Automatic Restoration of Omitted 2D Drawings by Using Pattern Learning of Repetitive Features

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Abstract: When the overviews of mechanical products are drawn in 2D drawings, various 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. When there are repetitive features in the omissions, they can be recognized and restored in the method. In this process, various patterns of repetitive features are learned and generalized patterns are made such as straight and circular patterns in the method. When 2D drawings including omitted repetitive features, they can be restored by applying the generalized patterns in the method.

Key-Words: pattern learning, repetitive feature, symplified expression, partial omission, 2D drawing, restoration

1 Introduction

When the overviews of mechanical products are drawn in 2D drawings, various simplified expressions are often applied to them. The automatic conversion of 2D drawings into solid models has been an issue and many methods have been proposed for the conversion (e.g. [1-5]). 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 bar is often omitted in the drawing. This omission is not geometric but 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 can correspond to a rectangle in a 2D drawing, it is easy to restore its omission because the solution can be obtained by recognizing correct dimensions and making only a correct rectangle. However, if there are small holes repetitiously in the bar such as Example 1 illustrated in Fig. 1, it becomes difficult to restore its omission. In human understanding, the repetitive circles in Fig. 1 can be recognized and that the circles would be repeated in the omission of bar can be assumed.

To computerize assumptions such as described above and the restoration of omissions in 2D drawings, the properties of line segments and the learning algorithm of repetitive features are applied in the method. Each of the features consists of line segments. For example, the properties of a circle as a line segment are coordinates of central point, diameter, etc. When the properties are applied to 2D drawings, for example, it is found seven circles are the same in their diameters in Fig. 1. Also, it is found all of the intervals between two adjacent circles are the same except for the omitted part and their arrangement is horizontal in Fig. 1. The same intervals and horizontal arrangement of the circles are learned as a horizontal pattern of repetitive line segments in the method. In the same way, several different horizontal patterns are learned, and a generalized horizontal pattern can be generated in the method. When the generalized horizontal pattern is applied to the circles in Example 1, omitted circles can be restored automatically by the method as in Fig. 2. As a result, the solid model of Example 1 can be made from Fig. 2 by using previously proposed methods (e.g. [1-2]).

In the method, horizontal, diagonal, vertical and circular patterns of repetitive line segments can be generalized, and repetitive features can be made from the repetitive line segments. As a result, omitted repetitive features can be restored in 2D drawings 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.

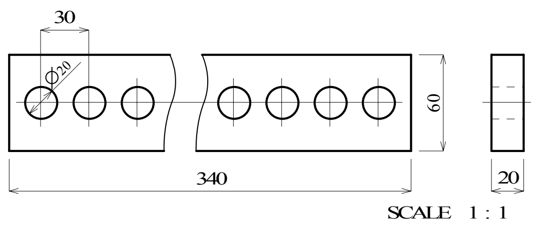


Fig. 1 Example 1

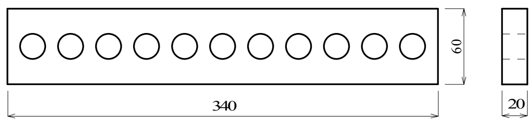


Fig. 2 Restored Example 1

2 Related Works

In our research, firstly an algorithm was developed that 2D assembly drawings could be converted to 3D models [1]. Though the algorithm could obtain solutions from various 2D assembly drawings, it was an issue that the numbers of solutions were exponentially increased when complex assembly drawings were applied. To reduce the numbers of solutions, the information of dimensions and parts lists was applied [2]. However, it had been an issue that many simplified expressions were applied to complex 2D assembly drawings. Though an algorithm to handle them was proposed [3], it could not apply to complex omissions such as Example 1. In the method, complex partial omissions in 2D drawings can be restored.

There are many researches to automatically convert 2D drawings to 3D models. Recently, 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. [6-9]). 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 [10] 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.

