A Method to Restore Partial Omissions in 2D Drawings

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ABSTRACT

When the overviews of mechanical products are drawn in 2D drawings, various kinds of simplified expressions are often applied. Though many researches have been conducted on the automatic conversion of 2D drawings into solid models, it has been still difficult to convert 2D drawings including the simplified expressions to solid models because they are not geometric and are based on human understanding. In this paper, a method is proposed that 2D drawings including partial omissions are automatically restored to correct drawings. Many continuous patterns of lines such as wavy lines could be recognized and learned, and generalized patterns can be made in the method. When new patterns including partial omissions in 2D drawings are input, they can be restored by applying the generalized patterns in the method.

Keywords: restoration, partial omission, property, pattern, continuity, learning, 2D drawing

1. INTRODUCTION

When the overviews of mechanical products are drawn in 2D drawings, various simplified expressions such as partial omissions and sectional views are often applied to the drawings. The automatic conversion of 2D drawings into solid models has been an issue and many methods have been proposed for the conversion [1-10]. However, it has been still difficult to handle the simplified expressions in their methods because their methods are based on only geometric processes. The simplified expressions are usually based on human understanding. For example, when a long bar is drawn in a 2D drawing, the middle part of the bar is often omitted in the drawing. This omission is not geometric and is based on human understanding. In this paper, a method is proposed that 2D drawings including partial omissions are automatically restored to correct drawings. If the long bar forms a rectangle, it is easy to restore its omission because the solution can be obtained by only making a correct rectangle. However, if there are small holes continuously in the bar as in Fig. 1, it becomes difficult to restore its omission.

The continuity of circles whose diameter is 20mm can be recognized and it is assumed that the circles would be continued in the omission of bar in Fig. 1 in human understanding. To computerize the recognition of repetitive lines such as the circles in Fig. 1, pattern recognition and learning techniques are applied in the method. Each of line segments is recognized as a set of properties. For example, the properties of circles consist of their diameters, center points, etc. Line segments of which overviews are the same can be recognized by comparing the properties of all line segments. Also, the continuities of line segments whose overviews are the same are recognized as properties of repetitive line segments such as intervals of two adjacent line segments. The properties of repetitive line segments are presently summarized as straight patterns and circular patterns in the method. When two or more patterns of repetitive line segments are input and their continuity is straight, a generalized straight pattern can be learned in the method. Generalized patterns made in the method can be applied to restore the partial omissions of 2D drawings. In Fig. 1, the solution can be obtained as in Fig. 2 by the method. The method has been implemented as experimental systems and the effects of the method have been verified by applying many examples to them.

There are many researches to automatically convert 2D drawings to 3D models. Though the authors proposed several methods, simplified expressions in 2D drawings could not be handled [1-2]. Recently, Lee et al. proposed a CSG based method for symmetrical parts [3]. Lu et al. handled architectural 2D drawings [4]. Dimri and Gurumoorthy handled 2D sectional views [5]. Also, many approaches have been tried to automatically convert single freehand sketches to solid models (e.g. [6-10]). Generally these researches were based on the applications of geometric constraints. Therefore, it seems to be difficult to handle simplified expressions in 2D drawings when they become complex in those researches. In the method of this paper, learning algorithms referring [11] are introduced to handle the simplified expressions. The method would be applied to handle complex simplified expressions because the learning process of the method could be reinforced.

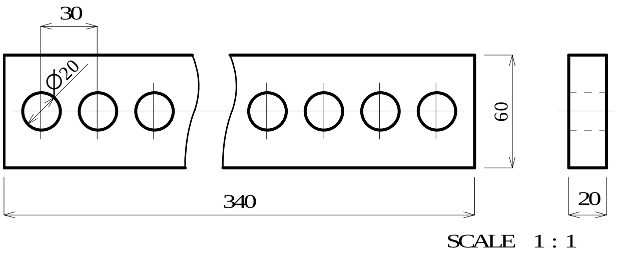

Fig. 1. Example 1

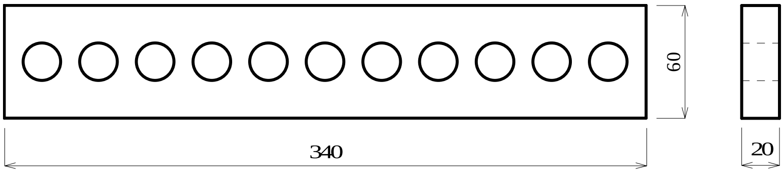

Fig. 2. Restored Example 1

2. PROPERTIES OF REPETITIVE LINE SEGMENTS

2.1 Problem Formulation

In all 2D drawings of this paper, useless information such as central lines, detailed dimensions and detailed parts lists are deleted to emphasize the method. In Example 1 as in Fig. 1, the middle part of that is omitted and break lines are drawn as free-form curves. The omission of Example 1 can be found by recognizing dimensions and the scale of 2D drawing. Since DXF files are used as CAD files in the method, texts and various kinds of lines can be recognized respectively. In Example 1, it is found that 340mm is contradicted from the scale of "1:1" in Fig. 1. Also, this contradiction can be found by comparing 60mm, 20mm and 340mm in Fig. 1.

