Title:
Effective Extraction of Sketch Features from Sketches for Converting to 3D Models in SFBCM

Authors:
Masaji Tanaka, tanaka@mech.ous.ac.jp, Okayama University of Science
Rikuu Zenkai, t18t035zr@ous.jp, Okayama University of Science
Masaaki Ohtsuki, ohtsuki@aikoku.com, Aikoku Alpha Corporation
Chiharu Higashino, higashino@aikoku.com, Aikoku Alpha Corporation

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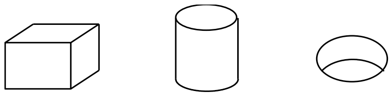
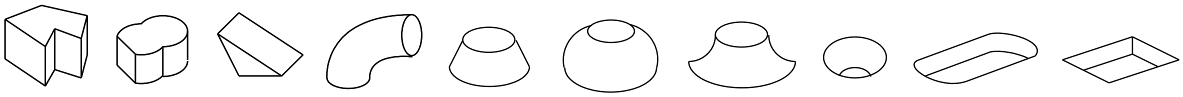
Introduction.

Sketches in the form of line drawings are commonly observed in magazines, books, manuals, etc. Sketches are also important for designers, particularly mechanical designers, when inventing new ideas for products and their parts. The automatic conversion of sketches into 3D models will be advantageous for several applications. For example, robots are expected to be able to understand sketches using converted 3D models in the future. Over the last 50 years, numerous methods have been developed for automatically converting sketches into 3D models. However, to date, no actual conversion system has been developed. We have been developing methods for this conversion for approximately eleven years. Consequently, we have proposed a method called SFBCM (Sketch Feature-Based Conversion Method) to achieve the conversion [9]. Fig. 1 shows three basic SFs (Sketch Features) indicating a cuboid, cylinder, and round hole. Each can be recognized and drawn easily by humans. In SFBCM, when a sketch is input, its 3D model can be obtained automatically by detecting and extracting SFs as 3D features step-by-step and then combining them in accordance with the sketch. When input sketches are complex, more SFs are required. Fig. 2 shows applied SFs from Fig. 1. The polygonal extrusion, curved extrusion, and rib sketch are derived from the cuboid sketch. The pipe, taper, convex flange, and concave flange are derived from the cylinder sketch. The tapered hole, curved hole, and polygonal hole are derived from the round hole sketch.



(a) (b) (c)

Fig. 1: Three Basic SFs: (a) Cuboid, (b) Cylinder, and (c) Round hole.



(a) (b) (c) (d) (e) (f) (g) (h) (i) (j)

Fig. 2: Applied SFs: (a) Polygonal extrusion, (b) Curved extrusion, (c) Rib, (d) Pipe, (e) Taper, (f) Convex flange, (g) Concave flange, (h) Tapered hole, (i) Curved hole, and (j) Polygonal hole.

Fig. 3(a) shows Example 1 as a mechanical part. When it is input to SFBCM, a curved extrusion, cuboid, and polygonal extrusion sketch can be detected and extracted in this order as shown in Fig. 3(f),(h),(l),(o). When these SFs are combined as three 3D features, the solution of Example 1 can be obtained, as shown in Fig. 3(p). However, in our previous studies, the extraction process of SFs was not clear for the practical implementation of SFBCM. In this paper, a precise and effective process for the extraction is proposed.

Main Idea.

Related Works

Studies concerning the conversion of sketches into 3D models have been surveyed in [1]. Most studies were based on the Huffman-Clowes line labeling technique [3],[5]. In the technique, the objects of the sketches were limited to opaque trihedral polyhedrons. Each line segment of a sketch was labeled as "+" (convex line), "-" (concave line), or with an arrow (occluding line). From the labeling, all junctions were classified into the following four types: *L*, *W*, *T*, and *Y*-junctions. This naming was derived from the shapes of the alphabet, i.e., "L," "W," "T," and "Y," respectively. In Example 1, each line segment is labeled as shown in Fig. 3(b). Here, "+" lines are red, a "-" line is green, and arrow lines are blue. In Fig. 3(c), each junction is recognized. There are one *Y*-junction (red), four *W*-junctions (green), five *L*-junctions (blue), and two *T*-junctions (brown). The relationships between the labeling and junctions were summarized as a junction dictionary. Each junction can express a convex or concave shape of a 3D object drawn in a sketch. Malik [6] extended the technique to curved lines in sketches. In Fig. 3(b), a twin arrowed line (light blue) expresses a limb line of a cylindrical face. In Fig. 3(c), a light blue *L*-junction expresses a *Curvature-L-junction* that consists of a straight line and curve, and a gray *T*-junction expresses a *Three-Tangent junction* where a limb line is tangent to a curve.