3 Problem Formulation

In 2D drawings of this paper, central lines, detailed dimensions and parts lists are almost deleted because they are not important to explain the method. Generally partial omissions in 2D drawings are expressed by using break lines. In the method, break lines are drawn as free-form curves and the scales of objects are indicated in 2D drawings if necessary. DXF files are used as CAD files in the method. So texts and various lines can be recognized respectively in 2D drawings. Especially, since free-form curves are used only as break lines in 2D drawings, they can be recognized in the method. Two types of partial omissions are handled in the method. One is the omissions of middle parts in slim objects such as Example 1. Another is the omissions of partial outlines in symmetrical objects such as Example 2 illustrated in Fig. 3. In general, to avoid the interferences of the other parts, the partial omissions such as Example 2 sometimes appear in 2D assembly drawings.

The following preprocessing is performed in the method when dimensions and scales are different in 2D drawings such as Example 1.

(1) Search a different dimension from the scale of a 2D drawing. In Example 1, 340mm is searched as a different dimension from the scale of 1:1.

(2) Recognize two isolated surfaces concerned with the different dimension. In Example 1, two isolated surfaces can be recognized and colored red and blue respectively as in Fig. 4.

(3) Rearrange two isolated surfaces in accordance with the correct dimension of the 2D drawing. In Example 1, two isolated surfaces are rearranged as in Fig. 5.

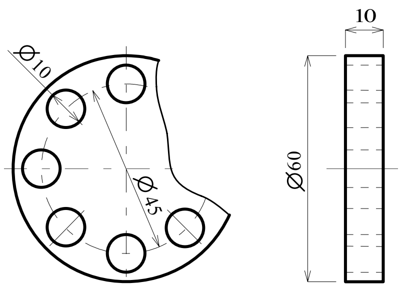


Fig. 3 Example 2

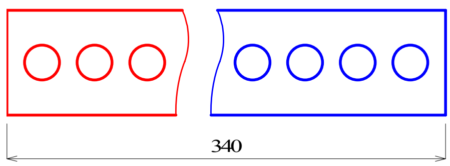


Fig. 4 Two isolated surfaces in Example 1

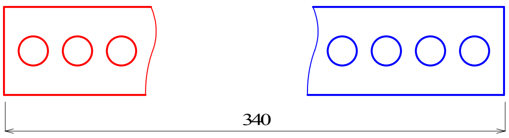


Fig. 5 Rearranged two isolated surfaces in Fig. 4

4 Properties of Line Segments

To handle repetitive line segments, various properties are given to line segments in the method. Presently, straight lines, circles, arcs and sine curves are handled as line segments in the method. Each of line segments is numbered in 2D drawings. In the front view of Example 1, there are thirteen line segments. They are numbered as $L1$, $L2$, ... , $L13$ as in Fig. 6. Also, x-y coordinate system is arranged in this figure. All properties of a line segment are type (straight line or circle or ...), style (solid or dotted), diameter, length, slope, center point, starting point and end point. Each of those points is expressed as (x, y). The slope is calculated as an angle of a line segment from x axis. Especially, type, style, diameter, length and slope are called the properties of shapes in line segments.

For example, the properties of $L2$ in Fig. 6 are as follows. The type is straight, style is solid, diameter is default, length is 60, slope is 90°, central point is (20,70), starting point is (20,40), end point is (20,100), Also, the properties of $L4$ in Fig. 6 are as follows. The type is circle, style is solid, diameter is 20, length is 62.83, slope is default, central point is (40,70), starting and end points are default.

In Fig. 6, by comparing the properties of shapes in all line segments, it is found $L2$, $L8$ are the same and $L4$, $L5$, $L6$, $L10$, $L11$, $L12$, $L13$ are the same. In Fig. 7, they are colored red and blue respectively.

