Computer-Aided Design AND APPLICATIONS www.cadanda.com

Feature Extraction from Sketches of Objects

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ABSTRACT

The automatic reconstruction of a 3D object from a sketch drawn as a line drawing has been very crucial research area since decades, especially in Computer-Aided Design and Computer Vision. Conventionally most of proposed methods have applied the technique of line labelling. However, generally this technique could be difficult for the reconstruction when the sketch includes many curves. In this paper, a method of reconstructing a 3D object as a solid model from a sketch by extracting features repeatedly is proposed. In the method, the sketches of cuboids, cylinders, holes and fillets are applied as features. In this paper, the algorithm of the method is explained in detail, and the effectiveness of the algorithm is explained by six examples that are difficult for conventional methods.

Keywords: sketch, line drawing, feature extraction, automatic reconstruction, 3D object, solid model, line labelling.

1. INTRODUCTION

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

In this paper, a method of reconstructing a solid model from a sketch of a product by extracting features from the sketch repeatedly is proposed. The method can handle curved objects drawn in sketches that are difficult to be handled by conventional methods. The effectiveness of the method is explained by six examples in this paper. For example, when a human looks at Example 1 illustrated in Fig. 1(a) that is a sketch of a perforated plate, he/she would recognize the sketch at a glance. In line labelling technique, each line segment could be labeled as in Fig. 1(b). However, the recognition of the shape of the hole would be difficult for the technique unless applying various kinds of assumptions. In contrast, the sketches of a cuboid and a hole are predefined in our method. When Example 1 is input to the method, each of the sketches is recognized and changed into a 3D cuboid and a 3D hole as in Fig. 1(c). In the method, a solid model illustrated in Fig. 1(d) can be obtained from Example 1 by subtracting the 3D hole from the 3D cuboid.

Basically we assume that a child firstly learns how to sketch primitives and features such as cuboids, cylinders, holes, etc. of 3D objects. In the method, primitives are included into features. Then he/she could draw sketches of 3D objects whose shapes are more complex by applying the sketches of the features. We assume that this recognition process of sketches could be considered as the reverse process of drawing sketches in a human. The basic idea of the method is to apply this recognition process of the features for reconstructing solid models from sketches. The rest of this paper is organized as follows. In Section 2, related works of this paper are described. In Section 3, each sketch of features is defined. In Section 4, the algorithm of the method is explained in detail by using Example 2. In Section 5, four examples are indicated. In Section 6, we discuss some of the limitations and extensibility of the method. In Section 7, we make our conclusions.

2. RELATED WORKS

There are a great many papers for the reconstruction and/or interpretation of sketches. The classification

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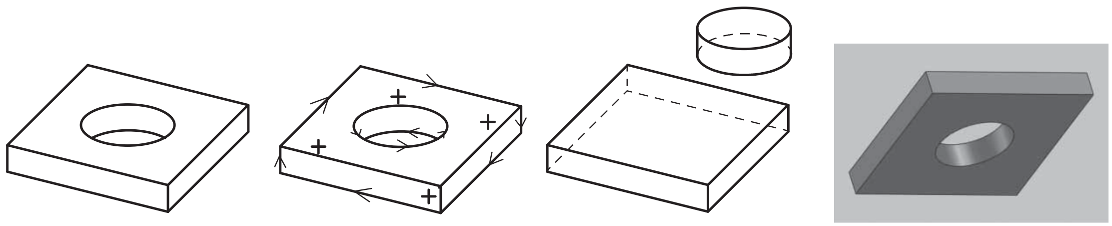

Fig. 1: Example 1: (a) Example 1, (b) Line labelled Example 1, (c) Decomposition of Example 1 into a 3D cuboid and a 3D hole, and (d) The overview of the solid model in Example 1.

of them is well indicated in [3]. Originally line labelling technique was developed as Clowes-Huffman labelling [2],[11]. In this labelling, sketches that are projections of opaque trihedral polyhedrons placed in general viewpoints were handled, and each of line segments are labelled "+" or "-" or arrowed. Arrowed lines correspond to occluding edges in 3D objects. Also, four types of vertices were defined as L junction, W junction, Y junction and T junction. Varley and Martin [23] extended the line labelling technique to tetrahedral polyhedrons and more types of junctions were defined such as K junction. Varley et al. also addressed high-ordered junctions of polyhedrons, e.g. [24, 25]. Kirousis [13] indicated the computational complexity of line labelling. Malik interpreted sketches of curved objects in line labelling, e.g. [15, 16]. He determined each of curved line segments drawn in sketches corresponds to either an edge of a cylindrical face or an occluding edge in 3D objects, and the junction catalog of curved lines was defined. Our method agrees with this determination. Also, Cooper [6–9] presented more rich labelling scheme for curved objects by extending [15]. However, Malik and Cooper did not mention how to create solid models of curved objects from sketches including curved lines. In general, to infer hidden shapes that are not drawn in sketches of 3D objects is difficult. For example, Grimstead and Martin [10] proposed a method to reconstruct solid models from sketches of trihedral polyhedrons by applying existed techniques such as [12],[19]. Also, the hidden topology of a 3D object drawn in a sketch was constructed, e.g. [24, 25], and Cao et al. [1] inferred that by their unique method in polyhedrons.

