A Method of Reconstructing 3D Models from Sketches by Extracting Features

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***Abstract*—The automatic reconstruction of a 3D object from a sketch has been very crucial research area in Computer-Aided Design and Computer Vision since decades. Conventionally most of proposed methods have applied the technique of line labelling. However, generally line labeling technique could be difficult for the reconstruction when input sketches include many curves. In this paper, a method for the reconstruction of mechanical parts by extracting features repeatedly is proposed. In the method, the sketches of cubes, cylinders, holes and fillets are applied as features. Four examples that are difficult for line labelling technique are indicated in this paper.**

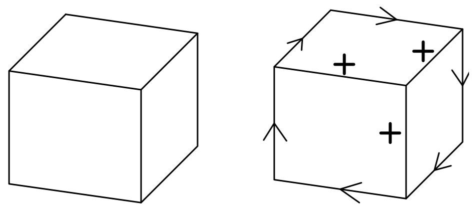
***Index Terms*—sketch, line drawing, reconstruction, CAD, feature, mechanical parts**

I. Introduction

Generally line drawings as sketches of 3D objects are widely used in designing mechanical products. The automatic reconstruction of a 3D object from a sketch has been very crucial research area in Computer-Aided Design and Computer Vision since decades. Conventionally most of proposed methods have applied the technique of line labelling. However, generally line labeling technique could be difficult for the reconstruction when input sketches include many curves.

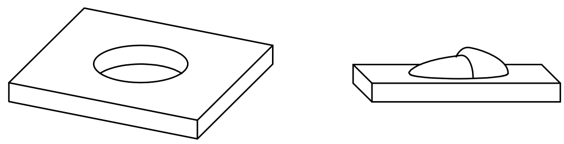
In this paper, a method of reconstructing a 3D model from a sketch of a mechanical part by extracting features from the sketch repeatedly is proposed. This method is an extension of the author's past work, e.g. [1-2]. Generally line labelling technique would be effective to recognize 3D convex or concave shapes from sketches. For example, Fig. 1(a) illustrates a sketch of a cube. In line labelling technique, firstly each of straight lines that form an outer loop of the cube is named an occluding edge and its label is an arrow. The directions of the arrows of all occluding edges are clockwise. Then three W junctions each of which consists of two occluding edges and an edge labeled "+" are recognized as in Fig. 1(b). Finally a Y junction consisting of three "+" edges can be found. A Y junction indicates a 3D convex shape in a sketch in line labelling technique. Therefore, a model of a 3D cube of the sketch can be generated automatically.

However, it seems to be difficult to suppose that a human understands sketches by only line labelling. For example, when a human looks at Example 1 illustrated in Fig. 2(a), he/she would recognize a sketch of a plate with a hole. In contrast, Example 1 could be also recognized as a strange solution as in Fig. 2(b) when line labelling technique is only applied. The reason why Example 1 is a plate with a hole would be because he/she has already known the sketches of plates and holes respectively.



(a) (b)

Figure 1. (a) A sketch of a cube, (b) line labelling in the cube.



(a) (b)

Figure 2. (a) Example 1, (b) a strange solution.

Originally it could be assumed that a child firstly learns how to sketch primitives and features of 3D objects. In this method, primitives are included to features. They could correspond to simpler tools for a human. Then he/she could draw sketches of tools whose shapes are more complex by applying sketches of features. On the other hand, cubes, cylinders, holes, etc. are the features of mechanical parts and they are modeled by combining the features step by step in solid modelers. This combining process is similar to the learning of how to draw sketches of tools in a human.

In contrast, the recognition processes of the sketches of mechanical parts could be considered as the reverse processes of drawing sketches of them in a human because generally the shapes of mechanical parts are too various. If popular tools are sketched, they would be recognized at a glance in a human. This method applies the recognition processes of the sketches of mechanical parts in a human. In the present step of this method, the sketches of cubes, cylinders, holes and fillets could be defined as in Section III. When a sketch of a mechanical part is input to this method, these features would be

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recognized and extracted step by step from the sketch. The 3D model as the solution of the sketch could be obtained from combining extracted features. Four examples that are difficult for line labelling technique are indicated in this paper.

