Journal of Engineering and Applied Sciences 12 (7): 1938-1945, 2017
ISSN: 1816-949X

Solid Reconstruction from Two Orthographic Views Using Extrusion and Comparative Projections

Hamid Haghshenas Gorgani, Iman Magh Soudi Neyestanaki and Alireza Jahantigh Pak
[1]Engineering Graphics Center, Department of Mechanical Engineering,
Sharif University of Technology, Tehran, Iran

Abstract: By knowing this fact that 2D engineering drawings which are impartible component of today design and manufacturing processes cannot be used directly as input of CAD/CAM systems and their editing is difficult it is necessary to reconstruct 3D solids from them. This process usually performed by two approaches: B-Rep (Boundary representation) and CSG (Constructive Solid Geometry). Each of these approaches have strengths and weaknesses. In this study, however represented algorithm is not exactly based on B-Rep or CSG approaches but mostly lies on CSG. This process consists of outer pattern recognition in each orthographic view by use of a mathematic algorithm regarding to real and virtual vertices then extrusion of these patterns and making subscripted solid from obtained extruded volumes. At the next step, inner patterns of each view which are straight or curved lines are extruded and some faces are obtained which fractionalize the volume of previous step into smaller volumes. The final solution is a subset of these volumes therefore an arbitrary subset is selected and orthographic views of result volume are generated. These orthographic views are compared with initial orthographic views. The process of selecting subsets, generating orthographic views and comparing views is continued until find complete conformity between views. Also, it is clear that, existence of answer without any vagueness is assured. One of advantages of this method is that finding solution volume is certain. This solution unlike B-Rep method has no vagueness and for as much as can cover all non-geometric volumes, one of the most important weaknesses of CSG method which is its limited domain is removed.

Key words: Solid model, orthographic views, extrusion, comparative views, strengths and weaknesses

INTRODUCTION

In last two centuries, 2-D orthographic drawings which are result of applying descriptive geometry in industry are principal guide for manufacturing, fabricate and assembly (Gorgani, 2016a, b). Beside these drawings have critical limitations such as increase of time and cost of design and manufacturing because they cannot be edited and used directly as input of engineering processes (Liu *et al*., 2001; Wang and Latif, 2007) and we can say their ideality degree is low (Gorgani, 2016a, b). So, it is necessary to create 3D solids from these orthographic drawings. In this way there is two principal approaches: B-Rep (Boundary representation) and CSG (Constructive Solid Geometry) (Nagendra and Gujar, 1988).

B-Rep approach which is older and most of studies in reconstruction of 3D solids from orthographic views implemented by it introduced as a bottom up method by Idesawa (1973). Principal idea of B-Rep approach is as following; first, 3D vertices are obtained from 2D vertices in different views then edges are attained by connecting 3D vertices, faces are gotten by joining these edges and finally, 3D solution solid earned from mentioned faces.

Also, Woo and Hammer and then Preiss presented a 3-step algorithm which was useful for objects with planar and cylindrical faces. Most of comprehensive works in B-Rep are performed by Wesley and Markowsky (1980) and Wesley and Markowsky (1981). Wesley was the first person who proposed to use an intermediate wireframe in this approach. Sakurai and Gossard (1983) suggested a B-rep base method which was efficient for objects with planar, cylindrical, conical, spherical and toroid with this limitation that revolution axis of each surface must be parallel to one of principal axis of drawing. Yan *et al*. (1994), Shin and Shin (1998), Kuo (1998) and Liu and colleagues continued the works of Markowsky and Wesley and made their algorithm more efficient, precise and robust with wider domain but yet main weaknesses of B-Rep which were disability to analyzing complex shapes because of calculative

Corresponding Author: Hamid Haghshenas Gorgani, Engineering Graphics Center, Sharif University of Technology, Tehran, Iran

problems, vague answers and possibility of having no answer in some cases, remains virginal (Lee and Han, 2001).