On the other hand, Robert [18] attempted to extract primitives such as cuboids from sketches of polyhedrons to obtain 3D models as solutions. Moreover, Wang attempted to extract cylinders from sketches including curved lines to reconstruct 3D curved objects, e.g. [26–28] and also attempted to recognize holes by applying [14]. In addition, Company et al. proposed a method for detecting rounds, fillets [4] and ribs [5] in sketches for the reconstruction. Also, Plumed et al. [17] proposed a method for detecting pockets and steps in sketches of polyhedrons for the reconstruction. The detection techniques of these features in [5],[17] would be useful for our method in the future though they could be applied only to polyhedrons. This usefulness is discussed in Section 6. In the aspect of feature extraction for the reconstruction, our method could be similar to Wang's works. However, though each of line segments in sketches was labelled in the works, our method does not label each of line segments. Additionally, though [4] handled rounds and fillets, it handled only each pair of arcs in sketches. Our method can handle single arc. As the result, generally our method can handle more various kinds of holes and fillets than these conventional methods for the reconstruction.

3. DEFINITIONS OF SKETCHES OF FEATURES

In our method, sketches are perfectly drawn in 2D CAD systems. A 3D object is assumed to be viewed from a general viewpoint that reveals all edges and vertices in a sketch. The lines drawn in the sketches consist of ellipses, arcs and straight lines. Hidden lines of the 3D objects are not drawn in the sketches. Only straight lines are divided at their intersections. Ellipses and arcs are never divided because it is difficult to handle the divisions in the present step of the method. This problem is also mentioned in Section 6. A point is defined as an endpoint of each line. A region is defined as a closed loop of lines. Between sketches and solid models, a point can correspond to a vertex, a line can correspond to an edge and a region can correspond to a face. When a 3D object drawn in a sketch is placed in Cartesian coordinate system, each of straight edges and the axes of curved edges is parallel to one of the axes of the system. In the present step of the method, seven types of sketches of features are handled. Fig. 2 illustrates each of the sketches of the features.

These sketches of features are defined respectively as follows.

- **Cuboid**: There are three parallelograms connecting to each other at their three straight lines and their endpoints are converged to a point. In the inside of each of these parallelograms, there are no solid lines. The ratio of height, width and depth of a 3D cuboid is determined by the ratio of lengths of three lines forming a Y junction in a sketch of the cuboid and the ratio of three angles between two lines of the Y junction. Since the determination of that relates with

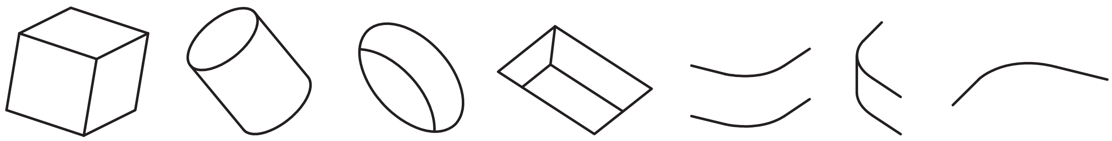

Fig. 2: Sketches of features in our method: (a) Cuboid, (b) Cylinder, (c) Round Hole, (d) Rectangular Hole, (e) General Fillet, (f) Partial Fillet, and (g) Hidden Fillet.

human sensibility and many researches handled this issue such as in [25], we do not handle the issue deeply in this paper. In our method, those ratios are determined sketchily. In the same way, the other 2D features can concretely convert to 3D features by using the ratios between lines and edges.

- **Cylinder**: There are an ellipse, an arc, and two parallel straight lines. The lengths of the two lines are the same. These lines connect to the ellipse and the arc respectively and tangentially, and two connecting regions can be formed. The curvatures of the arc and the ellipse are the same.
- **Round Hole**: There are an ellipse and an arc. 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. The curvatures of the arc and the ellipse are the same.
- **Rectangular Hole**: There are three straight lines forming a Y junction. They are inside of a parallelogram placed in the inside of some region. One of them connects to a point of the parallelogram. The other two straight lines can form another parallelogram while they form two T junctions to the original parallelogram.
- **General Fillet**: There are two arcs placed as a part of the sketch of a cylinder. Each pair of parallel straight lines connects to the arcs respectively and tangentially. The curvatures of the two arcs are the same. The central angle of each arc is smaller than π.
- **Partial Fillet**: Except one straight line connects to both of the arcs tangentially, the definition of “Partial fillet” is the same as “General Fillet”.
- **Hidden Fillet**: There are not two arcs placed as a part of the sketch of a cylinder but only one arc. Two straight lines connect to the arc respectively and tangentially. The central angle of the arc is smaller than π.

Generally 3D cuboids and 3D cylinders are positive 3D features when they are combined to make solid models as solutions in our method. In contrast, 3D holes are negative 3D features. 3D fillets are positive or negative 3D features. Whether a 3D fillet is positive or negative is determined when it combines to another solid model. These combination ways are the same as boolean operations as in solid modelers in the method.

4. ALGORITHM

Figure 3 illustrates the flowchart of the algorithm in our method. Each step of that is explained as follows by using Example 2 illustrated in Fig. 4(a).

