Title:
SFLCM: SFBCM with Learning for Automatic Conversion of Sketches into 3D Models

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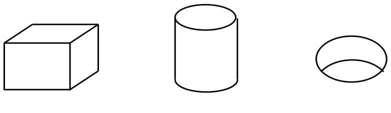
Keywords:
Sketch, 3D model, Automatic Conversion, SFBCM, SFLCM, Sketch Feature, Machine Learning, YOLO

DOI: 10.14733/cadconfP.2026.159-163

Introduction:

Sketches in the form of line drawings are commonly observed in magazines, books, and manuals, among others. 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 is advantageous for a variety of applications, including CAD, CG, CV, and so forth. Moreover, in the future, robots will be expected to understand sketches and convert to 3D models correctly. Over the past 50 years, numerous methods have been developed for the conversion, e.g. [1]. However, no exact conversion system has been developed to date. We have been developing methods for the conversion for about thirteen years, and proposed a *sketch feature-based conversion method* (SFBCM) to achieve this conversion, especially in mechanical objects [7-10]. On the other hand, with the rapid development of generative AI such as the Diffusion model, many studies and practical systems for the conversion of a single image into a 3D model have been developed during recent years. In particular, Tripo system, e.g. [4] would be superior than other systems, and it has already been publicly available. The comparison between Tripo and our proposed method in this paper is explained later.

In SFBCM, each sketch consists of straight lines, ellipses, elliptical arcs, and sometimes Bezier curves. Each sketch is drawn in 2D CAD, tablet, and so forth, as an orthogonal projection of an opaque object, viewed from a general perspective. Fundamentally, SFBCM uses *sketch features* (*SF*s). Fig. 1 shows three basic *SF*s: a cuboid, cylinder, and round hole. Each can be recognized as a 3D object, and also drawn easily by people. Each of their definition is not complex in CAD data, such as DXF data. For example, a cuboid sketch can be defined as three parallelograms sharing three straight lines forming a *Y*-junction explained below. In SFBCM, when a sketch is input, a 3D model is obtained by detecting and extracting *SF*s as 3D features step-by-step, and then assembling them in accordance with the original sketch. Fig. 2(a) shows Example 1 as a mechanical part. Its solution is obtained as follows.

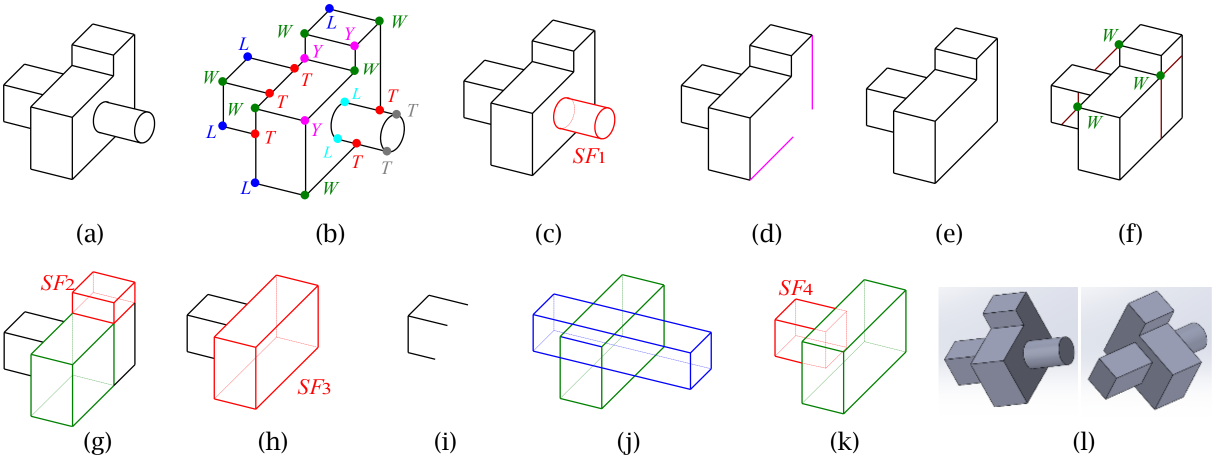


(a) (b) (c)

Fig. 1: Three basic *SF*s: (a) Cuboid, (b) Cylinder, and (c) Round hole.