CSG approach is based on this fact that, every final solution solid is a combination of some primitive solids. These primitives are gotten from recognition of their patterns in orthographic views and then extrusion of them. At the next step these obtained volumes impressed by Boolean operations and solution gained. This approach introduced by Aldefeld (1983). Aldefeld method was limited to objects with uniform thickness and needs user inference in recognition of patterns. Shum *et al.* (1997) proposed a CSG base method which needed 6 orthographic views as input. After it, Shum *et al.* (2001) represented a new method with 2-stage extrusion. At the first step of this algorithm, outer pattern of each view is extruded in its normal direction which called "basic solid". Then all extruded solids are subscripted and obtained volume called "extrusion solid". After it, inner elements of each view are filtered and another solid is gained which called "excess solid". Finally, excess solid is subtracted from extrusion solid and solution solid earned. Soni and Gurumoorthy (2003) proposed an algorithm which used revolution about an axis to generate primitive solids and so made wider domain for CSG. Lee and Han (2001) presented recognized design features for 2D drawings using expert system to generate solid models. Also, Hwang *et al.* (2004) analyzed a ship structure in orthographic views using CSG approach. Cicek and Gulesyn (2004) proposed a two stage method. At the first stage, inner elements of each view extruded to make primitive solids and locate them in their x-z coordinates. At the second stage, outer boundaries of each view are extruded and subscripted. Finally, primitives of the first stage are subtracted from extruded volumes of the second stage. Lee and Han (2005) presented a hint base algorithm which gave intersecting solids obtained from revolution of orthographic views elements. Fu *et al.* (2010) proposed a method to reconstruction of intersecting curved solids from 2D orthographic views based on CSG approach to wider its domain but anyway the principal weakness of CSG which is limited domain, stays virginal, however the most important strength of this approach is certain solutions.

In this study, however, represented algorithm is not exactly based on B-Rep or CSG approaches but mostly lies on CSG. This process consists of outer pattern recognition in each orthographic view by use of a mathematic algorithm regarding to real and virtual vertices then extrusion of these patterns and making subscripted solid from obtained extruded volumes. At the next step, inner patterns of each view which are straight or curved lines are extruded and some faces are obtained which fractionalize the volume of previous step into smaller volumes. The final solution is a subset of these volumes therefore an arbitrary subset is selected and orthographic views of result volume are generated. These orthographic views are compared with initial orthographic views. The process of selecting subsets, generating orthographic views and comparing views is continued until find complete conformity between views. Also, it is clear that existence of answer without any vagueness is assured.

So here, first mathematical preliminaries consist of definingextrusion, process of finding real and virtual vertices and then method of generating orthographic views are descripted. After it, the main process which uses mentioned preliminaries represented. In all steps, examples are used to clarify the matter and finally, advantages and limitations of this algorithm explained.

MATERIALS AND METHODS

Essential definitions and algorithms

Extrusion: Assume that S is a set of points in xy plane as shown in Fig. 1. So, we can define Eq. 1:

$$\mathrm{Ext}(S,z) = \{(x,y,z) \mid (x,y) \in S, z \in R\} \quad (1)$$

Ext(S, z) are points of set S which extruded along z direction. Please pay attention to this fact that S can be a single point an open curved, a straight line or a close curve. At the same way, we can define Ext(S, x) and (S, y).

