Computer-Aided Design and Applications

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A Learning System to Restore Operations of Isolated Line Segments in 2D Drawings

Masaji Tanaka, Toshiaki Kaneeda, Daisuke Sasae, Junichi Fukagawa and Ryosuke Yokoi

OkayamaUniversity of Science, {tanaka, kaneeda, sasae05, fukagawa05, yokoi06}@mech.ous.ac.jp

ABSTRACT

Presently solid modeling is essential for CAD and its applications. However, most of small companies still use 2D CAD systems mainly, and ordinarily solid models are made manually from 2D drawings because they are usually incorrect in geometry and simplified. If 2D drawings are correct, solid models would be automatically generated by existing systems. The authors have attempted to develop methods to automatically restore incorrect 2D drawings into correct 2D drawings, and repetitive features in partial omissions were already automatically restored. In this paper, a method is proposed that isolated line segments made by the partial omissions can be restored by using learning systems. In this method, various patterns of isolated line segments can be learned and be automatically restored.

Keywords: 2D drawing, partial omission, learning, restoration, isolated line segment.
DOI: 10.3722/cadaps.2008.354-362

1. INTRODUCTION

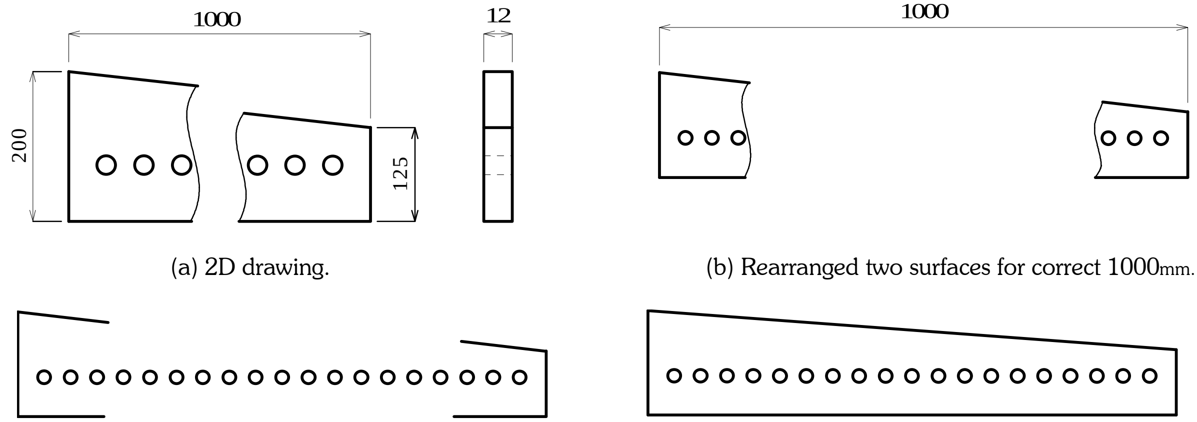
Presently solid modeling is essential for CAD and its applications. Many current CAD researches and developments are based on the solid modeling. However, most of medium and small-sized companies still use 2D CAD systems mainly. Though it is difficult and time consuming to manually generate solid models from 2D drawings, most of these companies perform this conversion manually because 2D drawings are usually incorrect in geometry and simplified. If 2D drawings are correct, solid models would be automatically generated by existing systems. The authors have attempted to develop systems to automatically restore incorrect 2D drawings into 2D correct drawings. Firstly, repetitive features of partial omissions in 2D drawings could be restored [10-11]. However, it was difficult to restore isolated line segments in the partial omissions. This problem is explained as follows by using Example 1 as in Fig. 1(a).

