Title:
Convertible Sketches of Mechanical Curved Objects into 3D Models by SFBCM

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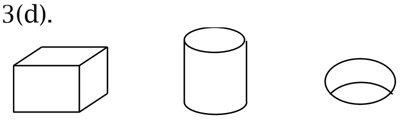
Introduction.
Sketches in the form of line drawings are commonly observed in magazines, books, manuals, etc. Sketches are also important for designers, particularly mechanical designers, when inventing new ideas of products and their parts. The automatic conversion of sketches into 3D models will be advantageous for several applications. For example, it is expected that robots will 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 converting sketches into 3D models for approximately ten years. Consequently, we have proposed a method as SFBCM (Sketch Feature-Based Conversion Method) to achieve this conversion [5-8].

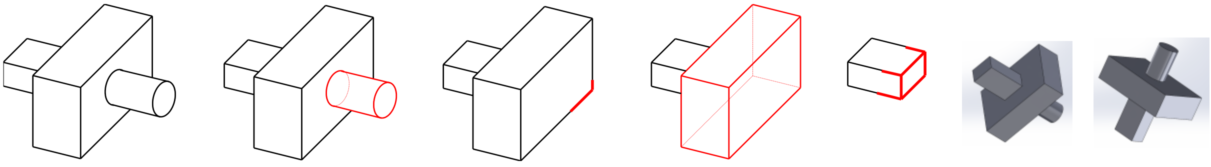
A simplified explanation of SFBCM is as follows. Fig. 1 shows three basic sketch features (SFs) indicating a cuboid, cylinder, and round hole. For example, a cuboid sketch can be defined as three parallelograms sharing three straight lines that form a *Y*-junction explained below. In SFBCM, when a sketch is input, its 3D model can be obtained by detecting and extracting SFs as 3D features step-by-step and then combining them in accordance with the sketch. Fig. 2(a) shows Example 1 that is a sketch of a mechanical part. When this example is input to SFBCM, first, a cylinder sketch (colored red) can be detected and its hidden lines can be drawn as shown in Fig. 2(b). In Fig. 2(c), the cylinder is extracted as a 3D feature and two straight lines are restored as two red lines. In Fig. 2(d), a cuboid sketch can be detected. After the cuboid is extracted, although a partial SF of a cuboid remains, it can be predicted as a cuboid sketch as shown in Fig. 2(e). Consequently, the solution of this example can be obtained as shown in Fig. 2(f) by combining the three 3D features in accordance with Fig. 2(a).

In SFBCM, many issues have been still remained for developing practical conversion systems. In our last research, we attempted to handle the sketches of chains, springs and screws [5]. Their shapes are complex so we introduced accessorial sketch features (ACSFs). Consequently, the following phenomenon was found. Fig. 3(a) shows a chain sketch. Fig. 3(b) shows two types of ACSFs in rings obtained from Fig. 3(a). However, if a ring sketch is defined as shown in Fig. 3(c), it can be seemed as a tapered ellipse as shown in Fig. 3(d).



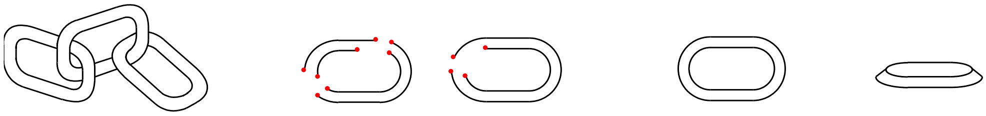
(a) (b) (c)

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



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

Fig. 2: Example 1: (a) Example 1, (b) Detection of a cylinder sketch, (c) Restoration of two lines, (d) Detection of a cuboid sketch, (e) Prediction of a cuboid sketch, and (f) Two overviews of the solution.



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

Fig. 3: Chain sketch and its elements: (a) Chain sketch, (b) Two types of ACSFs in rings, (c) Ring sketch, and (d) Sketch of a tapered ellipse.

