Reconstruction of 3D Solid Models Using Fuzzy Logic Recognition

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Abstract: - This paper presents an application of fuzzy logic theory to the reconstruction of solid models from engineering drawings. In engineering drawing, two-dimensional (2D) orthographic projections represent an object ambiguously, it requires a numerous amount of combinatorial searches in the process of reconstruction of three-dimensional (3D) drawing. This paper proposes an algorithm which applies fuzzy logic to identify the category of the object in order to implement the further operations. Once an object has been classified to be either rotational or prismatic the major operation of either revolve or extrude will be executed correspondingly to generate the 3D solid model. Compared with earlier approaches, the present method focuses on ambiguous issues which improves the efficiency of the reconstruction process. A program has been compiled to implement the present algorithm which has proved to be very practicable.

Key-Words: - fuzzy logic, reconstruction, engineering drawing, 3D, solid model.

1 Introduction
It has been almost forty years since the fuzzy logic theory was first introduced by Professor Zadeh in 1965. The theory of fuzzy logic has now evolved into a fruitful area containing various disciplines, such as calculus of fuzzy if-then rules, fuzzy graphs, fuzzy interpolation, fuzzy topology, fuzzy reasoning, fuzzy inferences systems, and fuzzy modelling. Applications of this theory can be found, for example, in artificial intelligence, computer science, control engineering, decision theory, expert systems, management science, operations research, and robotics to name but a few. Fuzzy logic theory provides an interface between humans and computers. It helps to reduce conflicts in human-computer interactions.

As the number of applications that use 3D solid models increases in mechanical engineering, such as analysis, prototyping, and tooling, there is a need to devise an efficient method of reconstructing a solid model from archived 2D data. One approach is reconstruction from orthographic projections, which is a 2D-oriented approach that is based on an analogy with conventional engineering line drawings. Reconstruction of a 3D solid model from orthographic projections is a procedure for recovering information from a low level to a high level. Although obtaining 2D projections from a given 3D object is straightforward, the inverse operation becomes rather implicit and difficult. The difficulties of this approach arise from the loss of semantic information when a 3D object is represented by 2D projections. Furthermore, it involves artificial intelligence (AI), which is to enable the computer to have human engineers’ ability to understand engineering drawings [1].

In order to generate a 3D solid model from the 2D line drawing, the following procedures have to be undertaken:
1. Extract elements (vertices, edges or regions) from 2D engineering drawing.
2. Understand the functionalities and correspondence of those elements.
3. Match the corresponding features (vertices, edges or regions) of 2D projections.
4. Reconstruct the 3D solid model.
5. Verify the result to the original given drawing.

Over the past two decades, researchers have come up with an array of algorithms to generate 3D objects from the user specified orthographic projections [3-14]. A few literature surveys have been conducted.
previously [2] [15] [16]. The most common representations used in the reconstruction problem are constructive solid geometry (CSG) and boundary representation (BRep).

Although the CSG and BRep methods have become dominant approaches for representing a 3D solid model, they have vital drawbacks respectively. The CSG approach is unable to support complex shapes and requires much user interaction. The BRep approach is verbose in data structure. Due to the disadvantages of CSG and BRep method the previous researches have not achieved the ultimate goal of the reconstruction. More important, those researches have not using computer to simulate the procedure which human engineers use to understand projections. The severest problem during the reconstruction is lack of semantic information resulting with ambiguity of connection between the corresponding elements in different views when a 3D object is represented by 2D projections. To deal with the ambiguous issues the present algorithm applied fuzzy logic theory which was designed for representing ambiguities and uncertainties.

It is clear that fuzzy logic, as a mathematical method, has advantages over conventional mathematical methods in dealing with information that is vague, imprecise an uncertain, which is always the case when human beings are involved. Systems that designed and developed using a fuzzy logic method have been shown to be more effective than those based on conventional approaches. More details of fuzzy logic and systems can be found in [20] and [21].

The present algorithm includes following steps;

1. Extract geometric elements from three orthographic views of the 2D engineering drawing.
2. Classify and evaluate elements by different types which comprise of line and arc (circle is treated as a special kind of arc).
3. Learn the functionalities and characteristics of geometric elements using fuzzy logic controller (FLC), thus decide the operating method of the reconstruction.
4. Extrude or revolve operation is applied to generate a draft solid model.
5. Boolean operations are being used appropriately to obtain the final 3D solid solution.