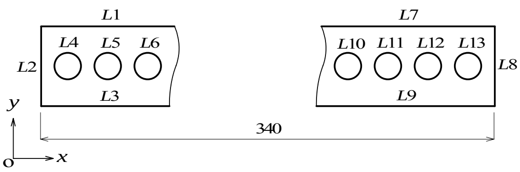


Fig. 6 Numbered line segments in Example 1

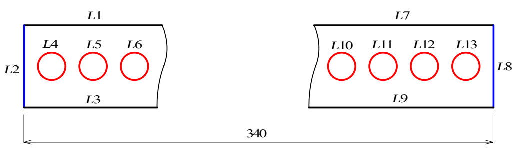


Fig. 7 Recognition of the same line segments

5 Properties of Repetitive Line Segments

Fig. 8 illustrates two patterns of repetitive line segments. In each of the patterns, line segments are arranged horizontally and all of the intervals between two adjacent line segments are the same. Those patterns are learned and generalized in the method. The elements of pattern learning are defined as various properties in the method. To learn the patterns, the properties of repetitive line segments are defined by at least three adjacent line segments. In the method, seventeen properties of repetitive line segments are defined as follows. Here, the center point of L_i (i=1, 2, ...) that is a line segment is expressed as (x_i, y_i).

[Properties of repetitive line segments]

(1) name (=horizontal or vertical or ...) (2) x_i-x_{i-1} (=$\Delta x_{i,i-1}$) (3) y_i-y_{i-1} (=$\Delta y_{i,i-1}$) (4) $\tan^{-1}(\Delta y_{i,i-1} / \Delta x_{i,i-1})$ (=$A_{i,i-1}$) (5) $\Delta x_{i,i-1} * \Delta x_{i,i-1} + \Delta y_{i,i-1} * \Delta y_{i,i-1}$ (=$D_{i,i-1}$) (6) Whether all of $A_{i,i-1}$, $A_{i-1,i-2}$, ... , $A_{2,1}$ are the same or not (=same or different) (7) Whether all of $D_{i,i-1}$, $D_{i-1,i-2}$, ... , $D_{2,1}$ are the same or not (=same or different) (8) The radius of curvature calculated from three center points of L_i, L_{i-1} and L_{i-2} (=R_i) (9) x value in the center of curvature (=Cx_i) (10) y value in the center of curvature (=Cy_i) (11) The slope of L_i based on the center of curvature (=S_i) (12) The slope of L_{i-1} (=S_{i-1}) (13) The slope of L_{i-2} (=S_{i-2}) (14) Whether all of S_i, S_{i-1}, S_{i-2}, ... , S_1 are the same or not (=same or different) (15) Whether all of R_i, R_{i-1}, ... , R_1 are the same or not (=same or different) (16) Whether all of Cx_i, Cx_{i-1}, ... , Cx_1 are the same or not (=same or different) (17) Whether all of Cy_i, Cy_{i-1}, ... , Cy_1 are the same or not (=same or different)

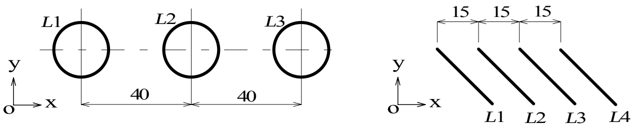
In the values of those properties, 0/0=1 is defined and the value is default in the case of a/0 ($|a| > 0$) in the method. The properties form (8) to (17) are applied to only circular patterns. So they are used and explained later. In a pattern of repetitive line segments, firstly the properties of L_i is calculated and then the properties of L_{i+1} is calculated. In the same way, the properties of L_{i+2}, L_{i+3}, ... are calculated continuously. For example, the properties of Pattern A in Fig. 8(a) are calculated as follows. Here, "h", "d", "s", "dif" mean "horizontal", "default", "same" , "different" respectively.

[Pattern *A*]

Step *L1*: (1) h (2) d (3) d (4) d (5) d (6) d (7) d.
Step *L2*: (1) h (2) 40 (3) 0 (4) 0° (5) 1600 (6) d (7) d.
Step *L3*: (1) h (2) 40 (3) 0 (4) 0° (5) 1600 (6) s (7) s.