Example 1 is a long bar and the central part of that is omitted. This omission is expressed by two break lines. In this method, the files of 2D drawings use DXF format. Since break lines are usually drawn as free-form curves, they can be recognized from the other lines. It is found that the scale of 1000mm is different from the scale of the other dimensions in Example 1. Also, it is found there are two surfaces that are separated to each other in Example 1. These two surfaces can be rearranged in accordance with correct 1000mm such as Fig. 1(b). When various kinds of properties are given to each of line segments and repetitive line segments, several patterns of repetitive line segments can be learned and generalized.

lines. When assuming that they form incorrect repetitive circles by the break lines, correct repetitive circles can be drawn as in Fig. 1(c). In this figure, two break lines are deleted and four line segments that cannot form any loops of line segments are generated. These four line segments are called isolated line segments in this paper. When they are extended, they may not form two straight lines. Therefore, it is difficult to restore isolated line segments in 2D drawings. Elsewhere, isolated line segments often exist in 2D drawings. For example, to draw many and complex dimensions, outlines are sometimes cut, and also the connections of line segments are sometimes incomplete in 2D drawings.

Though each of operations to restore isolated line segments is easy, when the numbers of isolated line segments increase in 2D drawings, the restoration operations would become time consuming and troublesome.

In this paper, a method is proposed that various patterns of isolated line segments in 2D drawings can be restored. In this method, firstly many properties are defined in the relationship between two line segments. When several operations to restore a pattern of two isolated line segments are required by a user, the process of these operations can be learned and generalized in this method. As a result, the pattern of two isolated line segments in any 2D drawings would be automatically restored by using generalized process.



(a) 2D drawing. (b) Rearranged two surfaces for correct 1000mm.

(c) Restoration of repetitive circles. (d) Restored Example 1.

Fig. 1: Example 1.

2. RELATED WORK

There are a great many researches to automatically convert 2D drawings into solid models as 3D models. Company et al. [2] categorizes the researches into two types. One is single-view approaches and another is multiple-view approaches. Single-view approaches are applied to line drawings such as rough sketches. Mainly the techniques of line labeling that express convex or concave edges of 3D objects and classified junctions of lines such as T-type, Y-type, L-type, etc. have been applied to the research of single-view approaches, e.g. [7],[12]. Multiple-view approaches are applied to orthographic views. Nagendra and Gujar [6] surveyed the research of multiple-view approaches in detail from 1970s to 1980s. The authors also proposed methods in the research [8-9].

In general, when orthographic views are correctly drawn in geometry, it is not difficult to generate solid models. However, most of actual orthographic views as mechanical drawings are incorrect in geometry because various kinds of simplified expressions are often applied to the drawings. Also, since it is difficult to draw free-form curves in 2D drawings, it is difficult to apply free-form surfaces to solid models generated from 2D drawings and it is an important issue that when the number of lines in a 2D drawing increases, the number of solutions would be increase exponentially. In recent years, several methods to automatically convert simplified 2D drawings to solid models have been proposed. For example, Lu et al. [5] handled simplified architectural 2D drawings. Dimri et al. [3] handled 2D sectional views. Cao et al. [1] handled single-view drawings without hidden lines. However, there are few researches to handle partial omissions in 2D drawings because fundamentally it is thought that they are not geometrical but artificial. The method in this paper applies automatic learning techniques to handle isolated line segments of 2D drawings.

3. PROPERTIES OF LINE SEGMENTS

In 2D drawings, various kinds of simplified expressions are basically defined such as sectional view, partial omission, etc. It is thought that they were not generated from geometric constraints but from artificial efficiency to draw 2D drawings. Therefore, learning techniques would be effective to handle the simplified expressions. The method in this paper is based on Iwama's research [4] that concern with acquisition of concepts and introspection by a machine. To acquire them, it seems necessary to study concepts acquired by very young children and to show mechanical steps that acquire such concepts. The acquisition of concepts could apply to the learning of simplified expressions in 2D drawings in this method.