This paper will focus on step 3 and 4 since the first two steps have been discussed in a previous paper [17].

2 Identify the Object by FLC

There are two types of FLC which have been widely applied: Mamdani-type and Sugeno-type. [20] These two types of inference systems vary somewhat in the way outputs are determined. The only difference between them is Mamdani’s fuzzy inference method has to apply a defuzzification for the output. Considering the present reconstruction application, defuzzification will not be applied since the output of the FLC would be constant which is either rotational or extrusion operation. Thus, the Sugeno controller has been adopted in the reconstruction program.

![Fig. 1 An engineering drawing represents a combined component](image)

In the process of interpreting 2D engineering drawings by human engineers, it is realized that identifying the category of each object (either rotational or prismatic) would be rather crucial for the initial reforming concept. Further operations (i.e. rotate or extrude) could be performed after the basic recognition to generate the candidates of solid models. However, it is too ambiguous to distinguish a
complex component from the characteristics of the geometric shape between rotational or prismatic by conventional method. An engineering component could be a combination of geometrical primitives, which cannot be described by a particular construction.

Fig. 1 shows an example that combines both rotational and prismatic primitives. For an experienced engineer, it is quite easy to linguistically explain Fig. 1 that illustrates a roughly symmetric c-shaped base block with a tube on the top. The explanation reflects the conducts of pattern recognition and classification which are characteristics of human being. Using conventional algorithm or certain crisp logic could not achieve this or would be too verbose to express the semantic feature of the engineering drawing. The present algorithm applied FLC to mimic the linguistic performance.

In order to understand the ambiguous issues of the geometrical description in the engineering drawing and construct a FLC, the following steps are undertaken:

1. Declare fuzziness from the engineering drawing.
2. Preprocess the input data for FLC.
3. Establish fuzzy set from fuzziness components as the input of the FLC.
4. Choose the membership function for each fuzzy set.
5. Set up the IF-THEN rules based on experienced knowledge.

### 2.1 The Fuzziness

Fuzziness can refer to various types of vagueness and uncertainty but particularly to the vagueness related to human linguistics and thinking. Fuzziness is a property of language. Its main source is the imprecision involved in defining and using symbols. Fuzzy sets will be built through those elements of fuzzinesses. Considering that engineering drawing, the present algorithm will set up three elements of fuzziness for the FLC.

From a broad point of view, a projection can be realised as symmetric or asymmetric by an appointed axis. According to the characteristics of geometric models, the rotational object is always perfecting symmetrical. However, in practice a rotational object usually has some inner details (such as holes, flanges, ribs) which will change the figure to part symmetrical. The grade of the symmetry is a principal issue to distinguish rotational from prismatic object and is the first element of fuzziness extracted from the drawing.

The second element of fuzziness would be considered through the style of distribution of circles in a projection view. In other words, the concentricity will help to understand the distribution of circles. In engineering drawing, an isolated circle could only be described as two types of feature, hole and cylinder. However, concentrical circles could be regarded as many uncertain features, such as tube, cone, hole with chamfer etc. It could be easily to realise that rotational objects usually have several concentric circles due to the rotate operation like the example shown in Fig. 2. Thus, the concentricity of circles can be studied as a fuzziness to differ rotational from prismatic object.

The last element of fuzziness in the FLC could be observed via dimensional perspective. The relationship between the size of circle and the outline in the projection has shown a potential approach to recognise rotational and prismatic object. Theoretically, one of the projections of a rotational object should be dominated by a large dimensional circle which also is the outline of the projection. Fig. 2 has shown an example which illustrates a circular outline in one projection view. The present algorithm will synthesize the dimensional information of circles to become one of the fuzzinesses in the FLC.
2.2 Preprocess the Input Data

The developed program accepts standard AutoCAD® drawing as input file. The drawing contained data follow British Standard BS 308 [18]. The line-types of the entities in the drawing could be solid or dashed or centre line. However, the different line-types need to be created in different layers conventionally. The data example of a linear entity in AutoCAD® drawing is shown as follow:

((-1 . <Entity name: 1925150>) (0 . "LINE") (5 . "32") (100 . "AcDbEntity") (67 . 0) (8 . "0") (10 90.0 200.0 0.0) (11 170.0 200.0 0.0) (210 0.0 0.0 1.0))

The program extracts the initial elements from the drawing database and classifies them into different sets by vertices, edges, circles, and arcs. The geometrical information which includes coordinate of vertices and dimension of entities has also been extracted during the processing. There are three types of input data which comprise of the fuzzy sets. The FLC needs to evaluate the fuzzy sets namely symmetrical, concentrical, and dimensional. According to fuzzy set theory, each given item of fuzzy set is assigned a value in the interval [0, 1]. The program has implemented a series of procedures to obtain the result of the input values.

