Title:
Introduction of Abstract Sketch Features for Automatic Converting Sketches into 3D Models

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Introduction:

Sketches in the form of line drawings are commonly observed in magazines, books, manuals, etc. Sketches are important for designers, especially engineering designers, when they invent new ideas of products, and many kinds of scenes that are difficult to express as 3D models. The automatic conversion of sketches into 3D models will be advantageous for several applications. In the last fifty years, numerous methods for automatic conversion of sketches into 3D models have been considered and developed [3]. Originally, Huffman-Clowes labeling is important in the conversion [2],[7]. In the labeling, each line segment of a sketch was labeled as "+" (convex line), "-" (concave line), or with an arrow (occluding line). So, the vertices were classified into the following four types of junctions: *L*, *W*, *T*, and *Y*-junctions. The information of the junctions was summarized as a junction dictionary. Fig. 1(a) shows Example 1 that is a sketch of an object. Fig. 1(b) shows the line labeling of Example 1. In this figure, arrowed, "+," and "-" lines are colored blue, red, and green, respectively. So, each junction can be recognized, as shown in Fig. 1(c). In this figure, two red points, five green points, eight blue points, and four brown point express *Y*-, *W*-, *L*-, and *T*-junctions, respectively. A *Y*-junction forming from three "+" lines means a convex corner, and another *Y*-junction forming three "-" lines means a concave corner.

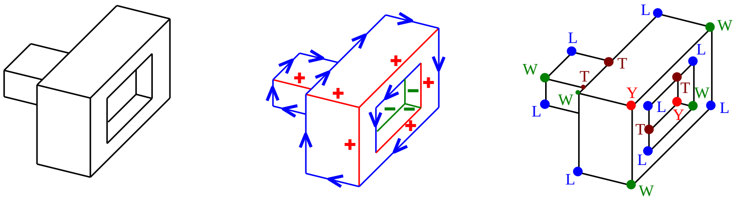

Fig. 1: Example 1: (a) Example 1, (b) Line labeling, and (c) Junctions.

Malik [8] created a junction dictionary for curved lines. Varley et al. [14] identified a "cubic corner" based on [9], which is effective for practical conversions. In recent years, 3D sketching systems have been developed [5-6]. Although these systems might be useful, they are only a few types of solid modelers, for example, CATIA and SolidWorks. Recently neural network, especially deep learning techniques have also been actively used for conversion [1],[4]. In the techniques, learning process is required for the conversion. Although the learning is suitable for known objects such as tables and chairs, it is not suitable for new type and/or creative objects because each of them must be learned individually and repeatedly. Therefore, the learning of these objects seems to be wasteful. Consequently, no real system for the conversion has been developed till now. We have also been developing methods for the conversion for about seven years [10-13]. Recently, we proposed a practical method as SFBCM (Sketch Feature-Based Conversion Method) [12]. In SFBCM, firstly sketch features are defined. Fig. 2 shows seven basic sketch features. Each of them can be recognized and drawn by people. So, we considered that if a complex sketch can be disassembled into sketch features, it can be converted into a 3D model. Also, people draw sketches as isometric and symmetric as possible. For example, people draw a cuboid sketch as Fig. 3(a) that is contradicted from [9],[14], and they never draw a sketch of a long pole not Fig. 3(b) but Fig. 3(c). Therefore, each length of lines in a sketch can usually be regarded as real length. Consequently, more practical conversion was enabled in SFBCM. However, several issues have remained. Especially, it is difficult to predict occluding shapes forming from *T*-junctions. Although we proposed an inductive learning system for restoring the occluding shapes [13], it was found that "learning" is an ideal method because unknowable much data will be required. In this paper, a method of predicting the occluding shapes is proposed by applying human perception. In this method, we abstract our conventional SF (Sketch Feature) to ASF (Abstract Sketch Feature).

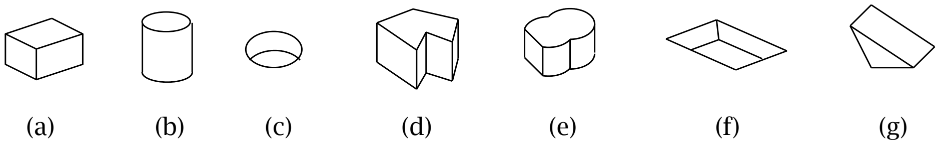

Fig. 2: Seven basic sketch features: (a) Cuboid, (b) Cylinder, (c) Round hole, (d) Polygonal extrusion, (e) Multi-extrusion, (f) Rectangular hole, and (g) Rib.

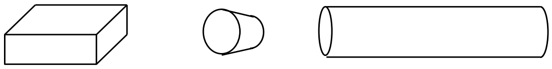

Fig. 3: Three types of sketches: (a) Ambiguous but understandable cuboid sketch, (b) A sketch of a long pole, and (c) Another sketch of the pole.