Also, the properties of Pattern B in Fig. 8(b) are calculated as follows.

[Pattern *B*]
Step *L*1: (1) h (2) d (3) d (4) d (5) d (6) d (7) d.
Step *L*2: (1) h (2) 15 (3) 0 (4) 0° (5) 225 (6) d (7) d.
Step *L*3: (1) h (2) 15 (3) 0 (4) 0° (5) 225 (6) s (7) s.
Step *L*4: (1) h (2) 15 (3) 0 (4) 0° (5) 225 (6) s (7) s.



(a) Pattern *A* (b) Pattern *B*

Fig. 8 Two horizontal patterns of repetitive line segments

6 Generalization of Patterns in Repetitive Line Segments

6.1 Generalized straight pattern

When Pattern *A* and *B* in Fig. 8 are compared, it is found there are same properties and different properties. In the different properties, when the values of them are replaced as "token", a generalized pattern can be made as follows.

[Generalized horizontal pattern]
(1) h (2) token (3) 0 (4) 0° (5) token (6) s (7) s.

The generalized pattern can be applied to any kind of horizontal patterns in repetitive line segments. In 2D drawings, when the same line segments are recognized, whether they form a horizontal pattern or not can be decided by applying the generalized horizontal pattern.

Fig. 9 illustrates a diagonal pattern of repetitive line segments. The finally properties of this pattern are as follows. (1) diagonal (2) 25 (3) 10 (4) 21.8° (5) 725 (6) s (7) s. When horizontal patterns are included into diagonal patterns, the generalized horizontal pattern described above can be synthesized to the diagonal pattern as follows. Here, "t" means "token".

[Generalized diagonal pattern]
(1) t (2) t (3) t (4) t (5) t (6) s (7) s.
In the same way, vertical patterns can be generalized as follows.

[Generalized vertical pattern]
(1) vertical (2) 0 (3) t (4) 90° (5) t (6) s (7) s.
Since the generalized diagonal pattern can cover horizontal and vertical patterns, it can be called the generalized straight pattern in the method.

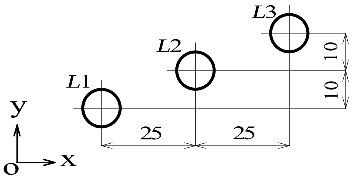


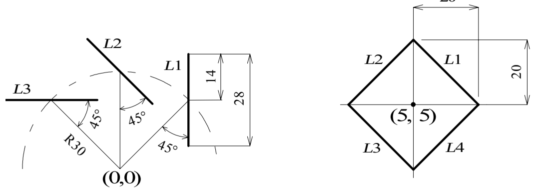
Fig. 9 A diagonal pattern of repetitive line segments

6.2 Generalized circular pattern

Fig. 10 illustrates two circular patterns of repetitive line segments. The properties from (8) to (17) described in chapter 5 can be calculated in this figure. S_i is calculated as an angle between L_i and the straight line whose end points are (x_i, y_i) and (Cx_i, Cy_i). (Cx_i, Cy_i) is the center of curvature in the pattern including L_i. The properties of Pattern *C* in Fig. 10(a) are calculated as follows. Here, "c" mean "circular".

[Pattern C]
Step *L*1: (1) c (2) d (3) d (4) d (5) d (6) d (7) d (8) d (9) d (10) d (11) d (12) d (13) d (14) d (15) d (16) d (17) d.
Step *L*2: (1) c (2) -21.21(3) 8.79 (4) 157.49° (5) 632.52 (6) d (7) d (8) d (9) d (10) d (11) d (12) d (13) d (14) d (15) d (16) d (17) d.
Step *L*3: (1) c (2) -21.21(3) -8.79 (4) 202.51° (5) 632.52 (6) dif (7) s (8) 30 (9) 0 (10) 0 (11) 45° (12) 45° (13) 45° (14) s (15) s (16) s (17) s.
Also, the properties of Pattern *D* in Fig. 10(b) are calculated as follows.