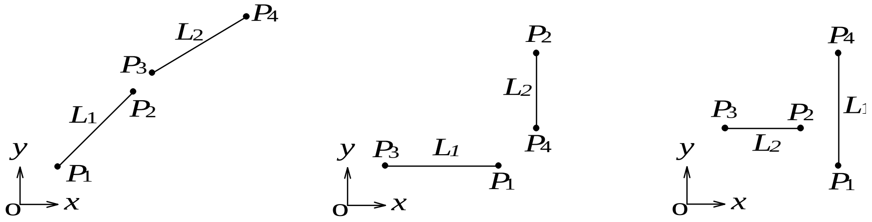
Actually, in very young children, the learning processes of many kinds of objects are very random and discrete. When they acquire a kind of objects such as apples, firstly many discrete properties of the objects are learned randomly and then learned properties are generalized little by little. The generalized properties could correspond to the concept of the objects. Though this generalization process in human may be very complex and difficult, the comparisons of input properties can be easily computed and they could correspond to rough concepts of the objects. When this computational process is applied to 2D drawings, especially partial omissions, many kinds of properties would be required for line segments.

For example, in Example 1 shown in Fig. 1(a), when many properties such as shape, length, center point, etc. are given to each of line segments, six circles can be recognized as the same circles. Moreover, when many properties such as distance, direction, etc. are given to each of repetitive line segments, they can be learned and generalized. The generalized repetitive line segments can apply to restore partial omissions such as the circles of Example 1. The method in this paper applies the learning techniques to restore isolated line segments of 2D drawings. Presently, this method handles only straight line segments as isolated line segments. The extension of this method to handle many kinds of line segments is discussed in section 6.

Generally extraordinary amount of properties would exist in the line segments of 2D drawings when a person watches them. This method handles only properties that are essential to restore isolated line segments. Most of properties in this method express the relationship between two line segments, and they are classified into four types. Each of the properties is as follows. Here, the numbers and coordinates of points and line segments are automatically computed when line segments are input to this method.

[Properties of line segments]
1. General properties
(1-1) Number of all points (*n*)
(1-2) Number of all line segments (*n*)
(1-3) Numbers of two line segments (*Lx*, *Ly*)
(1-4) Numbers of terminals in each of the two line segments {*Lx*(*Pa*, *Pb*), *Ly*(*Pc*, *Pd*)}
2. Contact of two line segments
(2-1) Connection terminal (0 or *Px*)
(2-2) T-connection terminal (0 or *Px*)
(2-3) Imaginary intersection (0 or *Px*)
(2-4) Imaginary T-connection terminal (0 or *Px*)
3. Direction of two line segments
(3-1) Parallelism (*pa*) If $pa<5$, the value of this property is "true" or the value is "false".
(3-2) Squareness (*sq*) If $sq<5$, the value of this property is "true" or the value is "false".
(3-3) Straightness (*st*) If $st<5$, the value of this property is "true" or the value is "false".
4. Distance of two line segments
(4-1) Solitude terminals in nearest terminals between two line segments exist. (yes or no)
(4-2) Number of intersecting line segments when two line segments are closed (*n*)
(4-3) Nearest terminals between two line segments (*Px*, *Py*)
(4-4) Farthest terminals between two line segments (*Px*, *Py*)

In these properties, "T-connection" is the same as "T-type junction" [7] in two line segments. When two line segments are extended, if an intersection can exist between them, it is defined as "Imaginary intersection". The values of the properties of directions can be changed by users. "Straightness" is a geometric tolerance and it is defined from two separated line segments and one imaginary line segment that connects them in their nearest terminals in this method. Fig. 2 illustrates three patterns of two isolated line segments.



(a) (b) (c)

Fig. 2: Three patterns of two isolated line segments.

In 2D drawings, generally isolated line segments often form the three patterns as in this figure. So they are targets to restore isolated line segments in this method. When the properties described above are applied to Fig. 2(a), the values can be calculated as follows. (1-1) 4 (1-2) 2 (1-3) *L*1, *L*2 (1-4) *L*1(*P*1, *P*2), *L*2(*P*3, *P*4) (2-1) 0 (2-2) 0 (2-3) *P*3 (2-4) 0 (3-1) true (3-2) false (3-3) true (4-1) yes (4-2) 0 (4-3) *P*2, *P*3 (4-4) *P*1, *P*4.