First, all junctions of lines are detected as shown in Fig. 2(b) using Huffman-Clowes line labeling technique [2-3], for the detection of *SF*s easily. In this technique, all junctions of lines are classified into four types: *L*, *W*, *T*, and *Y*-junctions. This naming was derived from the shapes of the alphabets, i.e., "L," "W," "T," and "Y," respectively. Malik [5] extended the technique to curved lines. For example, a *Curvature-L*-junction connects a line tangentially to a curve, and a *Three-Tangent* junction connects a line tangentially to an ellipse. In this figure, four *L*-junctions (blue), six *W*-junctions (green), five *T*-junctions (red), three *Y*-junctions (pink), two *Curvature-L*-junctions (light blue), and two *Three-Tangent* junctions (gray) are detected. Consequently, a cylinder sketch (*SF*1) can be detected as shown in Fig. 2(c). In this figure, a hidden arc can be drawn because the cylinder is already recognized as a 3D feature. After *SF*1 is extracted from the sketch, two (pink) lines become isolated as shown in Fig. 2(d). Each is called an isolated line that does not form any closed loops of lines. These can be connected by their extension in SFBCM as shown in Fig. 2(e).

In this figure, no *SF*s shown in Fig. 1 can be detected. In this case, *additional lines* (*AL*s) are drawn to assist the *SF* detection. In SFBCM, two *AL*s are drawn from each of *W* and *L*-junctions like extending lines. Each extension continues until it contacts the other line; otherwise, it is removed. In Fig. 2(f), five *AL*s (colored brown) are drawn from three *W*-junctions. Consequently, two cuboid sketches (colored green and red) can be detected, as shown in Fig. 2(g). In this case, the red one is detected as *SF*2 as shown in this figure, because if the green one is detected and extracted, an *ASF* explained below appears. After *SF*2 is extracted, *SF*3 is detected as shown in Fig. 2(h). After extraction, five lines remain as shown in Fig. 3(i). These lines can form a part of a cuboid sketch, so we call it an *abstract sketch feature* (*ASF*) of a cuboid. Fig. 3(j) shows the region where the *ASF* may exist. In SFBCM, the length of the *ASF* can be predicted as it were contacting *SF*3 at the center of its back surface. This prediction corresponds to the human perception. The detailed explanation of *ASF*s is described in [9]. Consequently, *SF*4 is detected as shown in Fig. 2(k). After extraction, there are no lines. Therefore, all extracted 3D features are assembled step-by-step, from *SF*4 to *SF*1, in accordance with the original sketch as Fig. 3(a). In this process, all dimensions of 3D features and their relative positions must be decided. In SFBCM, we assume that sketches drawn by people are as isometric and symmetric as possible [8]. Therefore, the ratio of the lengths of lines in a sketch corresponds to the ratio of the lengths of edges in its 3D model. Consequently, the solution can be obtained as shown in Fig. 2(l).

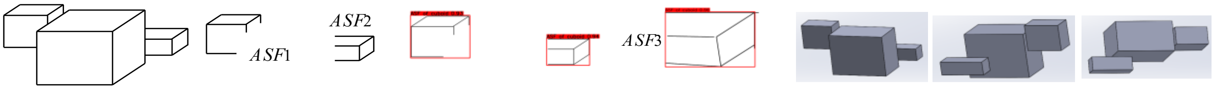


(a) (b) (c) (d) (e) (f)

(g) (h) (i) (j) (k) (l)

Fig. 2: (a) Example 1, (b) Detection of all junctions, (c) Detection of *SF*1, (d) Extraction of *SF*1, (e) Restoration of two isolated lines, (f) Five *AL*s drawn from three *W*-junctions, (g) Detection of *SF*2 (h) Detection of *SF*3, (i) Detection of an *ASF* of a cuboid, (j) The region where the *ASF* may exist, (k) Detection of *SF*4, and (l) Two overviews of the solution.

Many types of *ASF*s can be made from an *SF*. Fig. 3(a) shows Example 2, consisting of three cuboids. After the central cuboid sketch is extracted, two *ASF*s (*ASF*1, *ASF*2) of a cuboid remain as shown in Fig. 3(b). In these two *ASF*s and the *ASF* of Fig. 2(i), the shapes and the numbers of lines are different from each other. Therefore, it would be impossible or meaningless to define an *ASF* of a cuboid in CAD data, although defining the *SF* of it is simple. This phenomenon is the same in the other *ASF*s. Therefore, we applied YOLO [6] that is an image learning system, to detect *ASF*s efficiently. Consequently, a hybrid method as SFBCM with YOLO was proposed in [11]. In Fig. 3(c), the two *ASF*s are detected by YOLO. Furthermore, a broken ASF (*ASF*3) such as shown in Fig. 3(d) can also be detected by YOLO, because to use YOLO is equal to having eyes for computers. The experimental results in this paper were obtained using YOLOv11. The number of training data for the *ASF* of a cuboid was more than 500, and the accuracy of detecting these three *ASF*s was more than 93%. Fig. 3(e) shows the solution of Example 2. During this study, we have considered that YOLO can detect not only *ASF*s but also *SF*s. In particular, complex and/or curved *SF*s are difficult to detect from CAD data, but easy for YOLO. Therefore, in this paper, we attempt to detect complex *SF*s, especially in mechanical elements, such as gears. We call our proposed method SFLCM (*sketch feature learning based conversion method*).