1) Recognize each of lines and regions. Each of straight lines, ellipses and arcs is recognized, and each of regions is recognized. When Example 2 illustrated in Fig. 4(a) is input to our method, each region can be numbered as r1, r2, ..., r8 as in Fig. 4(b).
2) Draw additional lines of L, W junctions. Each of two straight lines forming an L junction is extended to the nearest solid line. Also, each of two lines in both sides of a W junction is extended to the nearest solid line. The extended parts of the lines are additional lines. All of additional lines are drawn as dashed lines. From Step 2 to Step 9, whenever two straight lines are intersected, they are divided at their intersection. This division corresponds to the definition of a line in the

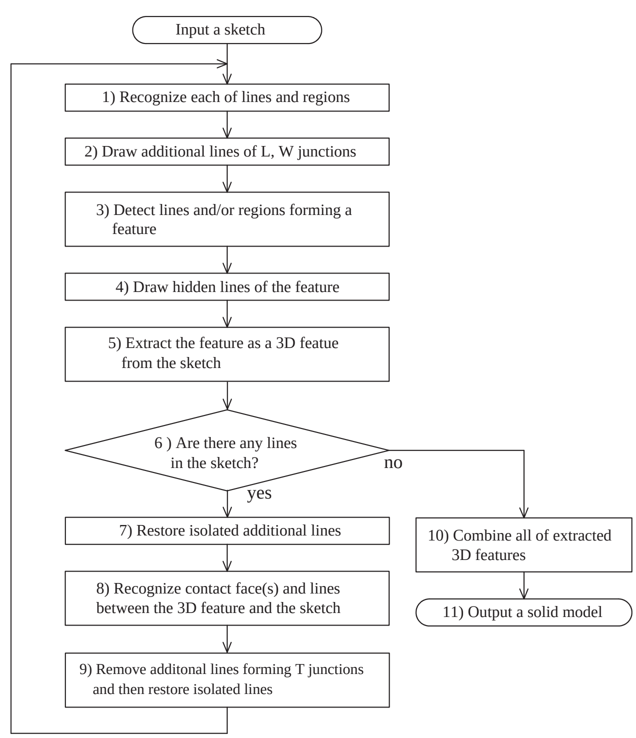

Fig. 3: The flowchart of the algorithm in our method.