II. Related Works

There are a great many papers for the reconstruction. The classification of them is indicated such as in [3]. When designers draw a sketch of a 3D object, more number of visible edges and less number of hidden edges would be drawn to express the object effectively. More effective positions of 3D objects projected to sketches are called general positions. When designers draw sketches of mechanical parts, it is natural that they draw only visible lines. So in this method, hidden lines are not drawn in sketches, and 3D objects are viewed in general positions. Under these constraints, line labelling technique has been developed and many kinds of junctions such as Y junction and W junction were summarized into junction catalogs, e.g. [4-12]. Although these references handled only polyhedrons as 3D objects, moreover, sketches of curved 3D objects have been handled and the junction catalogs of curved lines were summarized, e.g. [13-15].

On the other hand, Robert [16] attempted to extract polyhedral primitives such as cubes from the sketches of polyhedrons to obtain 3D models as solutions. Also, Wang et al. [17-19] attempted to extract cylinders from sketches including curved lines for the reconstruction. However, their methods did not handle machining features such as holes and fillets in 3D objects.

III. The Algorithm of This Method

In this method, sketches are perfectly drawn in 2D CAD systems as the orthogonal projections of 3D objects placed in general position. Hidden lines of the 3D objects are not drawn in the sketches. Also, each of input sketches to this method consists of ellipses, arcs and straight lines. Each of straight lines does not intersect to any other lines. A point is defined as an intersection of lines. A region is defined as a closed loop of lines. They correspond to an edge, a vertex, and a face in 3D models.

The flowchart of the algorithm in this method is illustrated in Fig. 3. Six types of sketches of features are defined in this method as follows.

- CUBE

  There are three parallelograms connecting to each other at their three straight lines and their endpoints are converged to a point.
- CYLINDER

  There are an ellipse, an arc, and two parallel lines. These lines connect to the ellipse and the arc respectively and tangentially, and two connecting regions are formed.
- HOLE

  There are an ellipse and an arc. The arc is a part of the ellipse. The arc is placed in the inside of the ellipse and they are connected to each other. The ellipse is placed in the inside of some region.
- GENERAL FILLET

  There are two arcs and four straight lines. The two arcs are placed like a part of the sketch of a cylinder. Each pair of parallel lines connects to the arcs individually and tangentially.
- PARTIAL FILLET

  There are two arcs and four straight lines. The two arcs are placed like a part of the sketch of a cylinder. Three lines connect to the end points of the arcs individually and tangentially. One line connects to both of the arcs tangentially.
- HIDDEN FILLET

  There are an arc and two straight lines. Each of these lines connects to the arc tangentially.

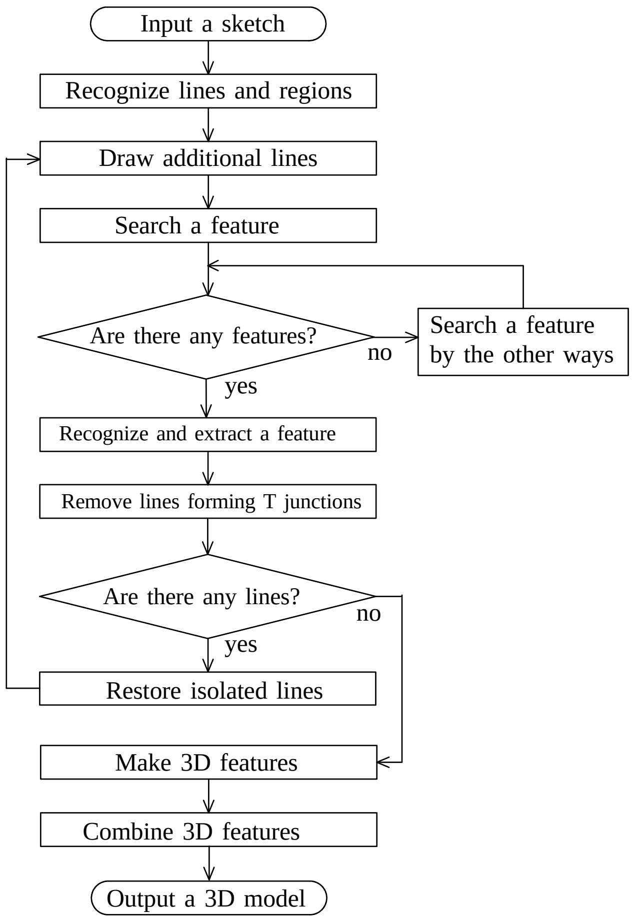


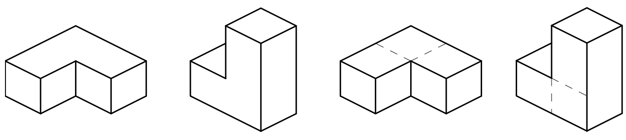
Figure 3. Flowchart of algorithm in this method.