4. AUTOMATIC LEARNING OF RESTORATION PROCESSES OF ISOLATED LINE SEGMENTS

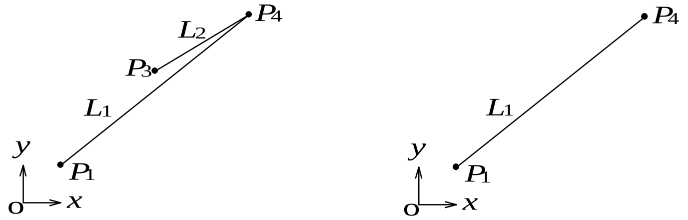
To restore isolated line segments in 2D drawings, the following four operations of CAD systems are handled in this method.

[Restoration operations]

(1) Pick up a line segment. (2) Delete a line segment. (3) Draw a line segment. (4) Stretch a line segment.

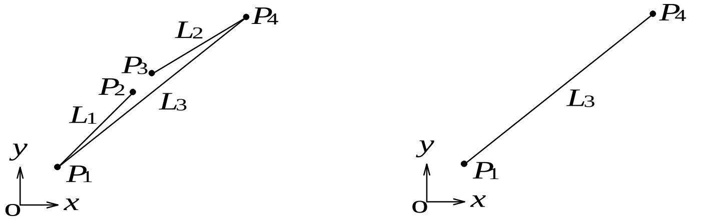
The original numbers of points (*P*1, *P*2, …) and line segments (*L*1, *L*2, …) are not changed by these operations in this method. Each process to restore isolated line segments can be realized by assembling the restoration operations. When a process to restore isolated line segments is performed repetitively in 2D drawings, the process can be learned and generalized in this method. The learning and generalization of processes to restore isolated line segments are explained by using Fig. 2 as follows.

In Fig. 2(a), suppose that two isolated line segments must be connected to form a straight line segment in a 2D drawing. Many combinations of restoration operations described above can exist for this restoration. For example, firstly *L*1 is stretched to *P*4 as in Fig. 3(a). Then *L*2 is deleted as in Fig. 3(b). In this case, *L*1 and *L*2 can be swapped. In another example, firstly *L*3 is drawn between *P*1 and *P*4 as in Fig. 4(a). Then *L*1 and *L*2 are deleted as in Fig. 4(b). Since the two processes to restore *L*1 and *L*2 are different, they are learned separately. Here, the learning of the former process is explained as follows.



(a) Stretch of *L*1. (b) Deletion of *L*2.

Fig. 3: Restoration of Fig. 2(a) by stretching *L*1.



(a) Drawing of *L*3. (b) Deletion of *L*1 and *L*2.

Fig. 4: Restoration of Fig. 2(a) by drawing *L*3.

In Fig. 3(a), the values of properties of *L*1 and *L*2 are as follows. (1-1) 3 (1-2) 2 (1-3) *L*1, *L*2 (1-4) *L*1(*P*1, *P*4), *L*2(*P*3, *P*4) (2-1) *P*4 (2-2) 0 (2-3) 0 (2-4) 0 (3-1) true (3-2) false (3-3) false (4-1) no (4-2) 0 (4-3) *P*4 (4-4) *P*1, *P*3. When *L*2 is deleted as in Fig. 3(b), the properties of two line segments disappear and the data of *L*1 only exists. The terminals of *L*1 in Fig. 3(b) are *P*1 and *P*4. Also, the data as (*P*1, *P*4) is the same as the property of (4-4) in Fig. 2(a). As a result, this process can be generalized as follows. Here, the generalized process is named Straight_line_ operation(1).