Because of the omission, two isolated surfaces can be recognized by finding closed loops of outlines in the front view of Example 1. These surfaces can be replaced in accordance with the correct dimension of 340m as in Fig. 3. In this figure, two surfaces are colored red and blue. In the method, since break lines are drawn as free-form curves in 2D drawings, they can be recognized from the other lines. The correct 2D drawing as the solution in Example 1 can be obtained by deleting break lines and adding insufficient lines between the two surfaces. In the method, various kinds of properties are given to line segments for the restoration of partial omissions in 2D drawings as follows.

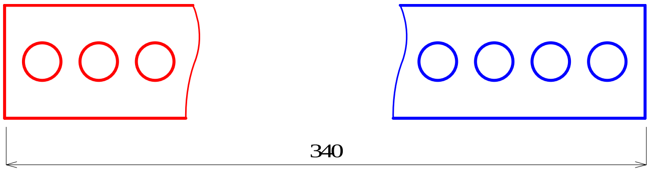

Fig. 3. Replaced two surfaces according to 340mm in Fig. 1

2.2 Properties of Line Segments

When *x*-*y* coordinate system is arranged in accordance with the dimension line of 340mm as in Fig. 4, it is found that diameters and *y* coordinates of center points in all of circles are the same. The diameters and y coordinates are called the properties of circles in Fig. 4. In the method, presently straight lines, arcs and circles are handled as line segments. Each of line segments is numbered (*L*1, *L*2, ... , *L*13) as in Fig. 4. All properties of line segments in the method are type (straight, arc or circle), style (solid or dotted), diameter, length, slope, center point, starting point, end point, normal vector, connecting lines of starting point and connecting lines of end point. Each of the points is expressed in *x*-*y* coordinates. The slope is calculated as the rate of difference between starting point and end point. The normal vector is expressed as a unit vector and directs the outside of a surface described above.

For example, the properties of $L2$ in Fig. 4 are as follows. The type is straight, style is solid, diameter is default, length is 60, slope is (0, 1), center point is (20,70), starting point is (20,40), end point is (20,100), normal vector is (-1,0), connecting lines of starting point is $L3$, connecting lines of end point is $L1$. Also, the properties of $L4$ in Fig. 4 are as follows. The type is circle, style is solid, diameter is 20, length is 62.83, slope is default, center point is (40,70), starting point is default, end point is default, normal vector is default, connecting lines of starting point and end point are default. By comparing the properties of all line segments in Fig. 4, it is found that the shapes, lengths and slopes of {$L2$, $L8$} and {$L4$, $L5$, $L6$, $L10$, $L11$, $L12$, $L13$} are the same respectively. In Fig. 5, {$L2$, $L8$} are colored purple and the seven circles are colored green.

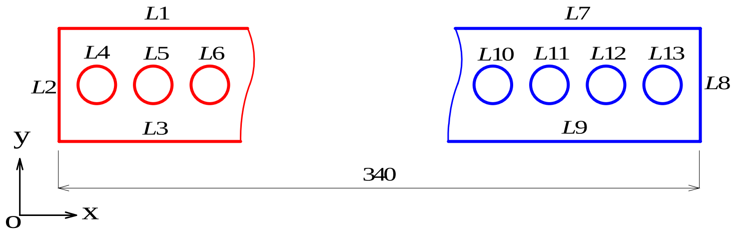

Fig. 4. Numbered and coordinated line segments in Fig. 3

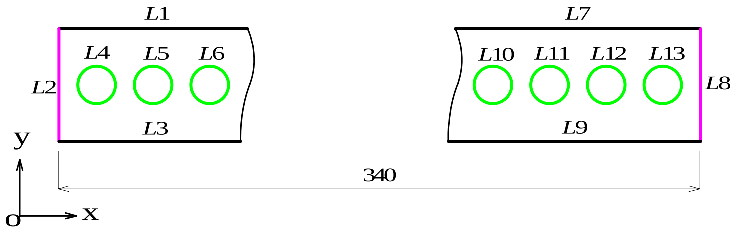

Fig. 5. Recognition of the same line segments in Fig. 4

2.3 Properties of Repetitive Line Segments

When two break lines are deleted in Fig. 5, $L1$, $L3$, $L7$ and $L9$ become unstable because the connecting lines of them are default in their properties of starting points or end points. If line segments of which connecting lines are nothing exist after break lines are deleted, they are also deleted. The four unstable line segments would be extended until they reach the other line segments after omitted circles are restored in Example 1.