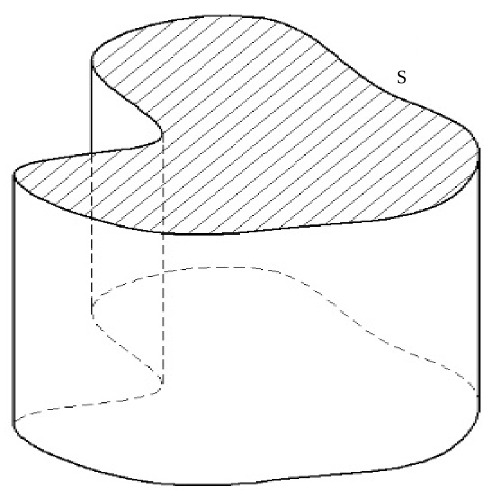

Fig. 1: A set of points in xy plane which are extruded

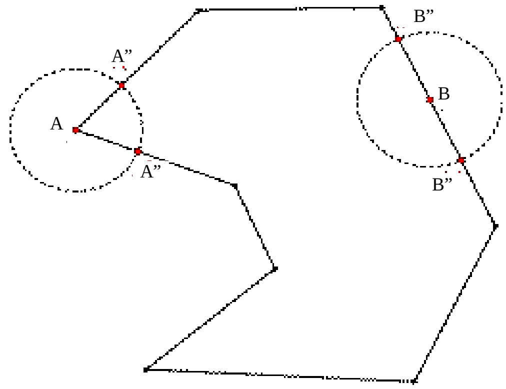

Fig. 2: A polygon with vertex point A and non-vertex point B

Finding real vertices of a polygon: Assume a polygon in xy plane such as shown in Fig. 2 and call its perimeter points as P. If $(x_0, y_0) \in P$ be an arbitrary point, plot a circle with its center at (x_0, y_0) and radius of ε. Decrease value so subscription of this circle and P becomes exactly two points. Connect each of these two points to (x_0, y_0) and find slopes of two obtained lines as m+ε and m-ε. We define that if Eq. 2 be true then (x_0, y_0) is a real vertex of the polygon:

$$\lim_{\varepsilon \to 0} m_{+\varepsilon} - m_{-\varepsilon} \neq 0 \quad (2)$$

By continuing this process we can find all real vertices of the polygon. For example, in Fig. 2 this algorithm calls point A as a real vertex and point B as a non-vertex point.

Finding virtual vertices of a closed loop: Assume closed loop C in xy plane which is continuous and bounded. We want to obtain absolute maximum and minimum in y-direction. Now, assume $(x_0, y_0) \in C$ be an arbitrary point on C, we have Eq. 3:

$$d_x(x_0, y_0) = \lim_{x \to x_0} \frac{y - y_0}{x - x_0}; (x, y) \in C \quad (3)$$

If $dx(x_0, y_0) = 0$ or does not exist then (x_0, y_0) is an extreme point. Now to finding absolute maximum and minimum points it is sufficient to search between these extreme points and find extreme points with max. and min. y values. Similarly, we can find absolute max. and min. points along x-direction. These four points (absolute max. and min. points along x, y-directions) help us to find virtual vertices and generation of orthographic views. For example in Fig. 3 for points A, B, C, d_x does not exists and for other named points $d_x = 0$, so by searching between these points, we can find out that, I and E are absolute max. and min. points along y-direction and F and D are absolute max. and min. points along x-direction.

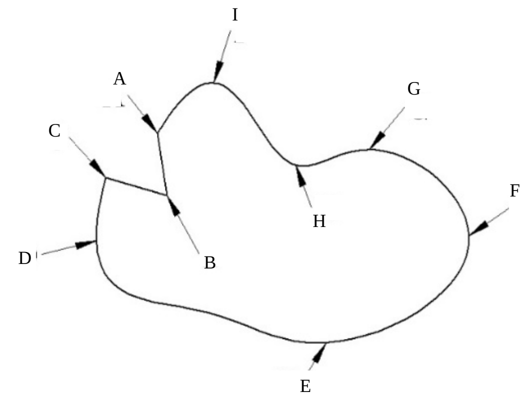

Fig. 3: A closed loop with extreme points

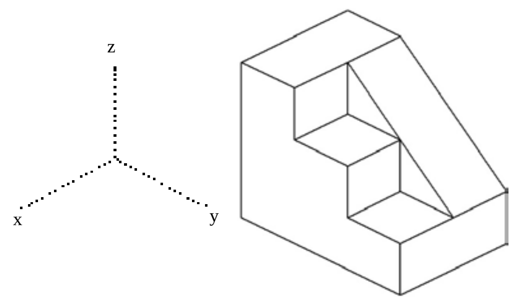

Fig. 4: An example of a 3D object which we want to generate its orthographic views

Generating orthographic views from a 3D object: Assume that, V is a set of outer surface points of a 3D object such as Fig. 4. (Pay attention to this fact that V does not contain inner points of mentioned object). We want to generate orthographic view of this object on xy plane.