[Straight_line_operation(1)]
Step 1. Pick up two line segments (*Lx*, *Ly*)
Step 2. If the values of properties of *Lx* and *Ly* are the same as the following values, the following steps are performed. (1-1) 4 (1-2) 2 (1-3) *Lx*, *Ly* (1-4) *Lx*(*Pa*, *Pb*), *Ly*(*Pc*, *Pd*) (2-1) 0 (2-2) 0 (2-3) token (2-4) token (3-1) true (3-2) false (3-3) true (4-1) yes (4-2) 0 (4-3) *Pa*, *Pd* (4-4) *Pb*, *Pc*. Here, "token" means a variable. Also, *x*, *y*, *a*, *b*, *c*, *d* of *Lx*, *Ly*, *Pa*, *Pb*, *Pc*, *Pd* are variables respectively.
Step 3. *Lx*(or *Ly*) is stretched and *Ly*(or *Lx*) is deleted.
Step 4. The terminals of *Lx*(or *Ly*) become (*Pb*, *Pc*) that is the value of (4-4) in Step 2.

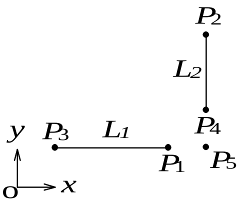
In Fig. 4, another operation named Straight_line_operation(2) can be generated as follows.

[Straight_line_operation(2)]
Step 1. Pick up two line segments (*Lx*, *Ly*)
Step 2. If the values of properties of *Lx* and *Ly* are the same as the following values, the following steps are performed. (1-1) 4 (1-2) 2 (1-3) *Lx*, *Ly* (1-4) *Lx*(*Pa*, *Pb*), *Ly*(*Pc*, *Pd*) (2-1) 0 (2-2) 0 (2-3) token (2-4) token (3-1) true (3-2) false (3-3) true (4-1) yes (4-2) 0 (4-3) *Pa*, *Pd* (4-4) *Pb*, *Pc*.
Step 3. *Lz* is drawn. Its terminals become (*Pb*, *Pc*) that is the value of (4-4) in Step 2.
Step 4. *Lx* and *Ly* are deleted.

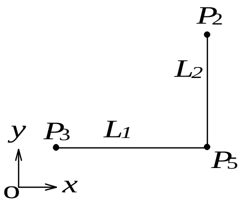
In Fig. 4(a), though two sets of properties are generated among *L*1, *L*2 and *L*3, they become meaningless for the generalization of Straight_line_operation(2). In general, the generalizations of restoration processes seem to be linear transformations. When input vector is (*Lx*, *Ly*), output vector can be expressed as (*Lx*', 0), (*Ly*', 0) or (*Lz*, 0) in Straight_line_operations. Suppose that this relationship is expressed as $\boldsymbol{q}=A\boldsymbol{p}$. Here, $\boldsymbol{P}=(Lx, Ly)$ and $\boldsymbol{q}=(Lx', 0)$, $(Ly', 0)$ or $(Lz, 0)$. *A* expresses the properties of *Lx*, *Ly* and/or *Lz*. Firstly *Lx* and *Ly* are the same as *Lx*' and *Ly*' respectively. When *A* is changed into *A*', they would become different. When the number of restoration operations is *n*, the relationship of $\boldsymbol{p}$ and $\boldsymbol{q}$ described above can be expressed as $\boldsymbol{q}=A_nA_{n-1}\cdots A_2A_1\boldsymbol{p}$. The generalization of restoration processes can apply to the calculation of $B=A_nA_{n-1}\ldots A_2A_1$. In the processes to calculate this equation, many meaningless properties such as described above would be generated.