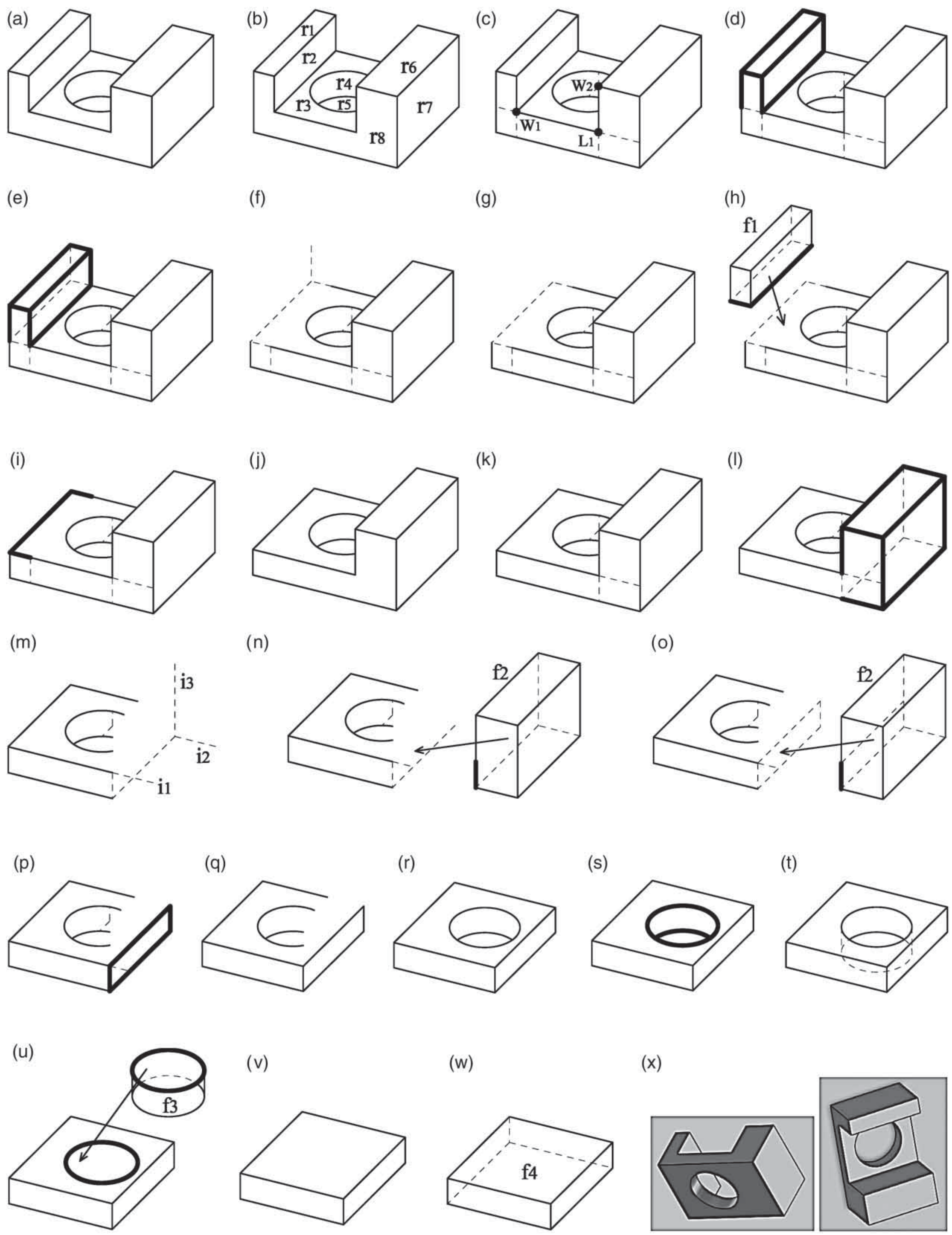

Fig. 4: Example 2: (a) Example 2, (b) Numbered each of regions, (c) Recognition of L and W junctions, (d) Detection of a cuboid, (e) Drawing of hidden lines of the cuboid, (f) Extraction of the cuboid, (g) Removal of an additional isolated line, (h) Correspondence of three additional lines with three edges of f1, (i) Change of the additional lines into solid lines, (j) Removal of additional lines, (k) Drawing of additional lines, (l) Detection of another cuboid, (m) Extraction of the cuboid, (n) Restoration of three isolated lines and correspondence of three additional lines with two edges of f2, (o) Addition of an additional line and an edge for forming a contact face in f2, (p) Change of the contact lines into solid lines, (q) Removal of additional lines, (r) Restoration of isolated lines, (s) Detection of a round hole, (t) Drawing of hidden lines of the hole, (u) Recognition of the contact face of f3, (v) Perfect extraction of f3, (w) Detection and Extraction of f4, and (x) Two overviews of the solid model in Example 2.

method. In general, since extendable L and W junctions tend to form concave shapes in a 3D model, it is effective to extend the lines of them to detect a sketch of a cuboid. Also, since too many additional lines become complex for the detection, the other junctions are not extended in the method. In Fig. 4(c), there are an L junction (L1) and two W junctions (W1, W2).

3) Detect lines and/or regions forming a feature. For example, after all fillets are extracted, it is easy to recognize cuboids and rectangular holes such as in Example 3. Also, it is natural that a cuboid is detected and extracted from the sketch in Example 1 after a round hole is detected and extracted. Therefore, a round hole, a general fillet, a partial fillet, a hidden fillet, a cylinder, a rectangular hole and a cuboid are detected in this order. In Fig. 4(d), a sketch of a cuboid can be detected and its solid lines are drawn as bold lines.
4) Draw hidden lines of the feature. Since the detected feature in Step 3 can convert to a 3D feature, the hidden lines of that can draw as additional lines to the sketch. Generally hidden lines are useful to detect the other features and contact faces described in Step 8. In Fig. 4(e), three hidden lines of the 3D cuboid are drawn.
5) Extract the feature as a 3D feature from the sketch. Each kind of features is extracted from the sketch as follows. In a cuboid, all of solid lines are removed. The 3D model of the cuboid is formed by these solid lines. Since intersected curved lines are not handled in the method, each cylinder and each hole exist separately in the solid model of input sketch. So, all of their lines are removed. In a general fillet, two arcs are removed and four lines are extended to make a cubic corner. In a partial fillet, two arcs and a line connecting to both of them are removed and three lines are extended to make a cubic corner. In a hidden fillet, an arc is removed and two lines are extended to make a corner. In Fig. 4(f), eight bold solid lines in Fig. 4(e) are removed.
6) Are there any lines in the sketch? There are many lines in Fig. 4(f). In this case, Step 7 is executed.
7) Restore isolated additional lines. After a feature is extracted, some isolated line that does not form any regions can exist. Since isolated additional lines hinder making contact faces, each of them is extended to the nearest line or is removed. A method to restore isolated lines was proposed in [22]. In Fig. 4(f), there is an isolated additional line. Since this line cannot extend to any other lines, it is removed as in Fig. 4(g).
8) Recognize contact face(s) and lines between the 3D feature and the sketch. When the 3D feature in Step 5 is extracted from the sketch, there are common parts of edges and lines between them. These edges and lines can become contact faces when two 3D features are combined in Step 10. If the edges do not form a face, additional edges can be added to make a rectangular face and also additional lines corresponding to the edges can be added in the sketch. Two or more contact faces can exist in a 3D feature. If two or more contact faces are intersected on a plane by their additional edges, they can be connected as a contact face. This case is explained in Example 6. After some contact face is formed, all of additional lines as contact lines corresponding to the contact face are changed into solid lines because they can become new edges of some 3D feature in the following steps. In Fig. 4(h), the extracted 3D cuboid named f1 is drawn. In this figure, it is found that three additional lines as contact lines correspond to three edges of a face of f1, and two solid edges of it are bold. In Fig. 4(i), these contact lines are changed into bold solid lines.
9) Remove additional lines forming T junctions and then restore isolated lines. Additional lines made in Step 2 tend to generate T junctions. However, there are no T junctions in the sketch of a cuboid. Also, too many additional lines become complex for Step 3. Therefore, each additional line of a T junction is removed. Then each isolated line is extended to the nearest solid line or is removed. Each isolated arc is extended as forming an ellipse. In Fig. 4(j), five additional lines are removed. Before Step 10 is executed, this figure is processed as follows. In Step 1, lines and regions are recognized. In Step 2, four additional lines are drawn as in Fig. 4(k). In Step 3, a sketch of a cuboid can be detected and its three hidden lines are drawn in Step 4 as in Fig. 4(l). In Step 5, the bold solid lines in Fig. 4(l) are removed as in Fig. 4(m). As the result, three isolated additional lines (i1, i2, i3) appear in this figure. In Step 7, these three lines are removed as in Fig. 4(n). In Step 8, it is found that three additional lines correspond to two edges of the 3D cuboid (f2) as in Fig. 4(n). Here, a contact solid edge is bold. Since the two edges do not form a face, an additional edge is added and also an additional line corresponding to the edge is added as in Fig. 4(o). In Fig. 4(p), five additional lines in Fig. 4(o) are changed into solid lines. In Step 9, three additional lines are removed as in Fig. 4(q), and then an isolated straight line and two isolated arcs are restored as in Fig. 4(r). Here, Step 1 and 2 are executed