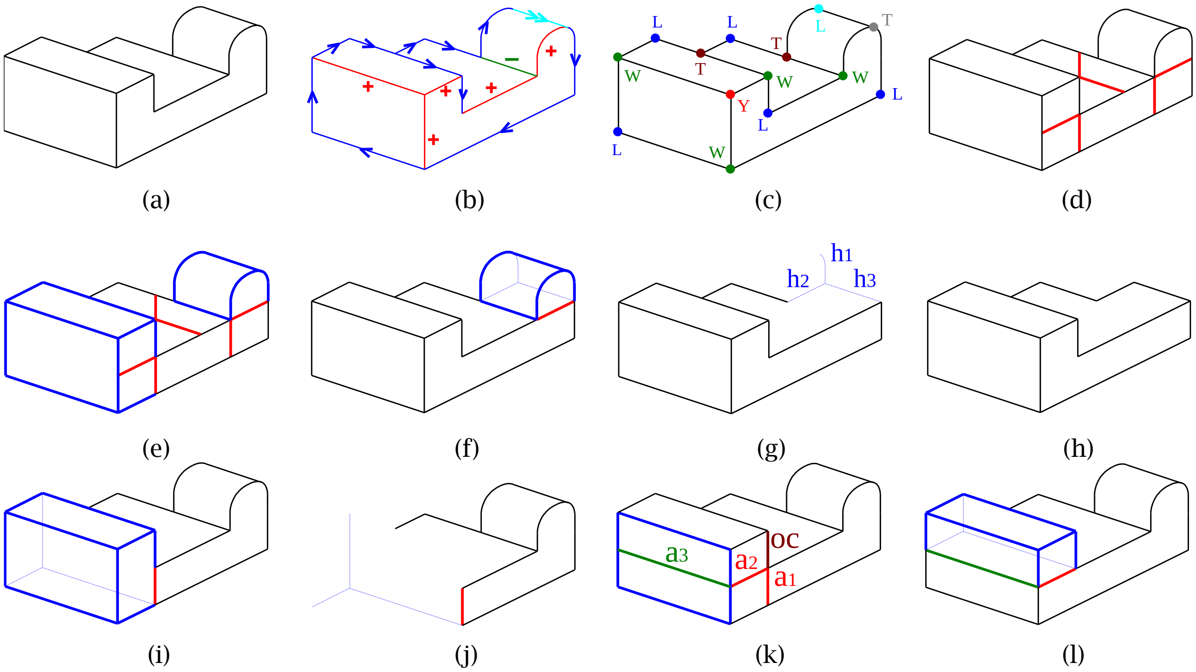
In the other studies, notably, Grimstead and Martin [4] attempted to realize an automatic conversion system. For example, they assumed that vertical lines in a sketch correspond to vertical edges in its 3D model. This assumption is applied to SFBCM. For example, each *Y*-junction always includes a vertical line to simplify the conversion. Recently, Plumed et al. [7] introduced datum information to complete a CSG feature tree and solids from sketches of polyhedral shapes. Although these studies are effective for conversion, the objects of convertible sketches are limited to polyhedrons. In addition, neural network techniques, particularly deep learning techniques, have been actively used for conversion, e.g. [2]. However, geometrical accurate conversion seems to be difficult only in image learning. Furthermore, the 3D modeling platform of SFBCM will be SimpleModeler, a product of Aikoku Alpha Corporation, with which two authors of this paper are associated.

Example 1

In SFBCM, each sketch consists of straight lines, ellipses, and elliptical arcs and is drawn correctly, such as the examples in this paper, using 2D CAD systems. Also, each sketch is an orthogonal projection of an opaque object viewed from a general position, and the target of SFBCM is limited to mechanical objects. The process to convert Example 1 into a 3D model is as follows. First, all lines are divided into line segments at their intersections, and each region, which is a closed loop of line segments, is recognized. Second, each line segment is labeled (Fig. 3(b)), and each junction is recognized (Fig. 3(c)). For example, the *Y*-junction consisting of three "+" lines represents a convex corner in the 3D model of Example 1. Third, ALs (Additional Lines) are drawn as follows. Each of two straight lines forming an *L*-junction is extended to the nearest solid line. Also, each of the two straight lines on both sides of a *W*-junction is extended to the nearest solid line. The extended parts of the lines are ALs. If two or more ALs are intersected, they are divided at their intersection(s). In Fig. 3(d), six ALs (red) are drawn. ALs can simplify the detection of SFs. From this figure, a cuboid and curved extrusion sketch (colored blue) can be detected, as shown in Fig. 3(e). For example, a cuboid sketch can be defined and detected as three parallelograms sharing three lines forming a *Y*-junction. The other definition of SFs is described in [10]. Here, the extraction of the curved extrusion sketch is attempted initially. In SFBCM, when an SF is detected, it can be converted into a 3D model as a 3D feature. Therefore, all hidden lines of the extrusion sketch can be drawn as dotted lines, as shown in Fig. 3(f). Except SFs of holes, our proposed extraction process of an SF consists of the following six steps:

Step 1 All solid lines, each of which is not an AL, are removed from the SF.
Step 2 AL(s) and SAL(s) (explained below) become solid lines because each of them becomes a boundary line between two SFs.
Step 3 All isolated dotted lines are removed. Here, an isolated line is a line segment that does not form any regions.
Step 4 All dotted lines, each of which forms a T-junction, are removed because there are no occluding lines after each SF extraction (more details below). After this removal, if there is some isolated line, it will not be removed (do not return to Step 3).
Step 5 All remaining dotted lines become solid lines because they are not hidden at this step.
Step 6 Each isolated solid line is extended to the nearest solid line.

Extracting the SFs of holes will obviously be simpler than doing the other SF extractions because ALs are essentially not required. Therefore, this process is omitted in this paper. In Fig. 3(f), when Step 1 is done in the curved extrusion sketch, hidden lines (h_1, h_2, h_3) appear as shown in Fig. 3(g). Also, an AL becomes a solid line in Step 2. Here, h_1 consists of an elliptical arc and a straight line. In Step 3, the arc and straight line are removed in this order. In Step 5, h_2 and h_3 become the part of the sketch, as shown in Fig. 3(h). On the other hand, if the extraction of the cuboid sketch in Fig. 3(e) is attempted initially, its hidden lines are drawn as three dotted lines, as shown in Fig. 3(i). After Step 1, these dotted lines appear, as shown in Fig. 3(j). In this figure, after Step 3, any SFs cannot be detected. Consequently, the solution of Example 1 cannot be obtained. This problem has left in SFBCM. Here, we introduce SALs (Secondary Additional Lines). Each SAL can be drawn from an AL and must be a new element of a parallelogram. In Fig. 3(k), there are two ALs (a_1, a_2), and a_3 can be drawn as an SAL from a_2. (*oc* is explained below) Consequently, a cuboid sketch can be detected, as shown in Fig. 3(l). From this figure, after Step 1, three hidden lines (h_1, h_2, h_3) appear, as shown in Fig. 3(m). Here, h_2, h_3, a_2, and a_3 form a parallelogram that becomes a contact face (*Cf*) to the other 3D feature. The detection of some *Cf* enables the combination of two 3D features easily. In this figure, h_1 is removed in Step 3, and then h_3 is removed in Step 4. Consequently, h_2 remains, as shown in Fig. 3(n). In this figure, there is an isolated solid line, and h_2 becomes a solid line in Step 5. Therefore, these two lines can be extended and connected as a solid line in Step 6. Consequently, a polygonal extrusion sketch can be detected as shown in Fig. 3(o). When the three extracted SFs are combined as 3D features, the solution of Example 1 can be obtained, as shown in Fig. 3(p).



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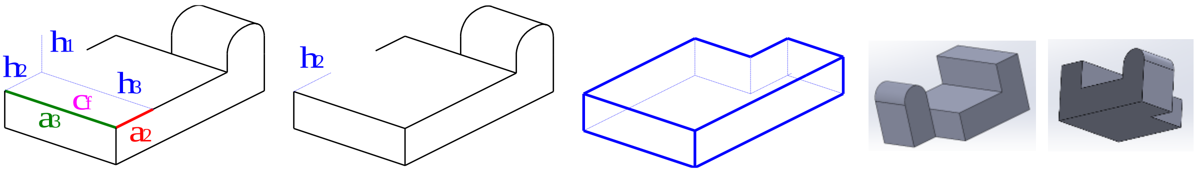
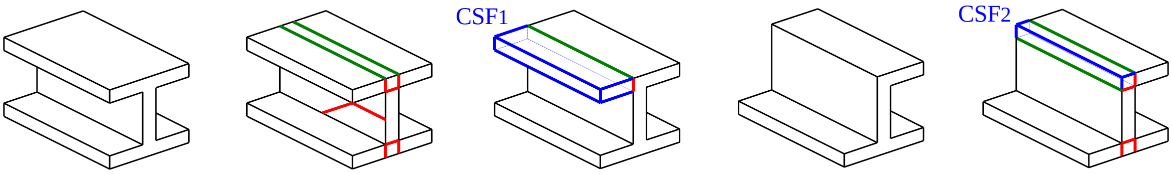