When some cube, cylinder or hole is recognized in a sketch, the hidden lines of its 3D model are drawn as additional lines because they can form contact faces described as follows. Additional lines are drawn as dashed lines. Also, in the recognition of a cube, three lines forming a Y junction are drawn as solid lines. Additionally the following three operations are applied in this method.

- *Extension of lines as additional lines:*

  Two straight lines forming a L junction are extended within the nearest region of a sketch. Two straight lines in both sides of a W junction are extended within the nearest region of a sketch and the W junction is changed into a junction consisting of five lines. The extended parts of the lines are additional lines. The reason why the lines are extended is explained in Fig. 4. When a work shaping a cube is machined, two samples in Fig. 4(a), (b) are basic. In this figure, when the extensions are applied as in Fig. 4(c), (d), it becomes easy to recognize the feature of the sketch of a cube for this method.

- *Restoration of lines:*
  When a feature is extracted from a sketch, some isolated line that does not form any regions can exist. They are extended until forming a region or removed from the sketch.
- *Shaping features:*
  If only two parallelograms that become parts of the sketch of a cube can be searched in a sketch, additional lines are drawn to the sketch to shape a complete sketch of the cube.



(a) (b) (c) (d)

Figure 4. Samples of extending lines.

When a feature is extracted from a sketch, to search another feature clearly, each line forming a T junction that consists of two straight lines shaping “T” is removed repeatedly, and then additional lines are drawn again. Basically solid lines are prior to dashed lines in the recognition of features. Features are extracted from a sketch repeatedly until there are no lines in the sketch. Basically the extractions of holes and fillets are prior to the extraction of cubes and cylinders. Also, general fillets, partial fillets and hidden fillets are extracted in this order. After all extractions are finished, extracted features are converted to 3D features and the 3D model of the sketch can be generated by combining them.

In the combinations, a contact face between two 3D features could be searched as follows. In the sketch of a cube, regions corresponding to contact faces are formed by additional lines. In the sketch of a cylinder, a region corresponding to a contact face is formed by its arc and a fillet is the same. In the sketch of a hole, its cylindrical face becomes the contact face of the 3D hole. Also, cubes and cylinders are prior to holes and fillets in their combinations.

The ways to extract 3D features from sketches are as follows. General fillets and partial fillets are changed into sketches of 3D corners when they are extracted from sketches. Each of hidden fillets is changed into a L junction. The 3D shape of a hidden fillet is made after all of the other 3D features are combined. The way to make that is the same way as solid modelers. All lines of cylinders and holes are removed. When a 3D cube is extracted from a sketch, all of its solid lines are removed because they are not needed to search another feature.

IV. Examples

In Example 1, firstly a sketch of a hole can be recognized as in Fig. 5(a) and extracted as in Fig. 5(b) in this method. Then a sketch of a cube can be recognized as in Fig. 5(c). Since the cylindrical face of the hole is the contact face to combine to the cube, they can be combined correctly and the solution of Example 1 can be obtained as in Fig. 5(d). This method never outputs Fig. 2(b) because only a sketch of a hole can be recognized in Example 1.

Fig. 6(a) illustrates Example 2 that is a sketch of a simplified and clarified motor bracket. In this method, firstly three holes can be recognized as in Fig. 6(b) and extracted as in Fig. 6(c). In this figure, two general fillets drawn as bold lines can be recognized, and each of them is extracted as in Fig. 6(d). In this figure, a pair of general fillets drawn as bold lines can be recognized. If the right fillet of them is extracted as in Fig. 6(e), two partial fillets and a hidden fillet can be extracted respectively as in this figure. However, no more features can be recognized in this figure. So another general fillet is extracted as in Fig. 6(f). In this figure, two partial fillets and a hidden fillet are extracted respectively. So a cube can be recognized as in Fig. 6(g). When the solid lines of the cube are removed, an isolated line and a line forming two T junctions are recognized as in Fig. 6(h). Since they can be removed, a cube can be recognized finally. Fig. 6(i) illustrates each of extracted features (f_1, f_2, … , f_{11}) in Example 2. They are combined as $f_9+f_{10}-f_1-f_2-f_3-f_4-f_5+f_6-f_7-f_8-f_{11}$. The way of combining f_{11} is the same way as solid modelers. Fig. 6(j) illustrates the overviews of the solution in Example 2.