[Pattern *D*]
Step *L*1: (1) c (2) d (3) d (4) d (5) d (6) d (7) d (8) d (9) d (10) d (11) d (12) d (13) d (14) d (15) d (16) d (17) d.
Step *L*2: (1) c (2) -20 (3) 0 (4) 180° (5) 400 (6) d (7) d (8) d (9) d (10) d (11) d (12) d (13) d (14) d (15) d (16) d (17) d.
Step *L*3: (1) c (2) 0 (3) -20 (4) 270° (5) 400 (6) dif (7) s (8) 14.14 (9) 5 (10) 5 (11) 90° (12) 90° (13) 90° (14) s (15) s (16) s (17) s.
Step *L*4: (1) c (2) 20 (3) 0 (4) 0° (5) 400 (6) dif (7) s (8) 14.14 (9) 5 (10) 5 (11) 90° (12) 90° (13) 90° (14) s (15) s (16) s (17) s.



(a) Pattern *C* (b) Pattern *D*

Fig. 10 Two circular pattern of repetitive line segments

The generalized circular pattern can be made from Pattern *C* and *D* as follows.

[Generalized circular pattern]

(1) c (2) t (3) t (4) t (5) t (6) dif (7) s (8) t (9) t (10) t (11) t (12) t (13) t (14) s (15) s (16) s (17) s.

7 Restoration of Omitted Repetitive Line Segments

7.1 Search of repetitive line segments in 2D drawings

Fig. 11 illustrates Example 3 that is a plate having many holes. To restore omitted repetitive line segments in 2D drawings, firstly repetitive line segments are searched in the method. The search algorithm of them is as follows.

(1) Pick up three adjacent line segments in a 2D drawing. Their properties of shapes are the same and they are called a core in this algorithm.

(2) If the core forms a straight or a circular pattern, the other line segments are searched whose properties of shapes are the same as the core and their properties of repetitive line segments except for (7) are the same as the core.

(3) The core and searched line segments in (2) of this algorithm are made as a set of repetitive line segments. The line segments of the set are arranged sequentially in *x*-*y* or polar coordinate system of the 2D drawing.

(4) In the same way, the other sets of repetitive line segments are searched.

In Example 3, three sets of repetitive line segments can be searched as $\{L_1, L_2, L_3, L_{12}, L_{11}, L_{10}\}$, $\{L_{14}, L_{13}, L_4, L_5, L_6\}$ and $\{L_9, L_8, L_7, L_{15}, L_{16}\}$.

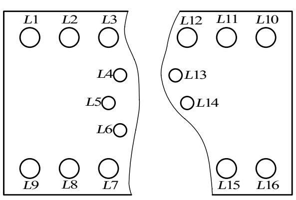


Fig. 11 Example 3

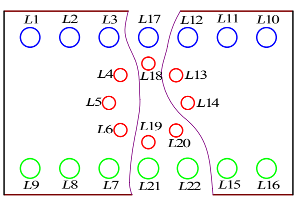


Fig. 12 Recognition of patterns in Example 3

7.2 Restoration proccess of omitted line segments

In a set of repetitive line segments, if the property (7) of repetitive line segments cannot always be "same", omissions of line segments might exist. In this case, the set is called an incorrect set. In the method, incorrect sets are restored to correct sets. Suppose a set of repetitive line segments consists of $\{L_1, L_2, \ldots, L_n\}$. Also, suppose the core of set consists of L_i, L_{i+1} and L_{i+2} that form a straight pattern. The properties of (1), (2), (3), (4) and (5) in repetitive line segments can be calculated from L_i, L_{i+1} and L_{i+2}. Of course, (6) and (7) are "same" in this case. When the values of the properties are applied from L_1 to L_n, the correct set can be redrawn in the 2D drawing. In the same way, incorrect circular patterns can be restored correctly.