(m) (n) (o) (p)

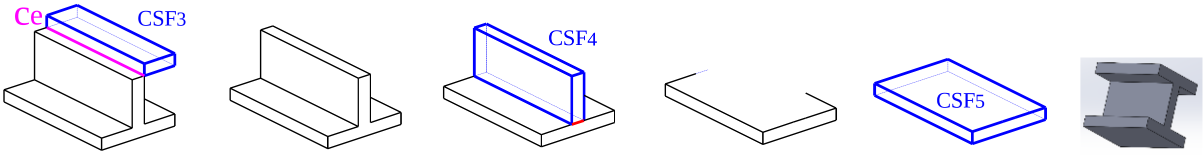
Fig. 3: Example 1: (a) Example 1, (b) Line labeling, (c) Junctions, (d) Additional lines, (e) Detection of two SFs, (f) Curved extrusion with hidden lines, (g) Appeared hidden lines, (h) Extraction of the curved extrusion, (i) Cuboid with hidden lines, (j) Appeared hidden lines, (k) Drawing of an SAL, (l) Detection of another cuboid, (m) Recognition of a contact face, (n) Removal of unnecessary dotted lines, (o) Detection of a polygonal extrusion, and (p) Two overviews of the solution.

Example 2

Fig. 4(a) shows Example 2 expressing an *H*-section steel. Although it can correspond to a polygonal extrusion sketch, its detection will be difficult because of its complexity. Therefore, we attempt this conversion by detecting simpler SFs. First, all ALs (red) and SALs (green) are drawn, as shown in Fig. 4(b). In Example 1, it is found that the detection of a simpler SF, which contains some SAL, is more effective than the other SF detection(s), so, second, a cuboid sketch (CSF1) is detected, as shown in Fig 4(c). It can be extracted as shown in Fig. 4(d). Third, after all ALs and SALs are drawn in this figure, CSF2 can be detected, as shown in Fig. 4(e). In Fig. 4(f), it is extracted. In this extraction, no contact faces can be detected, but a boundary line becoming a contact edge (Ce) between two 3D features can be detected, as shown in this figure. Each *Ce* enables the combination of two 3D features if there is no *Cf*(s). Forth, CSF3, shown in this figure, is detected and extracted, as shown in Fig. 4(g). After this extraction, CSF4 can be detected, as shown in Fig. 4(h). After it is extracted, a dotted line remains, as shown in Fig. 4(i). When the line becomes a solid line and an isolated solid line is extended, CSF5 can be detected, as shown in Fig. 4(j). Consequently, when five 3D features of the cuboid sketches (CSF1…5) are combined at contact faces or a contact edge, the solution of Example 2 can be obtained as shown in Fig. 4(k).



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



(f) (g) (h) (i) (j) (k)

Fig. 4: Example 2: (a) Example 2, (b) ALs and SALs, (c) Detection of CSF1, (d) Extraction of CSF1, (e) Detection of CSF2, (f) Extraction of CSF2 and detection of Ce, (g) Extraction of CSF3, (h) Detection of CSF4, (i) Extraction of CSF4, (j) Detection of CSF5, and (k) Overview of the solution.

Discussion

The most important idea of this paper is drawing ASLs. In Fig. 3(e), if a cuboid sketch is extracted first, any solutions cannot be obtained, as shown in Fig. 3(j). This phenomenon occurs from *oc* (brown), which is an occlusion line, and is the source of a_1 in Fig. 3(k). In general, inner occluding lines that are not contour lines are difficult to handle during the conversion because they often cover essential features in a sketch ([8] can be referred). We introduce SALs to solve this problem. Although drawing SALs to create parallelograms is obviously not easy, there are several patterns to draw correct SALs. Therefore, machine learning techniques may be useful, as shown in our previous studies, e.g. [11]. Also, neural network systems might be useful. The development of a more accurate sequence to extract SFs is an important issue. Also, finding the limitations of sketches that can apply to our proposed process becomes an issue.

Conclusions:

In this paper, an effective extraction process of SFs from sketches for converting to 3D models in SFBCM is proposed. The main idea is the introduction of drawing SALs from drawn ALs during the detection and extraction process of SFs. The effectiveness of SALs is indicated in two examples, and several issues are discussed in the paper.

Masaji Tanaka, https://orcid.org/0000-0002-5266-9182

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