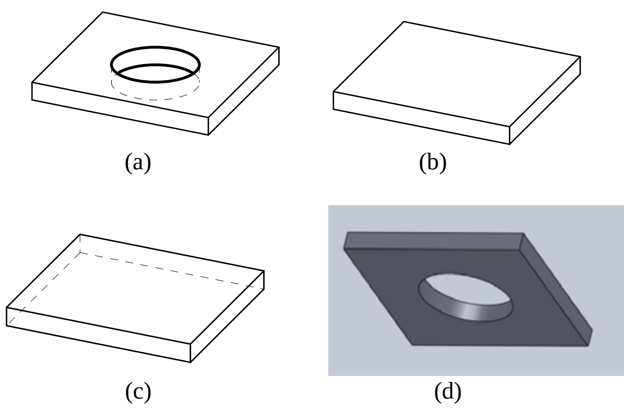


Figure 5. (a) Recognition of a hole in Example 1, (b) extraction of the hole, (c) recognition of a cube, (d) overview of the solution in Example 1.

Fig. 7(a) illustrates Example 3 that is a sketch of a bubble wrap. In this method, firstly four cylinders can be recognized individually as in Fig. 7(b) and they are extracted as in Fig. 7(c). In this figure, all of isolated lines are extended and four cylinders can be recognized as in

Fig. 7(d). In the same way, when these cylinders are extracted, two cylinders can be recognized as in Fig. 7(e). When these cylinders are extracted, finally a cube can be recognized. The solution in Example 3 can be obtained as in Fig. 7(f).

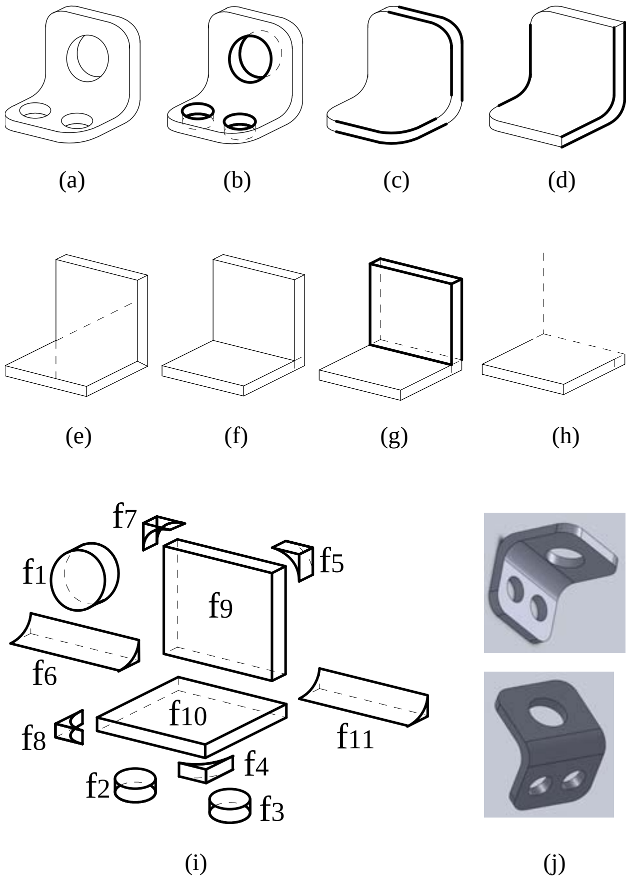


Figure 6. (a) Example 2, (b) recognition of three holes, (c) extraction of the holes and recognition of two general fillets, (d) extraction of the fillets and recognition of a pair of general fillets, (e) the case to extract the right bold fillet in (d), (f) the case to extract the left bold fillet in (d), (g) recognition of a cube, (h) removal of solid lines in the cube, (i) each of extracted features, (j) overviews of the solution in Example 2.

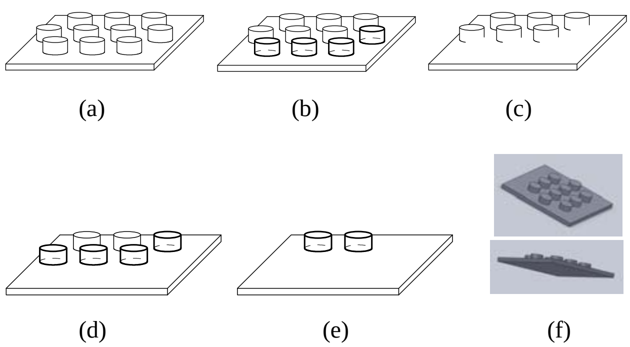


Figure 7. (a) Example 3, (b) recognition of four cylinders, (c) extraction of the cylinders, (d) recognition of four cylinders from (c), (e) recognition of two cylinders, (g) overviews of the solution in Example 3.