In this method, a sketch is drawn in 2D drawing systems on a PC, tablet, etc. Also, a sketch is an orthogonal and opaque projection of a 3D object placed in a general position. In the present step of this method, main targets of sketches are mechanical parts. In addition, each sketch consists of ellipses, elliptical arcs, and straight lines. Images and freehand sketches are not be handled in this method because this problem can be separated from the conversion. Also, SFs are quite different from "machining features" in CAD techniques. Firstly, we found simple sketches as shown in Fig. 2, and they can be recognized as 3D models. This is because finding more effective SFs for the conversion is a more important problem so that the abstraction of SFs is the main theme in this paper. However, abstracted machining features would be meaningless because they cannot be machined.

Main Idea:

Here, SFBCM is explained simply by using Example 1 shown in Fig. 4(a). Its detailed explanation can be referred in [10-13]. When Example 1 is input to SFBCM, first, an SF of a rectangular hole (red) can be detected as shown in Fig. 4(b). Form this figure, hidden lines of the SF can be drawn as dotted lines as shown in Fig. 4(c). So, the SF can be extracted as f_1 as this figure. f_1 is one of 3D features in this method. The contact face of f_1 to the other 3D feature becomes a blue dotted parallelogram in Fig. 4(d). Second, an SF of a cuboid (red) can be detected and extracted as f_2 as shown in Fig. 4(e). After f_2 is extracted, five (green) lines are remained. It is found that these lines can be seen as a part of an SF of a cuboid. So, we define it as an abstract SF (ASF) of a cuboid. From Fig. 2, five types of ASFs can be defined as shown in Fig. 5. They are cut SFs from *T*-junctions. Obviously, there are many more types of ASFs when each SF is cut in the other directions.

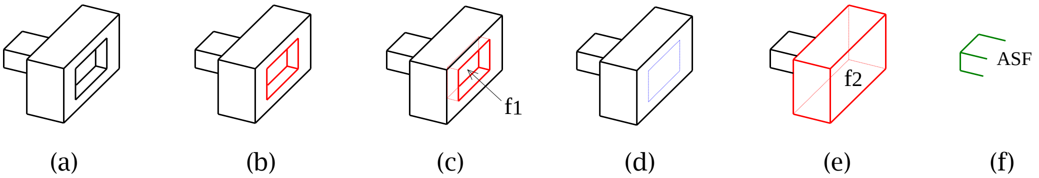

Fig. 4: Example 1 and detection of an ASF: (a) Example 1, (b) Detection of an SF of a rectangular hole, (c) Extraction of the SF (f_1), (d) Recognition of the contact face to f_1, (e) Detection of a cuboid (f_2), and (f) Detection of an ASF of a cuboid.

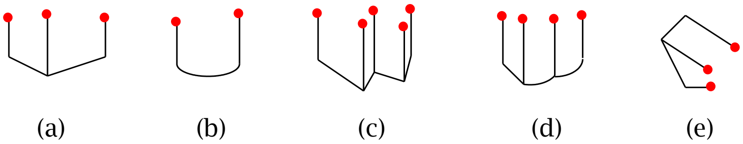

Fig. 5: Five types of ASFs: (a) Partial cuboid, (b) Partial cylinder, (c) Partial polygonal extrusion, and (e) Partial multi-extrusion.

From Fig. 4(e), a 3D coordinate system can be placed as shown in Fig. 6(a) from the convex Y-junction of f_1 (red). In this figure, P_1P_2 is one of the lines in the (green) ASF of a cuboid. In Fig. 6(b), P_1P_2 is extended as P_1P_3. In this figure, the ASF contacts to f_2 but their two *T*-junctions are removed. Therefore, it is found that if P_1P_3 is shorter than this figure, they are not contacted. In the same way, if P_1P_2 is extended as P_1P_4 as shown in Fig. 6(c), the ASF contacts to f_2 but if P_1P_4 is longer than this figure, they will be overlapped. Therefore, it is found that the length of the line is more than P_1P_2 and less than or equal to P_1P_4. Here, when a person looks at Example 1, he/she may predict that the ASF contacts to f_2 centrally. It is a human perception. In Fig. 6(d), P_1P_2 is extended as P_1P_5. In this figure, the (brown) contact face of the ASF is placed centrally to f_2. Consequently, an SF of a cuboid as f_3 can be defined from the ASF. Consequently, when three 3D features (f_1, f_2, f_3) can be combined at their contact faces, the 3D model of Example 1 can be obtained. In Fig. 6(e), another SF of a cuboid is drawn to Fig. 6(a). In this case, it is found that the length of f_3 is decided as P_6P_7 by seeing from y axis. Therefore, it is found that many problems still exist to predict the length of f_3.

