Reconstruction of 3D Solid Models Using Fuzzy Logic Recognition

Zhe Wang and Mohammed Latif

***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 improve the efficiency of the reconstruction process. A program has been compiled to implement the present algorithm which has proved to be very practicable.**

***Index Terms*—engineering drawing, fuzzy logic, reconstruction, solid model.**

I. 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

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Z. Wang is with the Department of Engineering and Technology, the Faculty of Science and Engineering, Manchester Metropolitan University, Manchester, M1 5GD (phone: 0044 161 247 6512; fax: 0044 161 247 1633; e-mail: z.wang@mmu.ac.uk).

M. Latif is with the Department of Engineering and Technology, the Faculty of Science and Engineering, Manchester Metropolitan University, Manchester, M1 5GD (e-mail: m.latif@mmu.ac.uk).

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].

II. 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 used in the reconstruction program.

In the process of interpreting 2D engineering drawings by human engineers, it is realized that identifying each component (either rotational or prismatic) would be rather crucial for the initial reforming concept. After basic geometric classification further operations (i.e. rotate or extrude) will be performed 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 recognition and pattern 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.

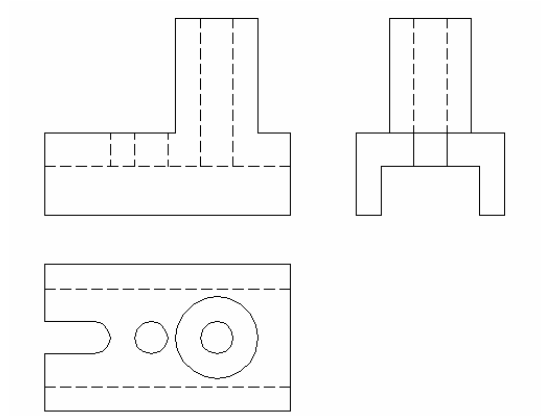

Fig. 1 An engineering drawing represents
a combined component

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.

Set up the IF-THEN rules based on experienced knowledge.

A. 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 axis. According to the characteristics of geometric models, rotational object is always perfect 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 realised that rotational objects usually have several concentric circles due to the rotate operations like the example shown in Fig. 4. 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

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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.

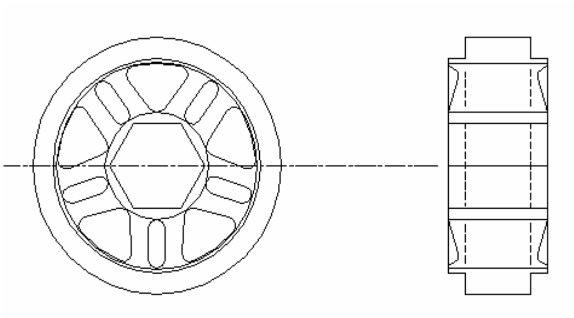

Fig. 2. A rotational object in two-view projection.

B. *Preprocess the Input Data*

The developed program accepts standard AutoCAD® drawing as input file. The drawing contained data which 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 executed from both vertical and horizontal direction.

$$\text{Vertically symmetric axis: } X = i;$$
$$\text{Horizontally symmetric axis: } Y = j;$$

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.

$$S = E_S / E \mid (E_S \in E);$$
$$S_F = \text{Max}(S_i, S_j) \mid (S_i, S_j \in S);$$

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.

$$B_v = (Y_t - Y_b), \quad B_h = (X_r - X_l);$$
$$B_x = \text{Max}(B_v, B_h);$$
$$D_F = (D_x - B_x) / D_x, \ \textit{for}\ D_x > B_x;$$
$$D_F = 0, \ \textit{for}\ D_x < B_x;$$

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 (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.

C. *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 [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 *symmetrica*l 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.