This phenomenon can give us a hint to limit convertible sketches of mechanical curved objects in SFBCM because our handling sketches of curved objects had been not comprehensive but partial. In short, not every cured object can be drawn in sketches, and mechanical curved objects drawn in sketches are usually limited such as flanges, pipes and simple covers except special parts such as chains, because it is difficult for people to draw and understand them. In this study, the process to limit convertible sketches of mechanical curved objects is explained, and then several new SFs are introduced. Finally, an actual example is indicated.

Main Idea.

Related Works

Papers concerned with this conversion were surveyed in [1]. Originally, Huffman-Clowes labeling is important to interpret sketches [2],[4]. In their study, the objects of sketches were limited to opaque trihedral polyhedrons, and each sketch was an orthogonal projection of an object viewed from a general position. Each line segment of a sketch was labeled as "+" (convex line), "-" (concave line), or with an arrow (occluding line). From this labeling, the vertices were classified into four types of junctions as *L*, *W*, *T*, and *Y*-junctions. This naming was derived from the shapes of the alphabets, i.e., "L," "W," "T," and "Y," respectively. The relationships between the labeling and the junctions were summarized as a junction dictionary. Although the dictionary could not handle the sketches of curved objects, Malik [10-11] advanced it to handle them.

Fig. 4 shows a sample of line labeling. Fig. 4(a) shows a sample sketch. In Fig. 4(b), each line segment is labeled. Arrowed, twin arrowed, "+," and "-" lines are colored blue, light blue, red, and green, respectively. Each arrowed line expresses an occluding edge of an object drawn in a sketch. Each twin arrowed line expresses a limb line of a cylindrical face of an object. Each "+" line expresses a convex edge, and each "-" line expresses a concave edge. From this figure, each junction can be recognized, as shown in Fig. 4(c), by using the junction dictionary. The two red points are *Y*-junctions. The left one expresses a convex corner because it consists of three "+" lines. The other expresses a concave corner. Four green points, three blue points, and a brown point express *W*-, *L*-, and *T*-junctions, respectively. Four *L*-junctions colored light blue express *Curvature-L-junction*s each of which consists of a straight line and a curved line. A gray *T*-junction expresses a *Three-Tangent junction* where a limb line is tangent to a curved line. Each of two pink points expresses a *Phantom-node* where a "+" curved line and an arrow line form an ellipse. Consequently, it is found that if sketches are drawn correctly, the line labeling of them are possible. However, there are no practical methods to automatically convert 3D models, particularly curved 3D models, from sketches.

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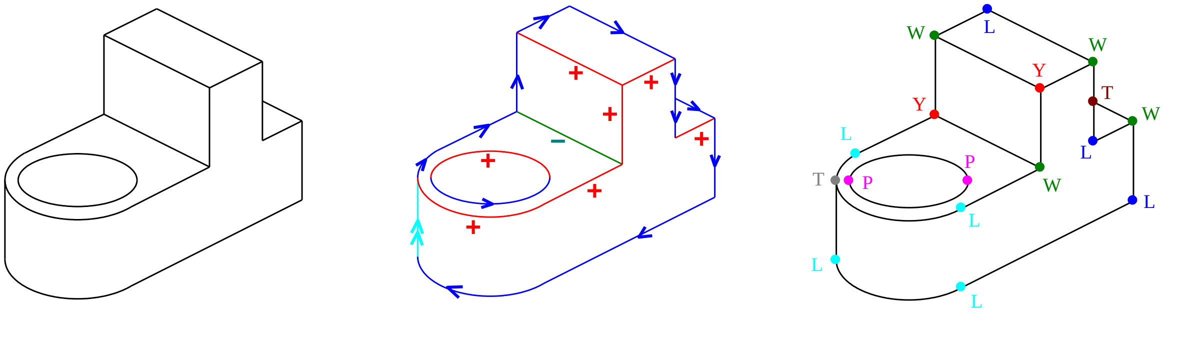
In recent years, to handle hand-drawn sketches for the conversion has been researched, e.g. [3] because sketches can be drawn with digital tool such as Apple pencil on iPad nowadays. Also, Neural Network techniques especially deep learning techniques have also been actively used for conversion, e.g. [9]. The techniques would be effective for simpler shapes such as polygons, and known objects such as tables, chairs, cups because they are based on image processing essentially. However, it will be difficult to convert sketches of mechanical objects especially creative ones into 3D models precisely and geometrically.