Plot some planes parallel to xz and yz planes until intersect V. First discuss parallel to xz planes. Assume that y_{max} and y_{min} be absolute max. and min. points along y-direction. Define Eq. 4 and 5:

$$plan_{xz}(y_0) = \{(x, y_{0,z}) \mid x, z \in R\} \quad (4)$$

$$S_{xz}(y_0) = V \cap plan_{xz}(y_0) \quad (5)$$

For example Fig. 5 $plan_{xz}(y_0)$ which is parallel to xz intersects the object. Based on mentioned definition, shown close loop is $S_{xz}(y_0)$. It is clear that for

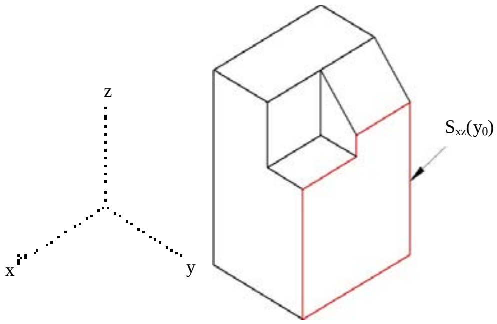

Fig. 5: $Plan_{xz}(y_0)$ which is parallel to xz intersects the object. Shown closed loop is $S_{xz}(y_0)$

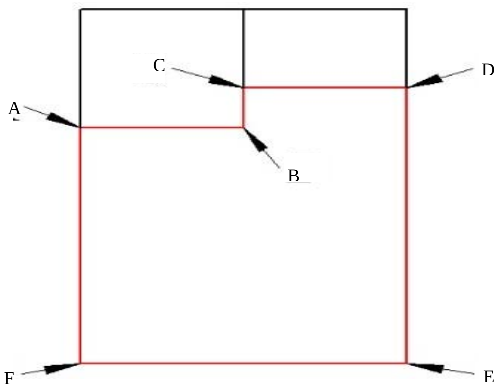

Fig. 6: Real vertices and absolute max. and min. points of $S_{xz}(y_0)$

different y'_0s, $S_{xz}(y_0)$ is null set or a closed loop. Based on mentioned algorithm, find real and virtual vertices of $S_{xz}(y_0)$ and then absolute max. and min. points along x-direction. For example in Fig. 6, named points are real vertices and points over AF and DE lines are absolute max. and min. points of $S_{xz}(y_0)$ along x-direction. Real and virtual vertices are stored in a set named as $D(S_{xz}(y_0))$. Now, project the points of set $D(S_{xz}(y_0))$ on xy plane. We have Eq. 6:

$$R(S_{xz}(y_0)) = \{(x, y_{0,0}) \mid \exists z \in R; (x, y_{0,z}) \in D(S_{xz}(y_0))\} \quad (6)$$

When points of set $R(S_{xz}(y_0))$ are projections of points of set $D(S_{xz}(y_0))$ on xy plane. For example, in Fig. 7, set $R(S_{xz}(y_0))$ only contains three points R_1, R_2 and R_3. If y_0 varies from y_{min} to y_{max}, a part of orthographic view of 3D object on xy plane obtained. So, we will have Eq. 7:

$$A_{xz}(V, xy) = \bigcup_{y=y_{min}}^{y_{max}} R(S_{xz}(y)) \quad (7)$$

When $A_{xz}(V, xy)$ is a part of orthographic view of V object on xy plane. For example, in Fig. 8, the lines plotted on horizontal plane (xy plane) are points of set $A_{xz}(V, xy)$. Similarly, we can plot some planes parallel to yz plane, find their intersection with V and obtain points of set $A_{yz}(V, xy)$. For example, in Fig. 9 the lines plotted on horizontal plane (xy plane) are points of set $A_{yz}(V, xy)$. So, we define Eq. 8:

$$Plot_{xy}(V) = A_{xz}(V, xy) \cup A_{yz}(V, xy) \quad (8)$$

In fact, as we can see in Fig. 10, $Plot_{xy}(V)$ is orthographic view of 3D object V on xy plane.