Firstly, the idea for symmetrical element in the projection is to compare every entity on each side of the symmetric axis. The comparison would be implemented from both vertical and horizontal direction.

Vertically symmetric axis: \( X = i \);
Horizontally symmetric axis: \( Y = j \);

By default, the central line will be picked as the symmetric axis. If there is no central line in the drawing, \( i \) can be evaluated by dividing the very left and right vertices equally, and \( j \) can be evaluated by dividing the very top and bottom vertices equally. For each direction, the result \( S \) will be the ratio of symmetric entities \( E_S \) to total entities \( E \). The bigger value \( S_F \) is chosen to be the final symmetrical input for FLC.

\[
S = E_S / E \mid (E_S \in E);
S_F = \max (S_i, S_f) \mid (S_i, S_f \in S);
\]

Secondly, for concentrical element this will only concern circular entities in the projection drawing. The coordinates of the central point of each circle have been classified by the program from database. The program will identify every central point to search concentric circles. The concentrical value \( C_F \) is the ratio of concentric circles \( E_C \) to total circles \( E \).

\[
C_F = E_C / E \mid (E_C \in E);
\]

Finally, from the dimensional point of view the program will compare the size of circles and linear border of the projection. The values of the diameter of circles \( D \) and the coordinates of vertices \( V \) are extracted from the database of the drawing. As mentioned in last section, one of the projections of a rotational object should be dominated by circles. In other words, the dimension of the diameter of the largest circle \( D_x \) must be the biggest dimensional value in the projection. The linear border of the projection is the area which surrounded by linear entities.

\[
B_v = (Y_t - Y_b), \quad B_h = (X_t - X_b);
B_i = \max (B_v, B_h);
D_F = (D_x - B_i) / D_x, \quad \text{for } D_x > B_v;
D_F = 0, \quad \text{for } D_x < B_v;
\]

There are two dimensions of the linear border, namely vertical length \( B_v \) and horizontal length \( B_h \). Each dimension can be calculated by the corresponding coordinates of border vertex: top vertex \( V_t (X_t, Y_t) \), bottom vertex \( V_b (X_b, Y_b) \), left vertex \( V_l (X_l, Y_l) \), right vertex \( V_r (X_r, Y_r) \). The larger value \( B_x \) between \( B_v \) and \( B_h \) will be chosen to evaluate the dimensional input \( D_F \) for the FLC.

2.3 Fuzzy Sets and Membership Functions

Membership functions characterise the fuzziness in a fuzzy set in a graphical form for eventual use in the mathematical formalisms. However, the shapes used to describe the fuzziness have very few restrictions indeed. It might be claimed that the rules used to describe fuzziness graphically are also fuzzy. Actually, there is yet no fixed, unique, and universal rule or criterion for selecting a membership function for a particular fuzzy set in general: a correct and good membership function is determined by the user based on his scientific knowledge, working
experience, and actual need for the particular application in question.

The present algorithm has adopted the intuitive method \cite{19} to assign the membership functions for three specific fuzzy sets, namely symmetrical, concentrical, and dimensional. The method is simply derived from the capacity of humans to develop membership functions through their own innate intelligence and understanding.

For the symmetrical fuzzy set, two membership functions namely symmetry and asymmetry have been assigned. Two functions so called ZMF and SMF that are polynomial based curves in Z-shape and S-shape have been specified to asymmetry and symmetry respectively. Fig. 3 shows the graphic of the membership functions of symmetrical variable. The membership functions define how each point in the input space (X-axis $S_F$) is mapped to a membership value (or degree of membership) between 0 and 1. The membership functions for concentrical and dimensional fuzzy sets have been assigned similar functions as symmetrical fuzzy set.