again. In Step 3, a round hole is detected and its lines are bold as in Fig. 4(s). In Step 4, the hidden lines of the hole are drawn as in Fig. 4(t). In Step 5, the hole named f3 is extracted as in Fig. 4(u). In this figure, since f3 is a negative 3D feature, the top face forming a circle becomes the contact face in f3, and it is drawn as a bold edge. Also, a circle corresponding to the face is temporarily drawn as a bold line. In Fig. 4(v), f3 is extracted perfectly. From this figure, it is obvious that f4 is detected and extracted as in Fig. 4(w).

10) Combine all of extracted 3D features. Each of two 3D features can be combined at their recognized contact faces. The order of the combinations of 3D features is the reverse order of the extractions of them except hidden fillets. Hidden fillets are combined after all of the other 3D features are combined. The way of combining hidden fillets is the same way of solid modelers such as in Example 3. From Fig. 4(w), all of extracted 3D features are combined as follows. Firstly f3 is subtracted from f4. Then f2 and f1 are combined to f4 in this order.

11) Output a solid model. The solid model of Example 2 is outputted as in Fig. 4(x).

5. EXAMPLES

Figure 5(a) illustrates Example 3 that images a palette. In our method, firstly a round hole is detected and its solid lines are drawn as bold lines, and also hidden lines are drawn as in Fig. 5(b). In Fig. 5(c), the hole named f1 is extracted. In Fig. 5(d), f2 and f3 are detected and extracted. In Fig. 5(e), two general fillets are detected as bold lines. These general fillets are extracted as two 3D general fillets (f4, f5) as in Fig. 5(f). In this figure, two partial fillets are detected as bold lines. These partial fillets are extracted as two 3D partial fillets (f6, f7) as in Fig. 5(g). In this figure, four hidden fillets are detected as bold lines. These hidden fillets are extracted as in Fig. 5(h). In this figure, a W junction and three L junctions appear. The additional lines of them are drawn in Fig. 5(i). From this figure, a rectangular hole is detected as in Fig. 5(j).