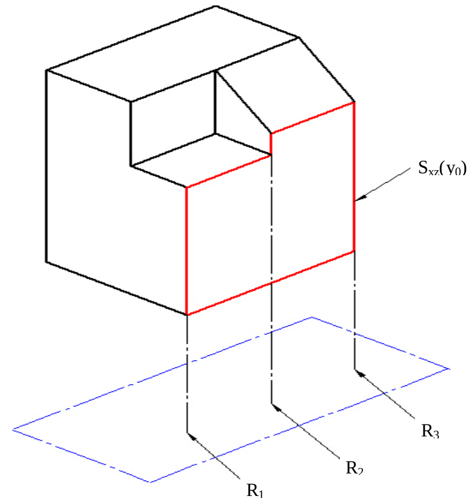

Fig. 7: Set $R(S_{xz}(y_0))$ as projection of $D(S_{xz}(y_0))$ only contains three points R_1-R_3

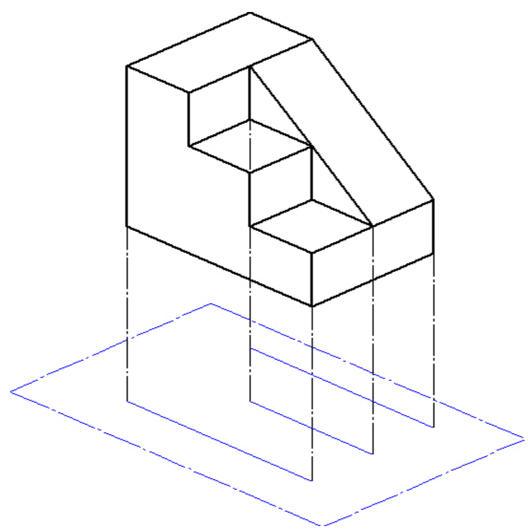

Fig. 8: An example; the lines plotted on horizontal plane (xy plane) are points of set $A_{xz}(V, xy)$

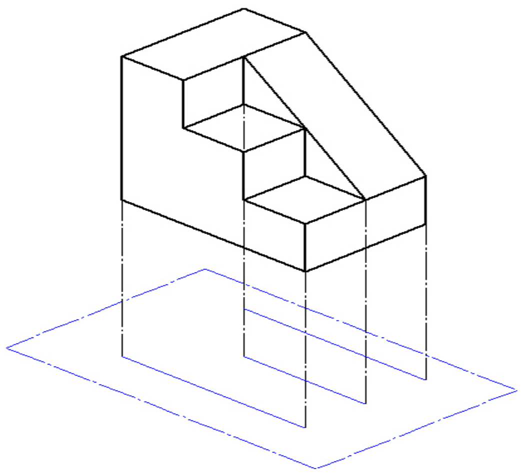

Fig. 9: An example the lines plotted on horizontal plane (xy plane) are points of set $A_{yz}(V, xy)$

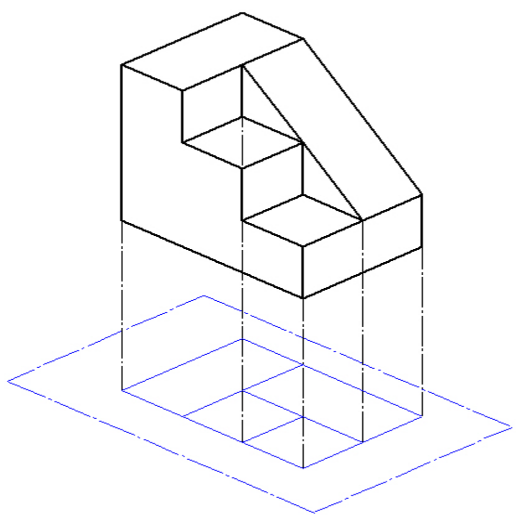

Fig. 10: $Plot_{xy}(V)$ as orthographic view of 3D object V on xy plane

RESULTS AND DISCUSSION

Reconstructing 3D solution object: Now, return to our main problem. Assume that two orthographic views of a 3D objects are given and requested to obtain its 3D shape. First, based on mentioned extrude definition, find outer pattern of each view, fill its inner surface with points and call it as S. Then extrude S of each view to intersect each other and find their subscription volume. Call obtained volume as V. For example, Fig. 11 shows the result volume with two given orthographic views. As we can see the result volume V is not true expected volume and needs to be repaired.