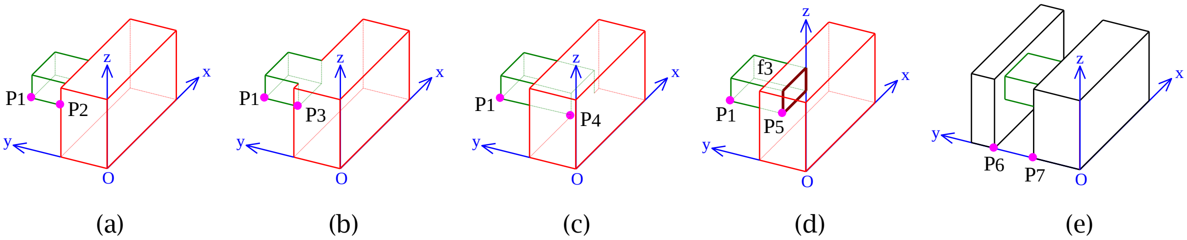

Fig. 6: Prediction of the length in the ASF: (a) 3D coordinate system, (b) Minimum contact between f_2 and the ASF, (c) Maximum contact between them, (d) Center contact between them, and (e) A case that the ASF contacts to both two cuboids.

Fig. 7(a) shows Example 2 that is a rotational mechanical part. When a cylinder sketch (f_1) is detected as shown in Fig. 7(b), it is clear the bottom ellipse becomes the contact face to the other 3D feature. When f_1 is extracted, f_2 and an ASF of a cylinder are detected as shown in Fig. 6(c). In the same way of

Example 1, f_3 can be predicted from the ASF as shown in Fig. 6(d). Consequently, the 3D model of Example 2 can be obtained by combining these three SFs (f_1, f_2, f_3).

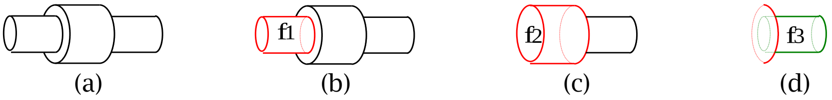

Fig. 7: Example 2: (a) Example 2, (b) Detection of F_1, and (c) Relationship between F_2 and F_3.

Fig. 8(a) shows Example 3 that is a mechanical arm part. It is the most difficult example in [12]. However, this example can be solved by the introduction of ASF. First, three holes can be extracted as shown in Fig. 8(b). Also, a round rib (f_1) and a multi-extrusion (f_2) are detected respectively. When they are extracted, a cylinder (f_3) and ASF(s) can be detected as shown in Fig. 8(c). Although the handling of the ASF(s) seems difficult, people can infer it because there are many similar objects each of which consists of a cylinder with ribs such as Fig. 8(d) like rockets and arrows. Therefore, it can be predicted that there are two same ribs and multi-extrusions (f_4, f_5) around f_3 such as shown in Fig. 8(e). Consequently, the solution of Example 3 can be obtained as shown in Fig. 8(f).

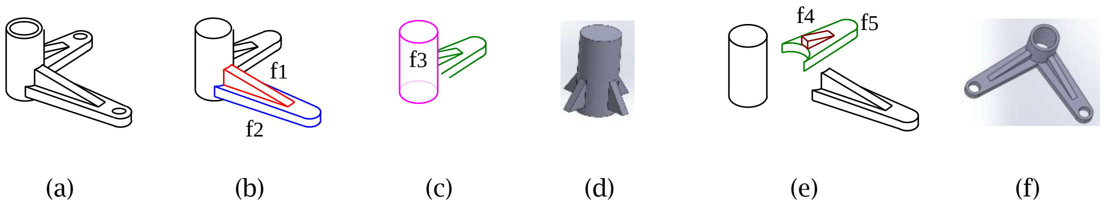

Fig. 8: Example 3: (a) Example 3, (b) Detection of a round rib and a mult-extrusion, (c) Detection of a cylinder and ASF(s), (d) Sample of a cylinder with ribs, (e) Prediction of a rib as f_4, and a multi-extrusion as f_5, and (f) Overview of the solution.

Conclusion:

In this paper, we introduce ASF to SFBCM for handling occluding shapes from *T*-junctions in sketches. In the explanation of Example 1, ASFs are defined as cut SFs, and the length of a cuboid ASF can be analyzed and predicted. This prediction can solve Example 2. In Example 3, a human perception of a cylinder with ribs can be applied, and the solution can be obtained. Several issues still exist in this research as follows:

1. There are many more ASFs, so it is necessary to find and summarize them.
2. In Example 3, a prototype of a cylinder with ribs is applied in accordance with human perception. It is necessary to find and summarize many more prototypes because they can proceed more abstraction of ASFs in this paper.
3. Continuously, to handle more complex sketches are the issues for our research.

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