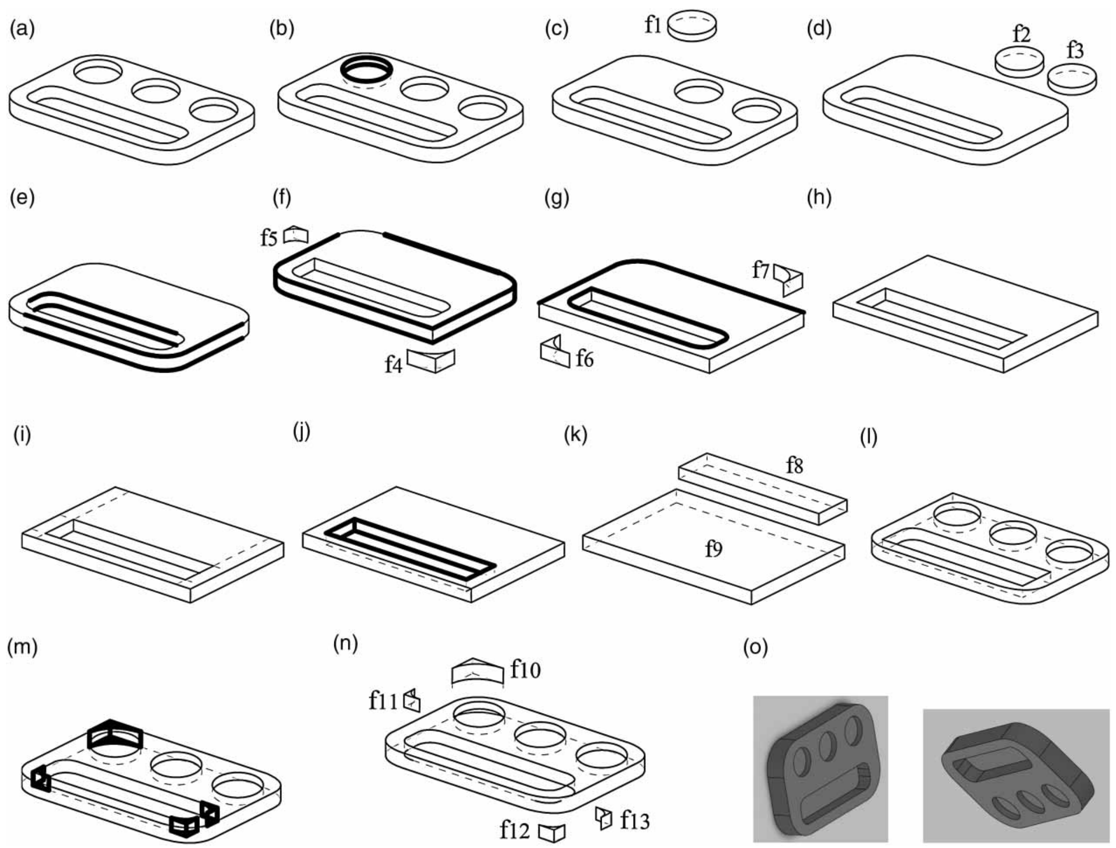

Fig. 5: Example 3: (a) Example 3, (b) Detection of a round hole, (c) Extraction of f1, (d) Extraction of f2 and f3, (e) Detection of two general fillets, (f) Extraction of the general fillets and detection of two partial fillets, (g) Extraction of the partial fillets and detection of four hidden fillets, (h) Extraction of the hidden fillets, (i) Drawing of additional lines, (j) Detection of a rectangular hole, (k) Extraction of the hole and detection of a cuboid, (l) Combination of all extracted 3D features except hidden fillets, (m) Recognition of four 3D hidden fillets, (n) Extraction of the fillets, and (o) Two overviews of the solid model in Example 3.

In Fig. 5(k), this rectangular hole (f8) is extracted and finally f9 is detected. In Fig. 5(l), all of extracted features described above are combined except hidden fillets. In this figure, four hidden fillets in Fig. 5(g) can be converted to 3D hidden fillets as in Fig. 5(m). In Fig. 5(n), they are extracted as f10, f11, f12, f13. Finally, the solid model of Example 3 is obtained as f9-f8-f7-f6 + f5-f4-f3-f2-f1-f10 + f11 + f12 + f13. Fig. 5(o) illustrates two overviews of that.

Figure 6(a) illustrates Example 4 that images a rectangular rubber seal. In Fig. 6(b), six arcs whose curvatures are the same are bold. If two narrow general fillets are detected from the arcs as in Fig. 6(c), they are extracted as in Fig. 6(d). It is obvious that the solid model of Example 4 cannot be obtained from this figure. So in our method, two wide general fillets are detected as in Fig. 6(e). Exceptionally, this search process of a feature can be executed if the solid model as the solution cannot be obtained from an input sketch in the method. In Fig. 6(f), the two wide general fillets are extracted and two partial fillets are detected. In Fig. 6(g), they are extracted and three hidden fillets are detected. In Fig. 5(h), they are extracted and a rectangular hole is detected. When the hole is extracted, a cuboid is detected finally. As the result, the solid model of Example 4 can be obtained as in Fig. 6(i).

Figure 7(a) illustrates Example 5 that images a bubble wrap. In the method, firstly four cylinders are detected as in Fig. 7(b). In Fig. 7(c), they are extracted and eight isolated lines appear. In Fig. 7(d), they are restored and four cylinders are detected newly. In Fig. 7(e), they are extracted and two cylinders are detected newly. When they are extracted, a cuboid is detected. As the result, the solid model of Example 5 can be obtained as in Fig. 7(f).

Figure 8(a) illustrates Example 6 that is referred from a figure of [1]. In Example 6, a fillet is newly added to the figure. In the method, firstly additional lines are drawn and a hidden fillet is detected as in

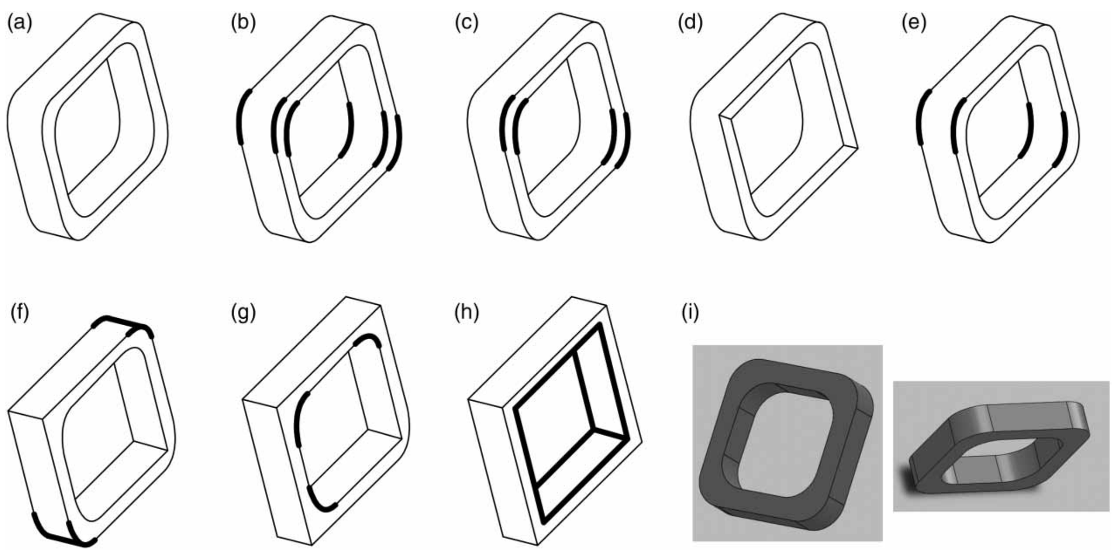

Fig. 6: Example 4: (a) Example 4, (b) Detection of six arcs whose curvatures are the same, (c) Detection of two narrow general fillets, (d) Extraction of the fillets, (e) Detection of two wide general fillets, (f) Extraction of the fillets and detection of two partial fillets, (g) Extraction of the fillets and detection of three hidden fillets, (h) Extraction of the fillets and detection of a rectangular hole, and (i) Two overviews of the solid model in Example 4.