In an incorrect pattern of repetitive line segments, whether added line segments to generate a correct pattern are omitted line segments or not in a 2D drawing can be decided as follows. Suppose a group of added and adjacent line segments exist between two groups of adjacent line segments existing originally in a 2D drawing. If two break lines become border lines among the three groups, the added and adjacent line segments are usually omitted line segments. Also, if there are incorrect dimensions in 2D drawings, added and adjacent line segments are usually omitted line segments. As a result, in Example 3, omitted line segments are restored by the method as in Fig. 12. In this figure, three patterns of repetitive line segments are colored blue, red and green respectively. Also, two break lines are colored purple. In the blue and green patterns, $\{L_{17}\}$ and $\{L_{21}, L_{22}\}$ are added respectively. In the red pattern, $\{L_{18}\}$ and $\{L_{19}, L_{20}\}$ are added sequentially.

When two break lines are deleted in Example 3, four straight line segments that cannot form any closed loops of outlines are made. They are colored brown in Fig. 12. They are extended until connecting to the other line segments in the method. These operations are the postprocessing of the method and are applied only to straight lines and arcs. As a result, Example 3 can be restored by the method as in Fig. 13. Also, Example 1 can be restored as in Fig. 2 and Example 2 can be restored as in Fig. 14.

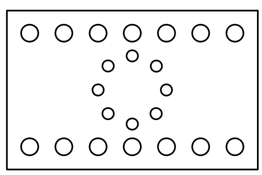


Fig. 13 Restored Example 3

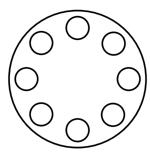


Fig. 14 Restored Example 2

8 Restoration of Omitted Repetitive Features

8.1 Generation of repetitive features

In Fig. 15, three horizontal patterns of line segments can be recognized as $\{L_1, L_3, L_5\}$, $\{L_2, L_4, L_6\}$ and $\{L_7, L_8, L_9\}$. These patterns can be considered as a horizontal pattern of triangles. These triangles can be made as follows. Firstly, recognize that L_1 and L_2 can be connected as a single line L_{12}. In the same way, L_3, L_4 and L_5, L_6 can be connected as L_{34} and L_{56} respectively. Next, recognize that L_{12} and L_7 can be connected as a single line L_{127}. In the same way, L_{348} and L_{569} can be made. Since L_{125}, L_{348} and L_{569} are the same triangles, a horizontal pattern of triangles can be made. In the same way, the patterns of various repetitive features can be made. The connections of line segments are continued until they form closed loops or they break their original patterns. The making of features can be effective when 2D drawings become complex.

All properties of a feature are the properties of shapes in all line segments forming that and centroid point. For example, the properties of L_{125} described above are the properties of shapes in L_1, L_2, L_5 and (30, 12). When line segments are changed to features in the properties of repetitions, center points are changed into centroid points and a slope is calculated in a typical line segment that is an element of a feature.

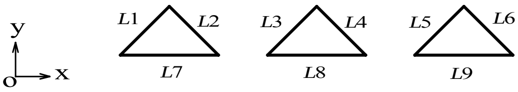


Fig. 15 A horizontal pattern of repetitive features

8.2 Examples in mechanical parts

Fig. 16 illustrates a mechanical drawing of a spring as Example 4. Five horizontal sets of repetitive line segments can be recognized after preprocessing of the method in Example 4. They are colored green, red, yellow, orange and blue respectively in Fig. 17. By forming closed loops in these line segments, two horizontal sets of repetitive features can be recognized. They are colored green and blue respectively in Fig. 18. When they are recognized as incorrect patterns of features, the correct patterns of features can be generated by adding omitted features as in Fig. 19. As a result, Example 4 can be restored as in Fig. 20 by the method.

Fig. 21 illustrates a mechanical drawing of a screw as Example 5. Four repetitive features can be recognized as in Fig. 22 after preprocessing of the method. In this figure, they are colored green, red, yellow and blue respectively. When they are recognized as incorrect patterns of features, the correct patterns of features can be generated by adding omitted features as in Fig. 23. As a result, Example 5 can be restored as in Fig. 24 by the method.