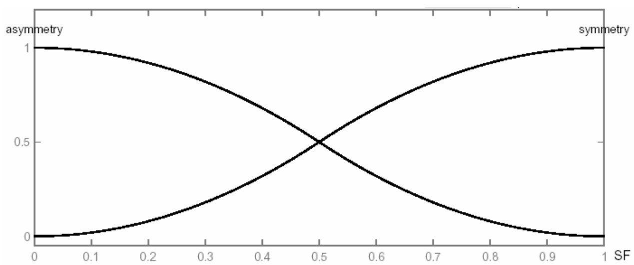

Fig. 3. The membership functions of the symmetrical fuzzy set

D. *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.
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.

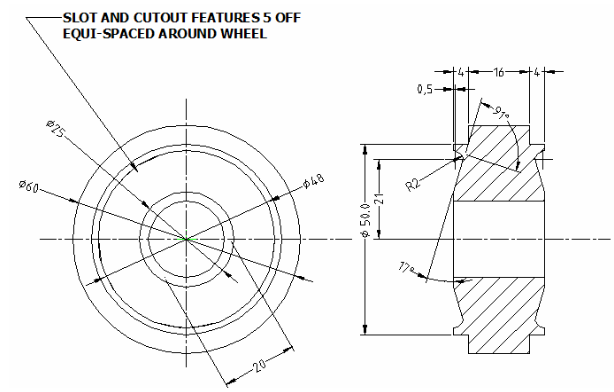

Fig. 5. The engineering drawing of a rotational object

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.

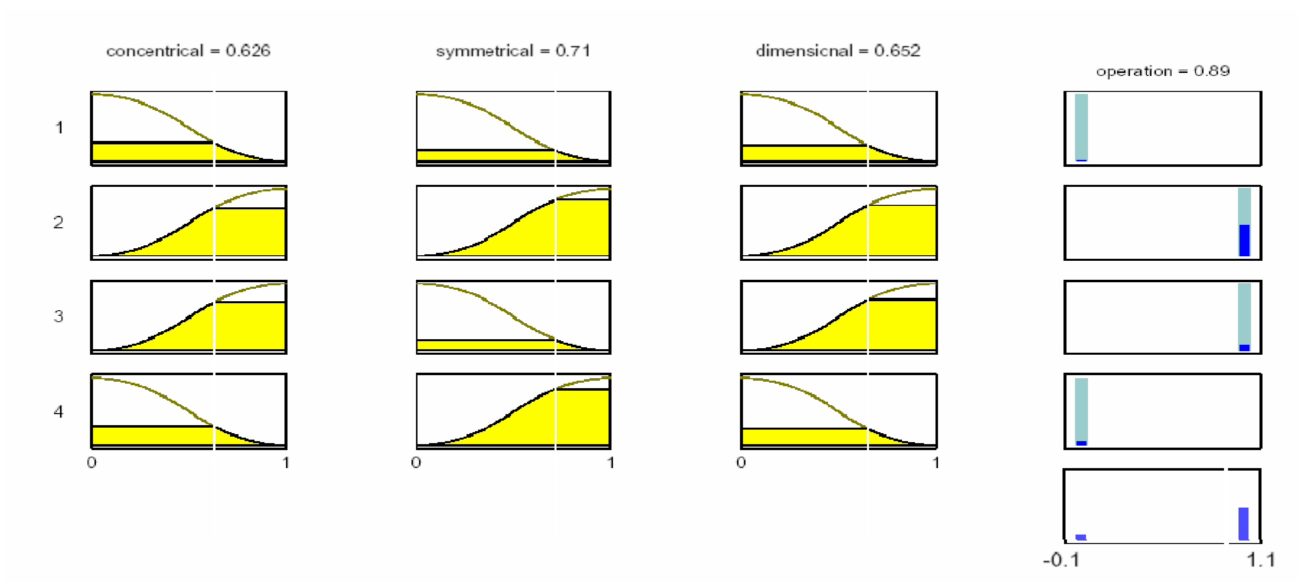

Fig. 4. Graphical Sugeno FLC

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III. 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.

Fig. 6 shows the flowchart of the whole generation process 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.

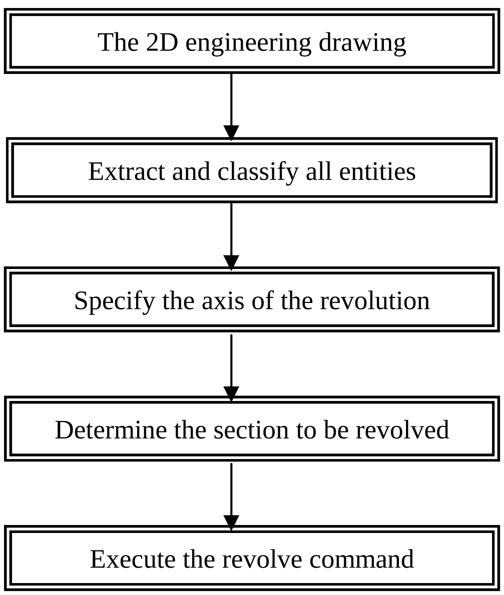

Fig. 6. The flowchart of rotational operation

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.

Fig. 7. The 3D solid model result

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.