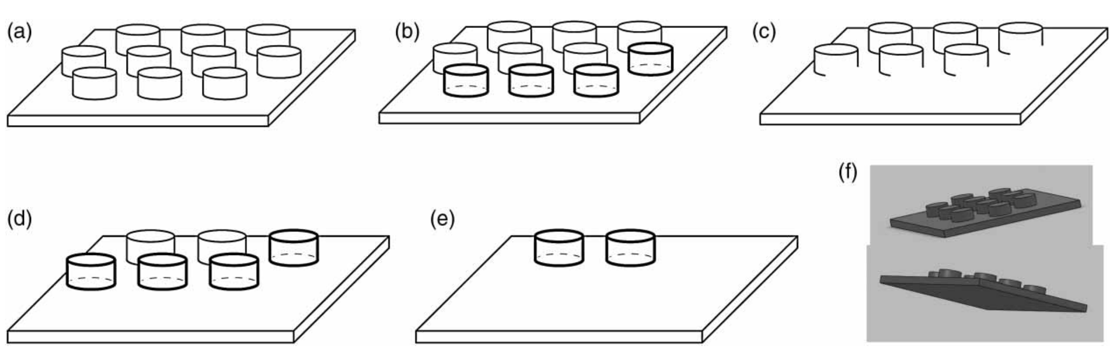

Fig. 7: Example 5: (a) Example 5, (b) Detection of four cylinders, (c) Extraction of the cylinders, (d) Restoration of isolated lines and detection of new four cylinders, (e) Extraction of the cylinders and detection of new two cylinders, (f) Two overviews of the solid model in Example 5.

Fig. 8(b). In Fig. 8(c), the fillet is extracted and additional lines are drawn again. In Fig. 8(d), a cuboid is detected. In Fig. 8(e), the solid lines of the cuboid are removed. In Fig. 8(f), two contact faces of the cuboid (f1) and five additional lines corresponding to them are recognized. In Fig. 8(g), these additional lines are changed into solid lines. In Fig. 8(h), all of additional lines forming T junctions are removed. As the result, an isolated solid line appears. In Fig. 8(i), this line is extended. In Fig. 8(j), additional lines are drawn again. In Fig. 8(k), another cuboid is detected. In Fig. 8(l), the solid lines of the cuboid are removed. In this figure, three isolated additional lines appear. In Fig. 8(m), they are removed, and it is found that four edges of the cuboid (f2) correspond to six additional lines. In this figure, two solid edges are bold to emphasize them. These four edges can form two rectangular contact faces by adding two edges as in Fig. 8(n). In this figure, two additional lines are also added. These two contact faces can be connected as a contact face by