Fig. 6 illustrates three patterns of repetitive line segments that are continued directly. In each of these patterns, all the shapes, lengths and slopes of line segments are the same and all of intervals between two adjacent line segments are the same. The same interval of each pattern in Fig. 6 can be expressed as (Vx, Vy). In Fig. 6(a)(b)(c), (Vx, Vy)=(20, 0), (Vx, Vy)=(40, 0), (Vx, Vy)=(60, -5) are calculated respectively. As a result, (Vx, Vy) can become a property of repetitive line segments.

When three patterns in Fig. 6 are learned as a same pattern whose name is “straight”, (Vx, Vy) can be extracted as a common property and a generalized straight pattern can be made in the method. Whether a new repetitive line segments is a straight pattern or not can be distinguished by the generalized straight pattern. Especially, since horizontal and vertical patterns of repetitive line segments are often used to 2D drawings, they are important and generalized in the method. The property of horizontal patterns becomes (Vx, 0). Also, the property of vertical patterns becomes (0, Vy). Both of horizontal patterns and vertical patterns are included to straight patterns.

Fig. 7 illustrates three circular patterns of repetitive line segments. The properties of circular continuity can be obtained by calculating the radiuses of curvature in them. When an arc can be formed by center points of three adjacent line segments in a pattern, the radius and center point of curvature in the pattern can be calculated from the arc. Therefore, radiuses and center points of curvature can become properties of repetitive line segments. They are expressed as Rc and (Cx, Cy) as variables in the method. Since the slopes of line segments are different to each other in circular patterns, they are defined again based on (Cx, Cy). When three patterns in Fig. 7 are learned as a same pattern whose name is circular pattern, Rc and (Cx, Cy) can be extracted as common properties and a generalized circular pattern can be made in the method. As a whole, (Vx, Vy), $(Vx, 0)$, $(0, Vy)$, Rc, (Cx, Cy) are properties of repetitive line segments in the method.

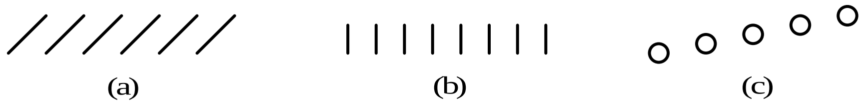

Fig. 6. Three straight patterns of repetitive line segments

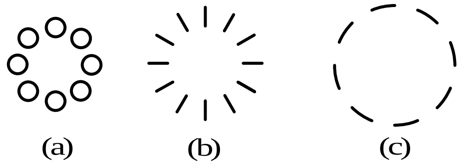

Fig. 7. Three circular patterns of repetitive line segments

3. ALGORITHM TO RESTORE PARTIAL OMISSIONS IN 2D DRAWINGS

Fig. 8 illustrates two examples of restoration processes in repetitive line segments including partial omissions. Fig. 8(a) illustrates a straight pattern of repetitive line segments including two partial omissions. The two omissions can be recognized by finding four break lines that are colored green in Fig. 8(b). When the generalized straight pattern of the method is applied to three circles that are colored red in Fig. 8(b), (Vx, Vy) can be calculated. Also, when the four break lines are deleted, it could be recognized that six circles in Fig. 8(b) are arranged on a straight line. When it is assumed that the six circles are an incorrect straight pattern, the correct pattern of repetitive circles could be generated as in Fig. 8(c) by using the values of (Vx, Vy). Fig. 8(d) illustrates a circular pattern of repetitive line segments including a partial omission. A break line can be recognized and colored green as in Fig. 8(e). When the generalized circular pattern of the method is applied to the ten line segments in Fig. 8(e), Rc and (Cx, Cy) can be calculated from them. After the break line is deleted, the ten line segments could be recognized as an incorrect circular pattern of repetitive line segments. The correct circular pattern of repetitive line segments could be generated as in Fig. 8(f) by using the values of Rc and (Cx, Cy). In Example 1, $L14$, $L15$, $L16$, $L17$ can be added as in Fig. 9 by the method. When the four unstable line segments in Fig. 9 are extended, the solution of Example 1 can be obtained by the method as in Fig. 2. In general, the algorithm to restore partial omissions of 2D drawings in the method is as follows.