References

[1] Lafue Gilles, "A theorem prover for recognizing 2-D representations of 3-D objects," *Artificial Intelligence and Pattern Recognition in CAD*, 1978, pp. 391-401.

[2] G. Requicha, H. B. Voelcker, "Solid modelling: A historical summary and contemporary assessment," *IEEE Comput. Graph. Appl.* 1982, March, pp. 9-24.

[3] Idesawa, M., "A system to generate a solid figure from a three view," *Bulletin of JSME*, 1973, 16(February), pp. 216-225.

[4] Wesley, M. A. and Markowsky, G., "Fleshing out wire frames," *IBM Journal of Research and Development*, 1980, 24(5), pp. 582-597.

[5] Wesley, M. A. and Markowsky, G., "Fleshing out projections," *IBM Journal of Research and Development*, 1981, 25(6), pp. 934-954.

[6] Preiss K., "Algorithms for automatic conversion of a 3-view drawing of a plane-faced part to the 3-D representation," *Computers in Industry*, 1981, 2(2), pp. 133-139.

[7] Sakurai, H., Gossard, D., "Solid model input through orthographic views," *ACM Computer Graphics*, 1983, 17(3), pp. 243-252.

[8] Aldefeld, B., "On automatic recognition of 3D structures from 2D representations," *Computer-Aided Design*, 1983, 15(2), pp. 59-64

[9] Aldefeld, B. and Richter, H., "Semiautomatic three-dimensional interpretation of line drawings," *Computers & Graphics*, 1984, 8(4), pp. 371-380.

[10] Preiss K., "Constructing the solid representation from engineering projections," *Computers & Graphics*, 1984, 8(4), pp. 381-389.

[11] Yan, Q., Philip, C. L. and Tang, Z., "Efficient algorithm for the reconstruction of 3D objects from orthographic projections," *Computer-Aided Design*, 1994, 26(9), pp. 699-717.

[12] Simon. S, P. Shum, W.S. Lau, "Solid reconstruction from orthographic opaque views using incremental extrusion," *Computer & Graphics*, 1997, 21, pp. 787-800.

[13] Shi_Xia Liu, Shi-Min Hu, "Reconstruction of curved solids form engineering drawings," *Computer-Aided Design*, 2001, 33, pp. 1059-1072.

[14] Weidong Geng, Jingbin Wang, "Embedding visual cognition in 3D reconstruction from multi-view engineering drawings," *Computer-Aided Design*, 2002, 34, pp. 321-336.

[15] Nagendra, I. V. and Gujar, U. G., "3-D objects from 2-D orthographic view --- A survey," *Computers & Graphics*, 1988, 12(1), pp. 111-114.

[16] Weidong Wang, "A survey of 3D solid reconstruction from 2D projection line drawings," *Computer Graphics Forum*, 1993, 12(3), pp. 137-158.

[17] Z. Wang, M. Latif, "Reconstruction of a 3D solid model from orthographic projections," *Proceedings of International Conference on GMAG03*, July 2003, London, pp. 75-82.

[18] Maurice Parker, *Manual of British Standards in engineering drawing and design*, British Standards Institution in association with Hutchinson, 1984.

[19] Timothy J. Ross, *Fuzzy logic with engineering applications*, McGraw-Hill, Inc. 1995.

[20] Zimmerman, H-J, *Fuzzy Set Theory – and Its Applications*, 3rd Edition. Kluwer Academic, 1996.

[21] Timothy J. Ross, *Fuzzy logic with engineering applications*, McGraw-Hill, Inc. 1995.

[22] Foley, van Dam, *Computer graphics principles and practice*, Addison-Wesley,Reading, Massachusetts, 1996.

[23] Martti Mantyla, *An introduction to solid modelling*, Computer Science Press, 1988.

[24] Gerald Farin, *Curves and surfaces for CAGD, A practical guide*, Morgan Kaufmann Publishers, 2002.

[25] I. C. Braid, "The synthesis of solids bounded by many faces," *Communications of the ACM,* 18(4), 1975.

[26] Masuda, H., "Topological operators and Boolean operations for complex-based nonmanifold geometric models," *Computer-Aided Design*, 1993, 25(2), 119-129

[27] Dutta, D. and Srinivas Y L, "Reconstruction of curved solids from two polygonal orthographic views," *Computer-Aided Design,* 1992, 24(3), 149-159

[28] Suh Tae Jung, Kim W. S, "Two phase 3D object reconstruction from two-view drawings," *IEICE Trans. Inf. & Syst.* 1999, E82D.