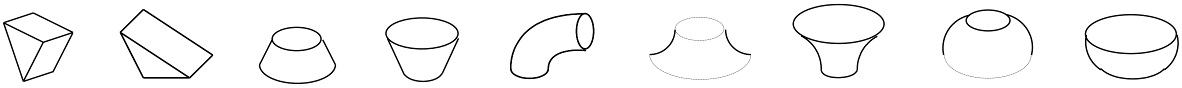


(a) (b) (c) (d) (e)

Fig. 3: (a) Example 2, (b) Detection of two *ASF*s, (c) Detection by YOLO, (d) Detection of *ASF*3, and (e) Three overviews of the solution using SFLCM.

Main Idea:

To date, we have found 30 *SF*s so far, e.g. [7],[10]. The main *SF*s except Fig. 1 are shown in Fig. 4. These were found from mechanical parts. The dotted lines in Figs. 4(f) and (h) mean that these are often invisible because they often connect to other *SF*(s) tangentially. The detection of an *SF* from an input sketch is started from three *SF*s in Fig. 1, and then *SF*s in this figure are detected, because of their appearance probability and complexity of shapes.



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

Fig. 4: Ten main SFs except Fig. 1: (a) Prism, (b) Rib, (c) Pudding, (d) Taper, (e) Pipe, (f) Concave flange, (g) Inverse flange, (h) Convex flange, (i) Round cup.

Each convertible sketch must consist of defined *SF*s in SFBCM. Therefore, to find more *SF*s will extend the limitation of convertible sketches. In mechanical objects, there are many complex sketches of machine elements, such as screws, gears, and so forth. In this paper, gears and handles are focused as *mechanical complex SF*s (*MSF*s). In our experiment, more than 100 data were trained by YOLO in each of the *MSF*s. Fig. 5 shows their sample sketches. It is difficult and time consuming to draw the sketches of this figure precisely by people. Therefore, these become rough sketches inevitably.

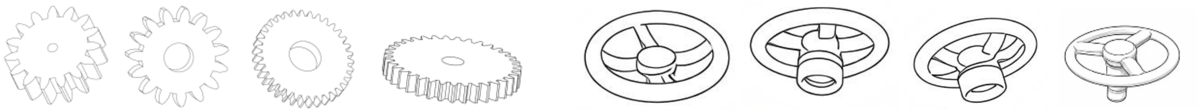
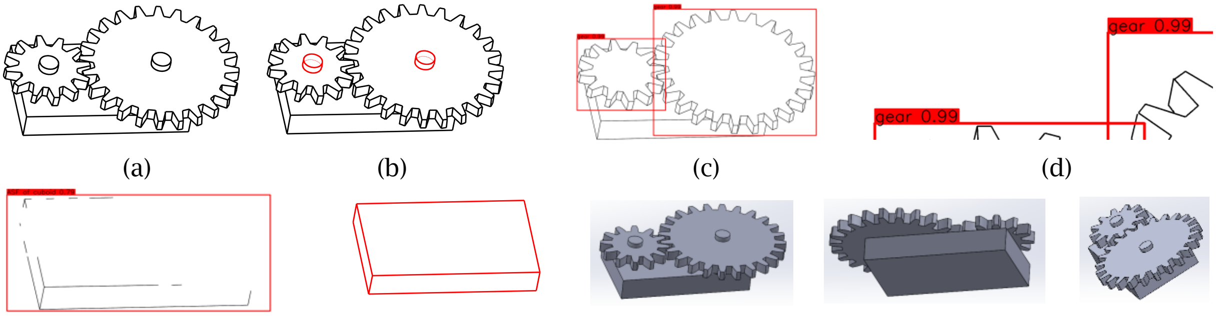


Fig. 5: Four *MSF*s of gears and four *MSF*s of handles.

Fig. 6(a) shows Example 3, which is a sketch of a simple gear unit. In SFLCM, the order of the detection is from *SF*s to *MSF*s and *ASF*s, and YOLO is applied to *MSF*s and *ASF*s. Therefore, first two cylinders are detected as shown in Fig. 6(b). After extraction, two gears can be detected by YOLO as shown in Fig. 6(c). Fig. 6(d) shows its text parts. In this figure, it is found that the accuracy of detecting the two gears is both 99%. After their extraction, several lines remain as shown in Fig. 6(e). When these are extended, no *SF*s can be detected. Therefore, *ASF*s are searched by YOLO. Consequently, an *ASF* of a cuboid can be detected as shown in this figure, and an *SF* of a cuboid can be predicted as shown in Fig. 6(f). Consequently, the solution can be obtained as shown in Fig. 6(g).