(a) (b) (c)

Fig. 4: Sample of line labeling: (a) Sample sketch, (b) Line labeling, and (c) Junctions.

Limitation of convertible sketches in mechanical curved objects

Fig. 5(a) shows a Malik's sample sketch. Although its all lines can be labeled uniquely as shown in Fig. 5(b), most people cannot imagine its 3D shape precisely. Also, it is difficult for people to draw sketches of unusual curved objects such as this sample. Therefore, convertible sketches of mechanical curved objects are inevitably limited. To find out the limit, we have searched plenty sketches of mechanical curved objects. Consequently, we have found several tendencies as follows:

- In the sketches of mechanical curved objects, cylindrical faces are usually drawn. Next, toroidal faces are drawn. Conical faces are sometimes drawn. Spherical faces are occasionally drawn but it is difficult to recognize their sketches. For example, a ball can only be drawn as a circle.
- Generally it is difficult to draw free-form surfaces in sketches so it is not necessary to consider their sketches in this conversion.
- Toroidal faces are usually drawn as fillets of mechanical objects. Conical faces are often drawn as chamfers of cylindrical objects.

Here, sketches of special mechanical curved objects such as chains, springs and screws are excluded. Their handling is described in [5]. Fig. 6 shows the sketches of three type cups with slightly different shapes. Although these cups are different from mechanical objects, it is easy to explain the tendencies described above. Fig. 6(a) shows a simple type cup and it can be handled by SFBCM because it can be disassembled into a cylinder sketch, a round hole sketch, and a pipe sketch. Fig. 6(b) shows a curved type cup. It is difficult to handle this sketch by SFBCM because the definition of SF(s) for curved cylinder(s) would be difficult. Fig. 6(c) shows a cup with a spout type. It is also difficult to handle this sketch by SFBCM because the definition of SF(s) of spout(s) would be difficult. Fig. 7(d) shows a conical type cup. If the SFs of a taper and tapered hole are defined, it is possible to handle this sketch.

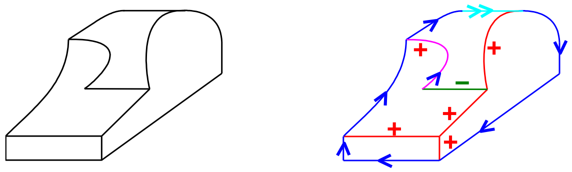
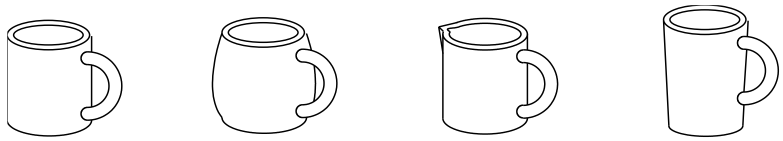


Fig. 5: Another Malik's sample: (a) Sketch and (b) Line labeling.

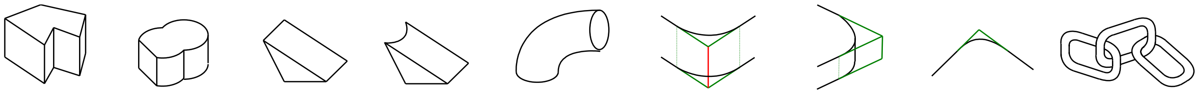


(a) (b) (c) (d)

Fig. 6: Sketches of three type cups: (a) Simple type, (b) Curved type, (c) With a spout type, and (d) Conical type.