(1) Recognize break lines.
(2) Recognize patterns of repetitive line segments by applying generalized patterns.
(3) Recognize incorrect patterns of repetitive line segments.
(4) Generate correct patterns by using properties of repetitive line segments.
(5) Extend unstable line segments until they reach the other line segments.

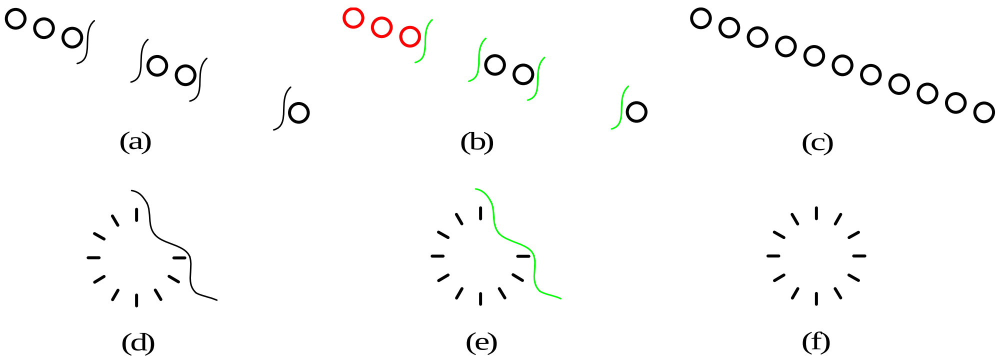

Fig. 8. Two examples of restoration processes in repetitive line segments including partial omissions

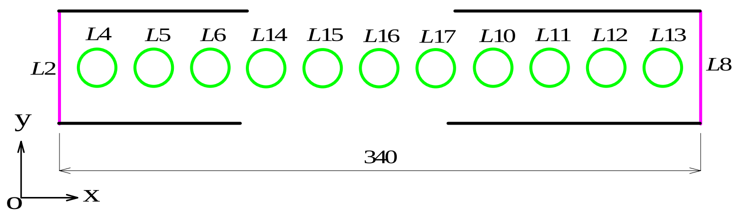

Fig. 9. Restoration of repetitive circles in Fig. 5

4. EXAMPLES

Fig. 10(a) illustrates Example 2 that is a mechanical spring. Since 105mm is contradicted from the scale of "1:1", it is found there are partial omissions in this figure. This contradiction can be restored as in Fig. 15(b). All of the same line segments in their overviews are colored purple, yellow, brown, green, red and blue respectively in Fig. 15(b). Since the relationships of these line segments are complex, the method makes blocks from them. Since red, blue and yellow line segments form straight patterns respectively, they can be connected as loops of line segments. In Fig. 10(c), they are colored red. When many patterns of repetitive line segments are handled as a few patterns of repetitive blocks, the restoration process could become simple. When the partial omissions of straight patterns in repetitive yellow line segments, blue line segments and red blocks are restored respectively, the partial omission of Example 2 can be restored by the method as in Fig. 10(d).

Fig. 11(a) illustrates Example 3 that is a tipped saw. A part of Example 3 is omitted and a break line is drawn in this figure. When the generalized circular pattern of the method is applied to Example 3, two circular patterns of repetitive line segments could be recognized and colored red and blue as in Fig. 11(b). After the break line is deleted, the two circular patterns could be recognized as incorrect circular patterns. The correct circular patterns of Example 3 could be generated as the solution by the method as in Fig. 10(d).

Fig. 12 illustrates Example 4 that is a simple fence. Fig. 13 illustrates the restoration process of Example 4. In Fig. 13(a), 2050mm is correct and break lines are deleted. All of the same line segments in their overviews can be recognized and colored green, blue and red respectively in Fig. 13(a). When the generalized straight pattern of the method is applied, four straight patterns could be recognized and colored blue, red, yellow and green respectively as in Fig. 13(b). On the other hand, when the generalized circular pattern of the method is applied, four circular patterns can be recognized and colored red, blue, yellow and green respectively as in Fig. 13(c). The four straight patterns of repetitive line segments in Fig. 13(b) can be made as a straight pattern of repetitive rectangular blocks. When this straight pattern is assumed as an incorrect pattern in the method, the correct pattern of the blocks could be made as in Fig. 13(d). In Fig. 13(c), only one circular pattern of repetitive line segments could be made as in Fig. 13(e). In this figure, they are colored brown. Therefore, it is found that circular patterns do not be effective for Example 4. In Fig. 13(d), when four unstable line segments are extended, the solution of Example 4 could be obtained by the method as in Fig. 13(f).