2.4 Fuzzy Control Rules

In general, a fuzzy rule, which is often expressed in the form of ‘IF – THEN’, is essentially a relation. Fuzzy sets are the subjects of fuzzy logic. The IF-THEN rule statements are used to formulate the conditional statements that comprise fuzzy logic. Each rule in the fuzzy knowledge base corresponds to a fuzzy relation.

After exploring the characteristics of rotational and prismatic objects, the following rules have been formulated:

1. If concentrical ($C_F$) is non-concentric and symmetrical ($S_F$) is asymmetric and dimensional ($D_F$) is small, then the operation is extrusion.

Fig. 4 Graphical Sugeno FLC
2. If $C_F$ is concentric and $S_F$ is symmetric and $D_F$ is large, then the operation is rotation.

3. If $C_F$ is concentric and $S_F$ is asymmetric and $D_F$ is large, then the operation is rotation.

4. If $C_F$ is non-concentric and $S_F$ is symmetric and $D_F$ is small, then the operation is extrusion.

Fig. 4 displays the graphical interpretation of the whole fuzzy inference process. The four small plots across the top of the figure represent the antecedent and consequent of the first rule. Each rule is a row of plots, and each column is a variable. The first three columns of plots (the twelve yellow plots) show the membership functions, namely symmetrical, concentrical, and dimensional referenced by the antecedent, or the if-part of each rule. The fourth column of plots (the four blue plots) shows the membership functions referenced by the consequent, or the then-part of each rule. In which, the value which is over 0.5 will be considered as a rotate operation, otherwise it will be an extrude operation.

3 Reconstruction Operations

Once FLC identified the category of the object, two different operations namely rotation and extrusion will be pursued. The extrusion algorithm has been discussed in another paper [17]. The rotational reconstruction operation will be focused here.

Fig. 5 shows a typical rotational object represented by orthographic projections. In the section view, the region to be revolved could be determined by the present algorithm.

![The 2D engineering drawing](image)

**Fig. 6 The process of rotational operation**

Fig. 6 shows the process of the whole generation of the rotational object. The program extracts all entities from the drawing database and classifies them as different categories before the FLC identification. For a rotational object, the section view would attract more attention because it contains most of the generating information.

Conventionally, the symmetrical axis should be drawn as a centre line in the section view of the engineering drawing, as it shown in Fig. 6. Normally, the centre line would be the revolve axis for the generation. The present algorithm explores the properties of every line to find out all centre lines from the section view. The longest centre line will be specified as the axis of the revolution.

Obviously, only one side of the entities by the rotational axis need to be considered to define the
region to be revolved. The region is a bounded planar face which created from closed shapes or loops. The boundary of the region consists of end-connected curves where each 2D vertex shares only two edges. The candidate vertices and corresponding edges will be selected from the drawing to form a closed loop by the program. The rotational region can be generated from the loop.

The program implements a rotate command by revolves the region around the specified axis anti-clockwise to obtain a 3D object. Fig. 7 shows a rendered 3D solid model which reconstructed by the present program.

In some cases, there are inner patterns in the drawing as it shown in Fig. 2. Boolean operations will be applied to achieve the patterned result from the 3D rotational object. Further details about Boolean operations will be discussed in another paper.

Fig. 7 The 3D solid model

4 Conclusion

This paper presents a solution to the problem of reconstructing 3D solid models from 2D engineering drawing. The problem of 3D model reconstruction is complex and involves many disciplines including computer graphics [22], computational geometry and solid modelling techniques [23-26]. All of these areas fall under the umbrella of CAD which is under continual development. The present reconstruction algorithm has applied fuzzy logic to identify the category of the object. It has been shown that the identification from the 2D engineering drawing could extraordinary improve the accuracy of the reconstruction results which have been struggling in some previous works [27] [28]. It has also been proved the efficiency of the algorithm that simplifies the process of the reconstruction, thus reduced processing time.

In this study, MATLAB® has been used to build the fuzzy logic control system. AutoCAD® has been implemented as the test bed of the algorithm. C++ and ObjectARX® were applied to compile the reconstruction program which contains approximate 1500 lines.

Future work will focus on dealing with more complicated inner details of the drawing. To extend the domain of geometric shapes to be reconstructed.

Reference:
[9]. Aldefeld, B. and Richter, H., Semiautomatic three-dimensional interpretation of line