Fig. 8(a) illustrates Example 4 that is referred from [10]. In this figure, a fillet is added to a figure of [10]. In this method, firstly a hidden fillet is recognized and extracted as in Fig. 8(b). Then a cube is recognized as in Fig. 8(c). In Fig. 8(d), the solid lines of the cube are removed. In Fig. 8(e), all of lines forming T junctions are removed. In this figure, an isolated line can be extended. So Fig. 8(f) can be drawn. In Fig. 8(g), a cube is recognized. In Fig. 8(h), the solid lines of the cube are removed. In Fig. 8(i), all of lines forming T junctions are removed. In Fig. 8(j), additional lines are drawn. In Fig. 8(k), a cube is recognized. In Fig. 8(l), the solid lines of the cube are removed. In this figure, since two isolated lines can be removed, a cube can be recognized finally. When all of extracted features are combined except the hidden fillet, Fig. 8(m) can be obtained. When the fillet is added to this figure, the solution of Example 4 can be obtained as in Fig. 8(n).

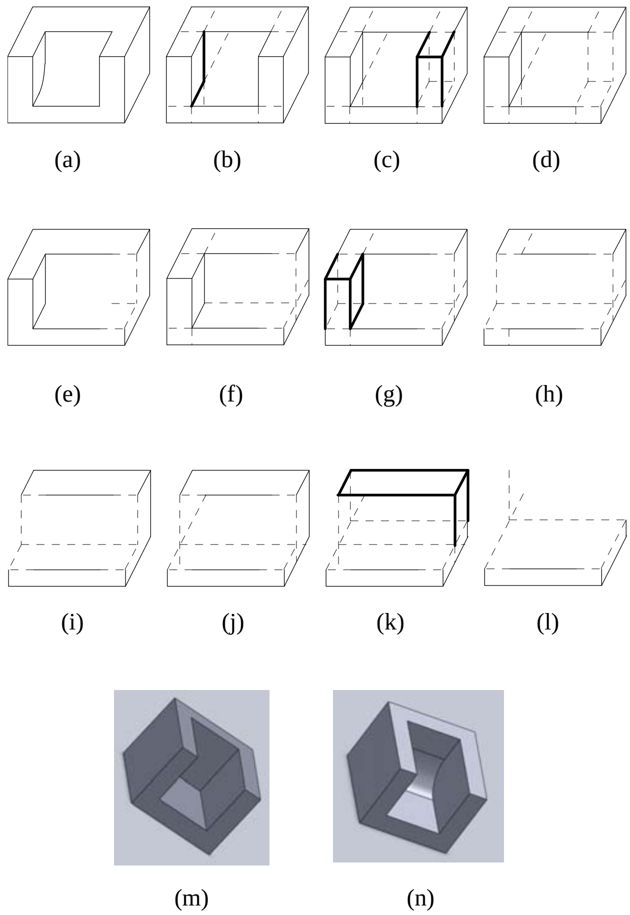


Figure 8. (a) Example 4, (b) recognition and extraction of a hidden fillet, (c) recognition of a cube, (d) removal of solid lines in the cube, (e) removal of lines forming T junctions, (f) restoration of an isolated line, (g) recognition of a cube from (f), (h) removal of solid lines in the cube in (g), (i) removal of lines forming T junctions in (h), (j) drawing of additional lines, (k) recognition of a cube from (j), (l) removal of solid lines in the cube in (k), (m) combination of extracted features except the hidden fillet, (n) overview of the solution in Example 4.

V. Conclusion

In this paper, a method of reconstructing a 3D model from a sketch of a mechanical part by extracting features is proposed. The effectiveness of this method is demonstrated by four examples in this paper. Since all of features applied in this method are adapted to machining features of mechanical parts, obviously this method cannot apply to 3D objects whose shapes are difficult to be machined such as pyramids and prisms. To handle them, the definitions of new features are required in this method. Also, when sketches of 3D objects whose shapes are very complex are input, the search of features would become more complex.

However, it seems to be difficult to handle examples of this paper by conventional methods using line labelling technique. Especially it is easier to recognize Example 3 by recognizing each of cylinders than by recognizing each of junctions of lines. The recognition of the cylinders is similar to the way of a human to understand Example 3. As the result, this method would be different from conventional methods using line labelling technique in the directions of their extensibility, and when this method is extended to more various kinds of sketches, it might become more human.

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