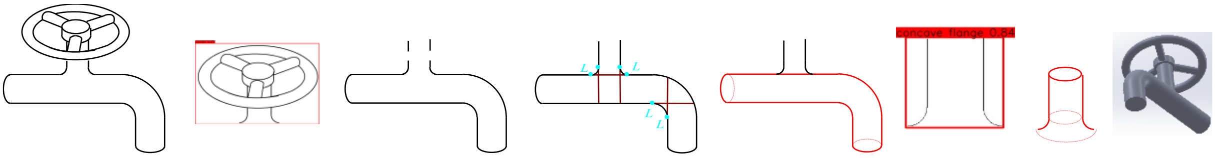


(a) (b) (c) (d)

(e) (f) (g)

Fig. 6: (a) Example 3, (b) Detection of two cylinders, (c) Extraction of the cylinders and detection of two *MSF*s of gears using YOLO, (d) Text parts of (c), (e) Extraction of the gears and detection of an *ASF* of a cuboid, (f) Prediction of a cuboid sketch, and (g) Three overviews of the solution.

Fig. 7(a) shows Example 4 that is a sketch of a tap. In this figure, no *SF*s can be detected, but an *MSF* of a handle can be detected (99% probability) by YOLO as shown in Fig. 7(b). After extraction, four isolated lines appear as shown in Fig. 4(c). Although two parallel lines can be generated by our conventional way as shown in Fig. 4(d), these cannot be extended because they do not intersect. Therefore, five *AL*s are drawn from six *Curvature-L*-junctions as shown in Fig. 7(d). Consequently, an *SF* of a pipe which is another type from Fig. 4(e) can be detected as shown in Fig. 7(e). After extraction, an *ASF* of a concave flange can be detected (84% probability) as shown in Fig. 7(f). From the detection, a concave flange connecting to a cylinder can be predicted as shown in Fig. 7(g). In conclusion, the solution can be obtained as shown in Fig. 7(h).



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

Fig. 7: (a) Example 4, (b) Detection of a handle, (c) Its extraction, (d) Generation of two parallel lines and five *AL*s, (e) Detection of a pipe, (f) Detection of an *ASF* of a concave flange, (g) Prediction of a cylinder and concave flange, and (h) Overview of the solution.

Conclusions:

In this paper, we propose a method called SFLCM that can handle not only conventional *SF*s and *ASF*s, but also more complex *SF*s such as *MSF*s using YOLO, and present two examples using gears and handles which are *MSF*s. Although it is difficult or impossible to detect *MSF*s and broken *SF*s such as shown in Fig. 3(d) from CAD data, YOLO can detect them with image learning. Therefore, we will handle more illustrative sketches, and that must be strong advantage for the conversion of sketches into 3D models compared to other learning-only systems such as Tripo described above. The results of all examples in this paper using Tripo (https://studio.tripo3d.ai/) are shown in Fig. 8. Each example was tested twice. Figs. 8(a), (b), and (c) correspond to Example 1. Fig. 8(a) shows a good fit, whereas the axes of the cylinders in Fig. 8(b) and (c) are tilted. Figs. 8(d), (e), and (f) correspond to Example 2. The front cuboid is too large in both cases. In Fig. 8(e), three cuboids are separated from it. In Fig. 8(f), a cuboid is separated and titled. Fig. 8(g) shows a good fit, except that the height of the two gears is slightly too high. Fig. 8(h) shows a good fit. The gear unit and tap are considered relatively easy to learn and convert because their sketches are not uncommon, but Examples 1 and 2 are difficult to convert due to their unique shapes. Based on approximately 50 case studies, we summarize the comparison between SFLCM and Tripo as shown in Tab. 1. Consequently, it is considered that SFLCM can convert not only known objects but also creative ones accurately, even though the convertible sketches must consist of *SF*s, while Tripo can convert only known objects but it can apply to extremely complex sketches, even although the accuracy of the solutions becomes vaguer. In SFLCM, in order to extend the limitation of convertible sketches and to generalize the algorithm, it would be necessary not only to explore more *SF*s and *ASF*s, but also to explore specific *SF*s and *ASF*s in individual domains.


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

Fig. 8: The results of all examples using Tripo: (a) Front view in Example 1, (b) Tilted cylinder, (c) Another tilted cylinder, (d) Front view in Example 2, (e) Separated three cuboids from larger one, (f) Separated and tilted cuboid from it, (g) Gear unit, and (h) Tap.

System	Convertible objects	Flexibility of conversion	Dimension	Geometrical suitability
SFLCM	Consisting of SFs	Low	Accurate	Accurate
Tripo	Known objects	High	Vague	Vague

Tab. 1: The comparison between SFLCM and Tripo.

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