In Fig. 2(b), suppose that *L*1 and *L*2 must be connected to form a right-angled corner in a 2D drawing. The restoration process of them is as follows. When the properties of the line segments are calculated, an imaginary intersection (*P*5) is generated as in Fig. 5(a). In this figure, the values of properties of *L*1 and *L*2 are as follows. (1-1) 5 (1-2) 2 (1-3) *L*1, *L*2 (1-4) *L*1(*P*1, *P*3), *L*2(*P*2, *P*4) (2-1) 0 (2-2) 0 (2-3) *P*5 (2-4) 0 (3-1) false (3-2) true (3-3) false (4-1) yes (4-2) 0 (4-3) *P*1, *P*4 (4-4) *P*2, *P*3. When the restoration of *L*1 and *L*2 is made by stretching them as in Fig. 5(b), the properties of them are changed as follows. (1-1) 3 (1-2) 2 (1-3) *L*1, *L*2 (1-4) *L*1(*P*3, *P*5), *L*2(*P*2, *P*5) (2-1) *P*5 (2-2) 0 (2-3) 0 (2-4) 0 (3-1) false (3-2) true (3-3) false (4-1) no (4-2) 0 (4-3) *P*5 (4-4) *P*2, *P*3.

In these properties, the value of (1-4) can be calculated from the other properties as follows. Firstly, it is found that *L*1 and *L*2 exist by the value of (1-3). Their terminals can be made of the properties of (4-3) and (4-4). Next, it is found that *P*3 and *P*2 are the terminals of *L*1 and *L*2 respectively by the initial properties of (1-4). Also, it is found that *P*5 is the common terminal of *L*1 and *L*2. As a result, two line segments can be made as *L*1(*P*3, *P*5) and *L*2(*P*2, *P*5). This restoration process can be generalized as Right-angled_corner_operation as follows.



(a) Generation of *P*5.



(b) Stretch of *L*1 and *L*2.

Fig. 5: Restoration of Fig. 2(b).

[Right-angled_corner_operation]

Step 1. Pick up two line segments (*Lx*, *Ly*)

Step 2. If the values of properties of *Lx* and *Ly* are the same as the following values, the following steps are performed. (1-1) 5 (1-2) 2 (1-3) *Lx*, *Ly* (1-4) *Lx*(*Pa*, *Pb*), *Ly*(*Pc*, *Pd*) (2-1) 0 (2-2) 0 (2-3) *Pe* (2-4) 0 (3-1) false (3-2) true (3-3) false (4-1) yes (4-2) 0 (4-3) *Pa*, *Pd* (4-4) *Pb*, *Pc*.

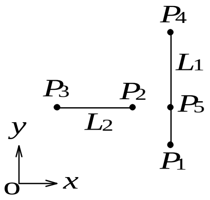
Step 3. Change the properties of Step 2 as follows. (1-1) 3 (1-2) 2 (1-3) *Lx*, *Ly* (1-4) *Lx*(*Pe*, *Pb*), *Ly*(*Pc*, *Pe*) (2-1) *Pe* (2-2) 0 (2-3) 0 (2-4) 0 (3-1) false (3-2) true (3-3) false (4-1) no (4-2) 0 (4-3) *Pe* (4-4) *Pb*, *Pc*.

Step 4. The values of the property of (1-4) in Step 3 are output and redraw *Lx* and *Ly*.

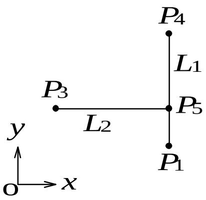
4.3 Restoration of two Isolated Line Segments to Make a T-connection

In Fig. 2(c), suppose that *L*1 and *L*2 must be connected to form a T-connection in a 2D drawing. The restoration process of them is as follows. When the properties of the line segments are calculated, an imaginary T-connection terminal (*P*5) is generated as in Fig. 6(a). In this figure, the values of properties of *L*1 and *L*2 are as follows. (1-1) 5 (1-2) 2 (1-3) *L*1, *L*2 (1-4) *L*1(*P*1, *P*4), *L*2(*P*2, *P*3) (2-1) 0 (2-2) 0 (2-3) 0 (2-4) *P*5 (3-1) false (3-2) true (3-3) false (4-1) yes (4-2) 0 (4-3) *P*1, *P*2 (4-4) *P*3, *P*4. When the restoration of *L*1 and *L*2 is made by stretching *L*2 as in Fig. 5(b), the properties of them are changed as follows. (1-1) 4 (1-2) 2 (1-3) *L*1, *L*2 (1-4) *L*1(*P*1, *P*4), *L*2(*P*5, *P*3) (2-1) 0 (2-2) *P*5 (2-3) 0 (2-4) 0 (3-1) false (3-2) true (3-3) false (4-1) yes (4-2) 0 (4-3) *P*1, *P*5 (4-4) *P*3, *P*4.