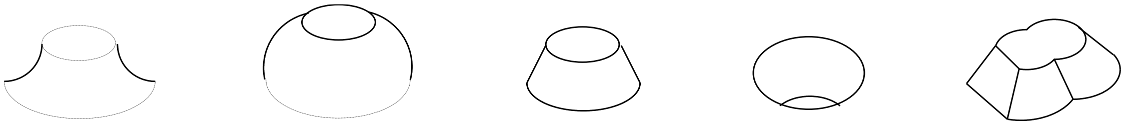
New SFs for Handling Sketches of Mechanical Curved Objects

Fig. 7 shows all SFs except Fig. 1 in SFBCM. For example, the definition of polygonal extrusion is that there are a polygon and several parallelograms, and each line segment of the polygon can become a line segment of a parallelogram, and also two adjacent parallelograms share a line segment. The other definition of SFs is described in [5-8]. In this study, five new SFs shown in Fig. 8 are added to SFBCM. Fig. 8(a) shows a concave flange that consists of two arcs, a dotted ellipse, and a dotted arc. These dotted lines are often invisible because they often become tangent lines to the other SFs. Fig. 8(b) shows a convex flange whose shape is the inverse of Fig. 9(a). Fig. 8(c) shows a taper. It can be defined as a tapered cylinder. Fig. 8(d) shows a tapered hole that consists of an ellipse and an arc whose radius is shorter than the ellipse. Fig. 8(e) shows a tapered multiple extrusion that corresponds to a taperd Fig. 7(b).



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

Fig. 7: Nine SFs: (a) Polygonal extrusion, (b) Shape with multiple extrusions, (c) Rib, (d) Round rib, (e) Pipe, (f) Front fillet, (g) Side fillet, (h) Hidden fillet, and (i) Chain.

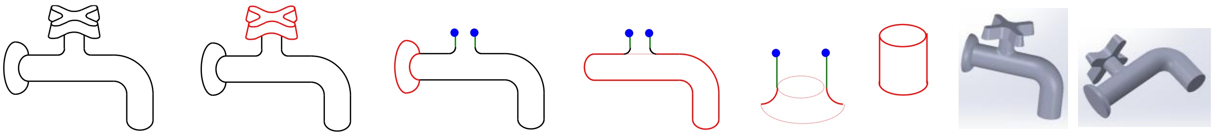


(a) (b) (c) (d) (e)

Fig. 8: Five new SFs: (a) Concave flange, (b) Convex flange, (c) Taper, (d) Tapered hole, and (e) Tapered multiple extrusion.

Example 2

Fig. 9(a) shows Example 2 that is a sketch of water faucet. When this example is input to updated SFBCM, first, the handle of it can be detected (and colored red) as a tapered multiple extrusion as shown in Fig. 9(b). In Fig. 9(c), the handle is extracted as a 3D feature, and it is found two blue points forming *T*-junctions are the part of an ASF (Abstract Sketch Feature). Detailed explanation of ASFs is referred in [6]. Also, a convex flange can be detected. In Fig. 9(d), the flange is extracted and a pipe can be detected by adding a dotted line. This addition can be automatically performed in conventional SFBCM. In Fig. 9(e), the pipe is extracted and a concave flange can be predicted. This prediction would be performed by recognizing contact face(s) between the pipe and the ASF of the flange. This recognition becomes an issue. In Fig. 9(f), the flange is extracted and a cylinder can be predicted. When all extracted 3D features are combined in accordance with Fig. 9(a), the solution of Example 2 can be obtained as shown in Fig. 9(g).



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

Fig. 9: Example 2: (a) Example 2, (b) Detection of a tapered multiple extrusion, (c) Appearance of an ASF and detection of a concave flange, (d) Detection of a pipe, (e) Prediction of a concave flange, (f) Prediction of a cylinder, and (g) Two overviews of the solution.

Conclusions

In this paper, convertible sketches to mechanical curved objects by SFBCM are clarified and limited, and several new SFs are defined. The effectiveness of the SFs can be indicated in Example 2. In this example, to predict a flange sketch between a pipe and a cylinder sketches becomes an issue. Also, more search of SFs and their ASFs will be an issue to extend the limitation of convertible sketches in mechanical curved objects.

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