linked to other systems, such as computer aided drawing, which already has practical applications to many products.

At present, this system is practically being utilized in the data generation of FEM analysis. The authors intend to expand and improve this system, including its linkage to other systems for process planning and making NC tape.

References

- (1) Togino.K., Computer Aided Design (in Japanese), (1969) Corona Publishing Co.
- (2) Okino. N., Journal of the J.S.P.E.(in Japanese), Vol.20, No.223(1978),P.677.
- (3) Braid.I.C., Designing with Volumes (1974), Cantab Press.
- (4) Okino.N. et al., Journal of J.S.T.P. (in Japanese), Vol.42, No.10(1975), P.17.
- (5) Spur.G. and Debler.H., Mecanique N300 December(1974),P.31.
- (6) Hosaka.M and Kimura.F., Journal of the J.S.M.E.(in Japanese), Vol.44, No.378 (1978), P.661.
- (7) Hosaka.M. and Kimura.F., Journal of the J.S.M.E.(in Japanese), Vol.45, No.389(1979),P.75.