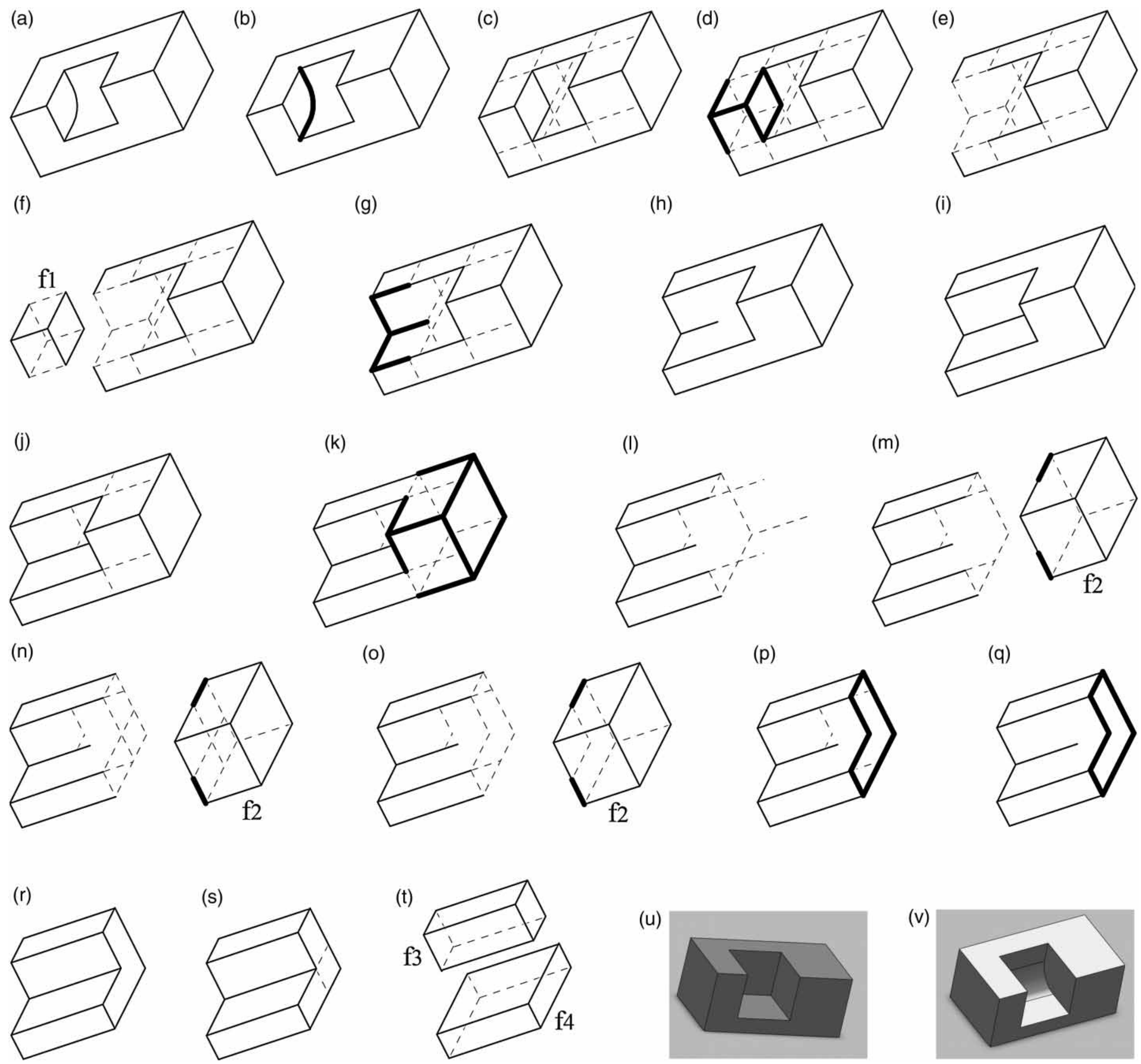

Fig. 8: Example 6: (a) Example 6, (b) Detection of a hidden fillet, (c) Extraction of the fillet and drawing of additional lines, (d) Detection of a cuboid, (e) Removal of the cuboid, (f) Recognition of two contact faces and five contact lines, (g) Change of the contact lines into solid lines, (h) Removal of additional lines of T junctions, (i) Restoration of an isolated solid line, (j) Drawing of additional lines, (k) Detection of another cuboid, (l) Removal of the cuboid, (m) Recognition of four contact edges and six contact lines, (n) Generation of two contact faces, (o) Connection of the two contact faces into a contact face, (p) Change of contact lines into solid lines, (q) Appearance of an isolated solid line, (r) Restoration of the line, (s) Drawing of additional lines, (t) Extraction of f3 and f4, (u) Combination of extracted features except the hidden fillet, (v) An overview of the solid model in Example 6.

removing two overlapping edges as in Fig. 8(o). In this figure, two additional lines corresponding to the two edges are also removed. In Fig. 8(p), all of additional lines corresponding to the contact face of f2 in Fig. 8(o) are changed into solid lines. As the result, an isolated solid line appears as in Fig. 8(q). In Fig. 8(r), this line is extended. In Fig. 8(s), additional lines are drawn again. It is obvious that f3 and f4 are extracted as in Fig. 8(t). In Fig. 8(u), a solid model is generated as $f4 + f3 + f2 + f1$. When the hidden fillet detected in Fig. 8(b) is combined to the model, the solid model of Example 6 is obtained as in Fig. 8(v).

6. DISCUSSION

Originally we proposed methods for automatic reconstructing solid models from orthographic views, e.g. [20,21]. In the methods, if an input orthographic view is drawn correctly, precise solutions could be obtained. Also, various kinds of orthographic views could be applied to the methods. In contrast, applicable sketches are strictly limited in the proposed method of this paper. For example, pyramids and prisms except cuboids cannot be applied in the present step of the method. Also, intersected curved 3D objects drawn in sketches cannot be applied in the present step of the method. One reason for generating these problems is that too many interpretations of features would be generated in Step 3 of Fig. 3 when an input sketch includes too various kinds of features such as pyramids and intersected cylinders. To apply them is a future issue for the method. However, the method can indicate the possibility of handling curved lines such as cylinders, holes and fillets comprehensively in sketches. To extend the limitation of the method, we consider that hybrid methods consisting of feature extraction and conventional techniques such as line labelling would be effective. For example, after all of features in the method of this paper are extracted from an input complex sketch, the sketch would become very simple. So it would become easy to obtain the solid model as the solution from the input sketch. The same way could be seen in [5],[17]. In these papers, mechanical features such as ribs and pockets are extracted from a sketch for detecting an ingot whose shape is simple although curved objects cannot be handled in them. On the other hand, since the detections of features in the method are strategic, the computational complexity would be increased when complex sketches are input to the method. To develop more precise algorithm for the detections and also to handle more complex curved lines are the future issues in the method.

7. CONCLUSIONS

In this paper, a method of automatic reconstructing solid models from sketches by extracting features is proposed. Seven types of sketches of features are defined. The algorithm of the method is indicated in detail by using Example 2. The effectiveness of the method is explained concretely in six examples that are difficult for the reconstruction in conventional methods. Then the advantages, issues and future prospects of the method are discussed. On the whole, the merits of our method in this paper would be summarized as follows.

- The method can handle curved features that are difficult to be handled by conventional methods for the automatic reconstruction of solid models from sketches as follows. In Example 1 and 2, round holes are handled. In Example 3, round holes and fillets are handled. In Example 4, fillets are handled. In Example 5, overlapped cylinders are handled. In Example 6, a hidden fillet is handled.
- The method can also handle combined cuboids by applying additional lines, so that polyhedrons and curved 3D objects drawn in sketches can be both handled comprehensively.
- The method would contribute to widely extend the technique of feature extraction in the reconstruction.

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