of (1-3). When the initial value of (1-4) and the final value of (4-3, 4) are compared, it is found that *L*1 is not changed and *P*2 of *L*2 is changed into *P*5. As a result, This restoration process can be generalized as T-connection_operation as follows.



(a) Generation of *P*5.



(b) Stretch of *L*2.

Fig. 6: Restoration of Fig. 2(c).

[T-connection_operation]

Step 1. Pick up two line segments (*Lx*, *Ly*)

Step 2. If the values of properties of *Lx* and *Ly* are the same as the following values, the following steps are performed. (1-1) 5 (1-2) 2 (1-3) *Lx*, *Ly* (1-4) *Lx*(*Pa*, *Pb*), *Ly*(*Pc*, *Pd*) (2-1) 0 (2-2) 0 (2-3) 0 (2-4) *Pe* (3-1) false (3-2) true (3-3) false (4-1) yes (4-2) 0 (4-3) *Pa*, *Pd* (4-4) *Pb*, *Pc*.

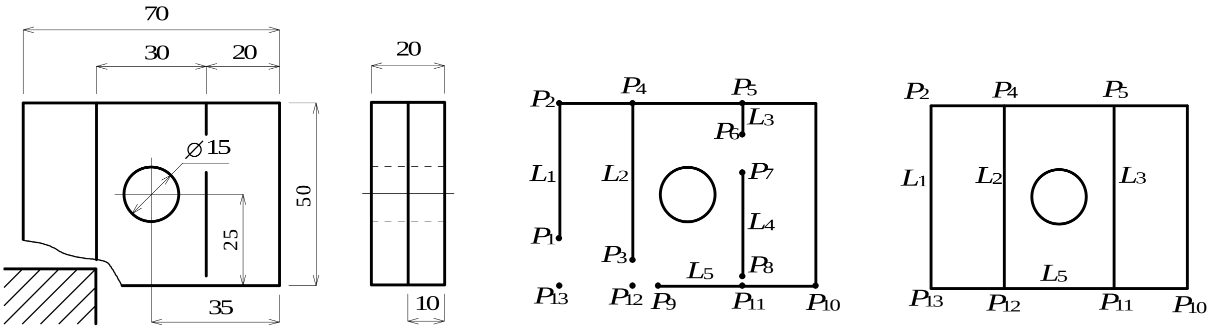
Step 3. Change the properties of Step 2 as follows. (1-1) 4 (1-2) 2 (1-3) *Lx*, *Ly* (1-4) *Lx*{*Pe*(or *Pa*), *Pb*}, *Ly*{*Pc*, *Pd*(or *Pe*)} (2-1) 0 (2-2) *Pe* (2-3) 0 (2-4) 0 (3-1) false (3-2) true (3-3) false (4-1) token (4-2) 0 (4-3) *Pe*(or *Pa*), *Pd*(or *Pe*) (4-4) *Pb*, *Pc*.

Step 4. The values of the property of (1-4) in Step 3 are output and redraw *Lx*(or *Ly*).

5. EXAMPLES

In Example 1, four isolated line segments in Fig. 1(c) can be restored into two line segments as in Fig. 1(d) by using Straight_line_operations described above. Fig. 7(a) illustrates the 2D drawing of Example 2 that is a plate. In Example 2, the lower left corner is omitted by another parts, and one line segment is cut by the dimension of ϕ15mm and one of its terminals does not reach to the other line segments because of a designer's mistake. Fig. 7(b) illustrates only outlines of front view in Example 2. In this figure, each of isolated line segments and their terminals are numbered. When a 2D drawing is input to this method, firstly an isolated line segment is searched and if the isolated line segment and another one line segment form a pattern of Fig. 2, the restoration of the isolated line segment is automatically performed by using generalized operations described above. In this method, the search and restoration of isolated line segments are performed repetitively until all isolated line segments disappear in the 2D drawing.