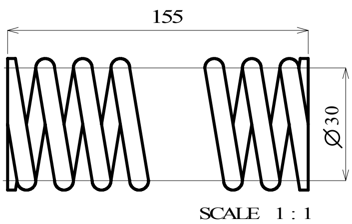


Fig. 16 Example 4

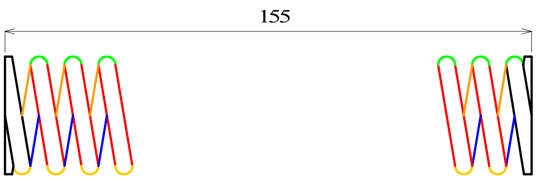


Fig. 17 Recognition of repetitive line segments in Example 4

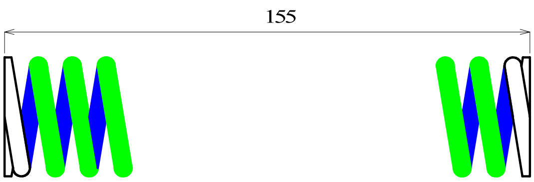


Fig. 18 Recognition of repetitive features in Example 4

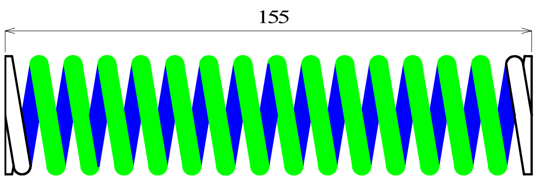


Fig. 19 Restoration of omitted features in Example 4

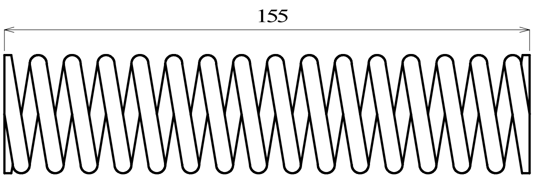


Fig. 20 Restored Example 4

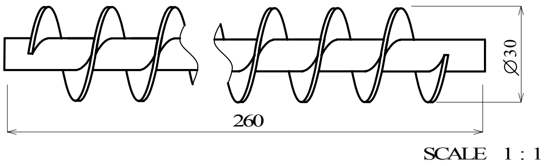


Fig. 21 Example 5

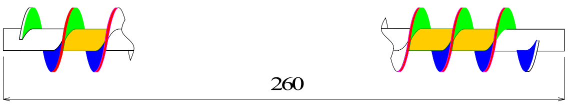


Fig. 22 Recognition of repetitive features in Example 5

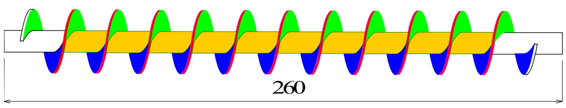


Fig. 23 Restoration of repetitive features in Example 5

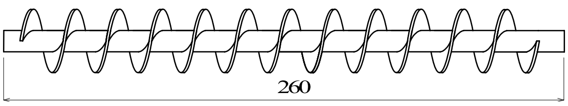


Fig. 24 Restored Example 5

9 Conclusion

Horizontal, vertical, diagonal, straight and circular patterns of repetitive line segments can be learned and generalized in the method. Also, the patterns of repetitive features can be made in the method. Various partial omissions in 2D drawings can be restored by using those patterns in the method. More various patterns can be made by increasing various properties. For example, the generalized pattern of repetitive circles of which diameters are continuously increased can be made by adding properties such as Dm_i/Dm_{i-1} where Dm_i expresses diameter i. Also, zigzag patterns, eddy patterns, etc would be generalized in the method. Moreover, the restorations of various omitted line segments that are not repetitive in 2D drawings are an issue in the method.

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