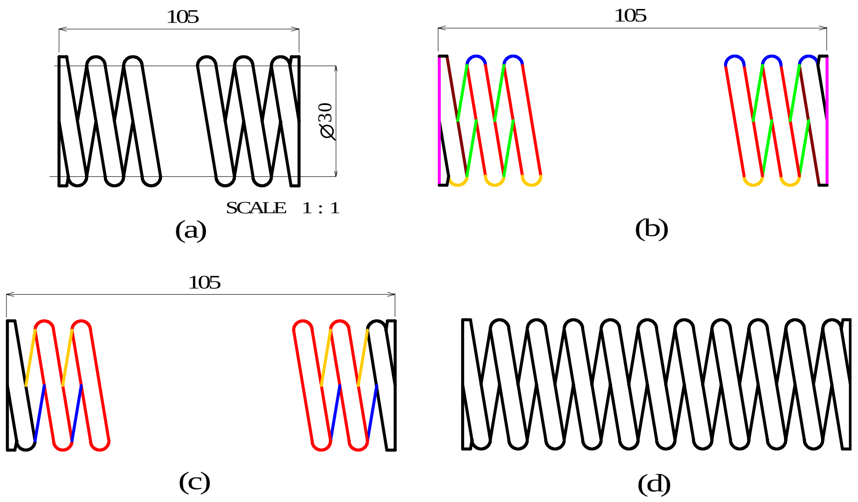

Fig. 10. Example 2

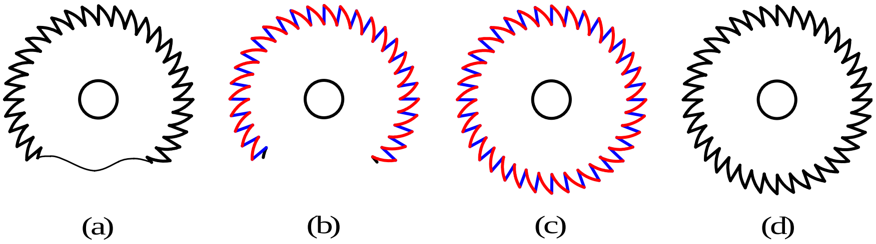

Fig. 11. Example 3

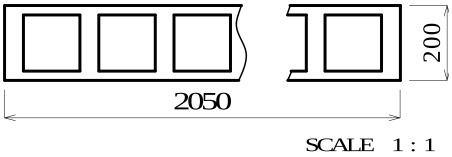

Fig. 12. Example 4

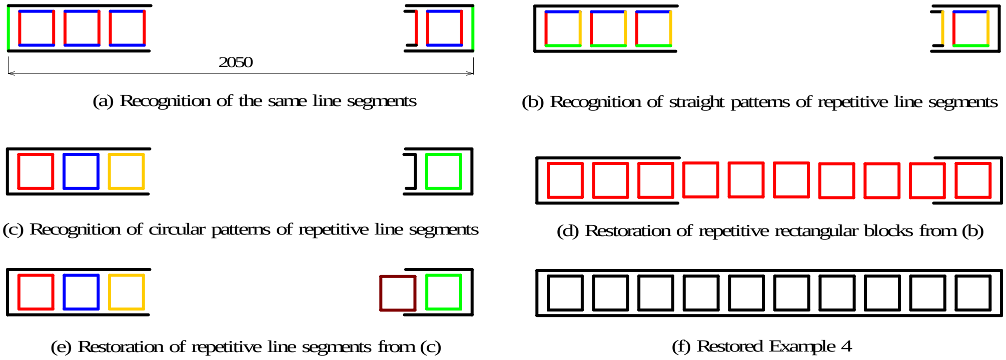

Fig. 12. The restoration process of Example 4

5. CONCLUSION

Straight patterns and circular patterns of repetitive line segments could be recognized, learned and generalized in their properties by the method. When there are some partial omissions in input repetitive line segments of 2D drawings, they could be restored by applying the generalized patterns of the method. Also, The restoration process could become simple when blocks are made by connecting similar patterns of repetitive line segments. In the same way, eddy patterns, oval patterns, etc would be handled by the method. Also, in the case that the sizes of repetitive line segments become continuously larger, the method could be applied by increasing properties. When various kinds of patterns are composite in 2D drawings including partial omissions such as Example 4, it would be difficult to restore the omissions by the method. In this case, patterns that can restore more line segments than the other patterns would be applied with precedence to restore the omissions. When 2D drawings become complex, the process to detect blocks from repetitive line segments would become difficult in the method. As a result, it is an issue to handle omitted 2D drawings including complex patterns such as wire netting and lattice structures in the method.

7. REFERENCES

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