In Fig. 7(b), if *L*1 and *L*5 are firstly searched by this method, their terminals (*P*1, *P*9) are stretched to *P*13. Next, *L*2 is stretched to *P*12. These restoration processes can be reversed as follows. Firstly, *L*2 and *L*5 are searched and their terminals (*P*3, *P*9) are stretched to *P*12. Next, *L*1 and *L*5 are stretched to *P*13. In *L*3, *L*4 and *L*5, if *L*3 and *L*4 are firstly searched, they become one straight line segment as *L*3(or *L*4) by using Straight_line_ operation(1). Next, *L*3(or *L*4) is stretched to *P*11. These processes can be also reversed. As a result, a solution of Example 2 can be obtained as in Fig. 7(c).



(a) 2D drawing. (b) Numbered isolated line segment. (c) Restored Example 2.

Fig. 7: Example 2.

6. DISCUSSION

In this method, the most important thing is the selection of properties. The properties must apply to the equation of $\boldsymbol{q}=A_nA_{n-1}\cdots A_2A_1\boldsymbol{p}$ in section 4.1. When arcs are applied to this method, the properties would be more complex. For example, Fig. 8 illustrates a disk as Example 3 whose lower left corner in its front view is omitted. In this example, an arc is numbered as *L*1 and two straight line segments are numbered as *L*2 and *L*3 respectively. To restore *L*1 into a circle, many properties must be defined to arcs and circles. A user can operate the restoration of *L*1 as follows. Firstly a circle is drawn in accordance with *L*1. Next, *L*1 is deleted. These operations would be generalized in this method.

Also, $L3$ does not reach to $L1$ because of a designer's mistake in Example 3. To stretch $L3$ until $L1$, new junctions between arcs and straight line segments must be defined as properties in this method.

Moreover, though this method can apply to only two line segments, many cases that the properties among three or more line segments are required would exist. For example, Fig. 8 illustrates a plate as Example 4 whose lower left corner in its front view is omitted. In this example, to make two right-angled corners, the relationship among four isolated line segments had better be acquired as properties. Probably a great many properties of line segments would be generated hierarchically in a 2D drawing, and the properties of two line segments in this method would become fundamental of them.

As a result, the acquisition of more suitable and hierarchical properties of line segments would become an important issue to handle various kinds of simplified expressions in 2D drawings. Moreover, the learning system of this method could apply to 3D CAD systems and the other systems. For example, in the solid model of an assembly, it is time consuming and troublesome to obtain its various sectional views in some CAD system. If the process to make sectional views in 3D assembly models can be learned and generalized, the process can be automated. The final purpose of this method is that every routine work is automated in virtual world.

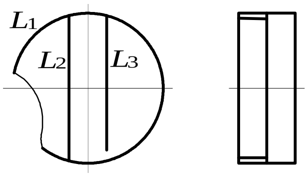


Fig. 8: Example 3.

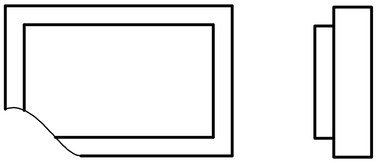


Fig. 9: Example 4.

7. CONCLUSION

In this research, a method to restore isolated line segments in 2D drawings is developed by using learning systems. To handle isolated line segments, the properties of two line segments can be clearly defined in this method. The properties enable the automatic learning and generalizing of various kinds of restoration processes, and generalized processes can apply to automatic restorations of various patterns of isolated line segments. Though only straight line segments are handled in this method, the possibility to apply this method to arcs is discussed. The experimental system of this method is implemented on a PC with Perl language. The effectiveness of this method has been verified by applying many examples of isolated line segments to the experimental system.

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