To repair this volume, in each view, all remained points except outer patterns (if exist) should be extruded

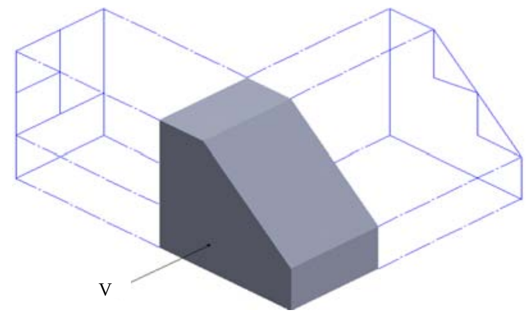

Fig. 11: Result volume with two given orthographic views

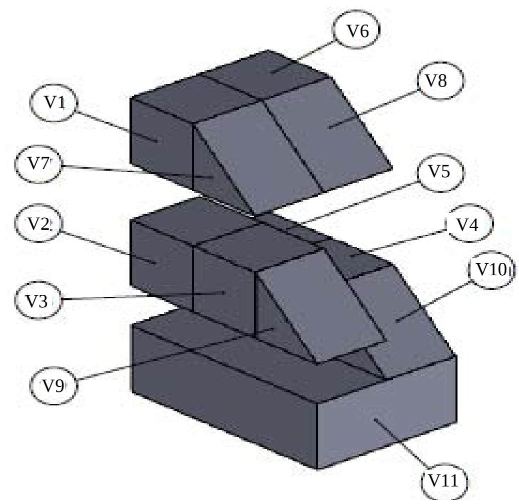

Fig. 12: The volume V, fractionalized into smaller volumes

as mentioned and form some additional planes. It is clear that these planes fractionalize obtained volume V into volumes V_1, V_2,...and V_N. For example, as shown in Fig. 12 the volume V of Fig. 11, fractionalized into smaller volumes of V_1, V_2...and V_{11}.

We know that to repairing volume V, some of volumes V_i, should be eliminated. So, define set of all volumes as V_t = {V_1, V_2,...and V_N. Now, define A_j as a subset of V_t and $V(A_i)$ as Eq. 9 below:

$$V(A_i) = \cup V_{j \in Ai} V_j \tag{9}$$

Based on mentioned algorithm, generate orthographic views of resulted $V(A_i)$ and compare them with given orthographic views. Now, define R_i as Eq.10:

$$R_i = \begin{cases} 1 & \text{complete conformithy between} \\ & \text{orthographic views} \\ 0 & \text{existance of any nonconformity} \\ & \text{between orthographic views} \end{cases} \tag{10}$$

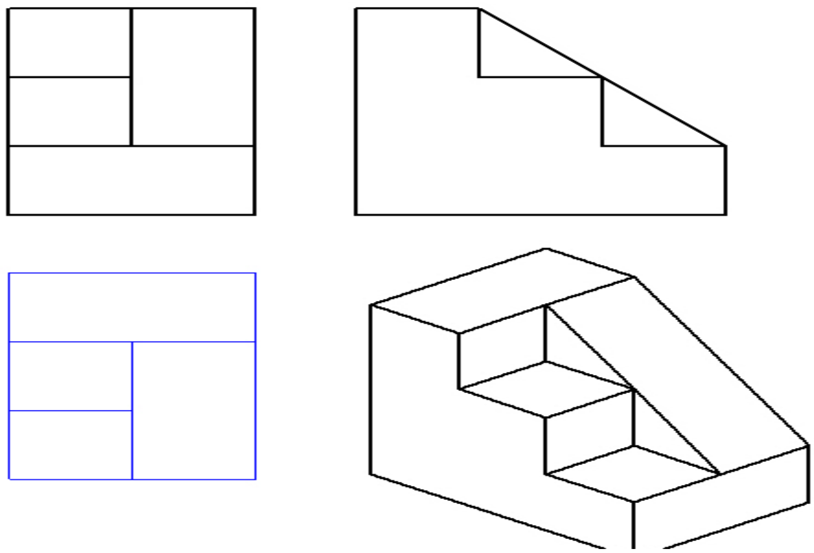

Fig. 13: Desired result obtained for A_4 when $R_1 = R_2 = 1$ or $R(V(A_4)) = 1$

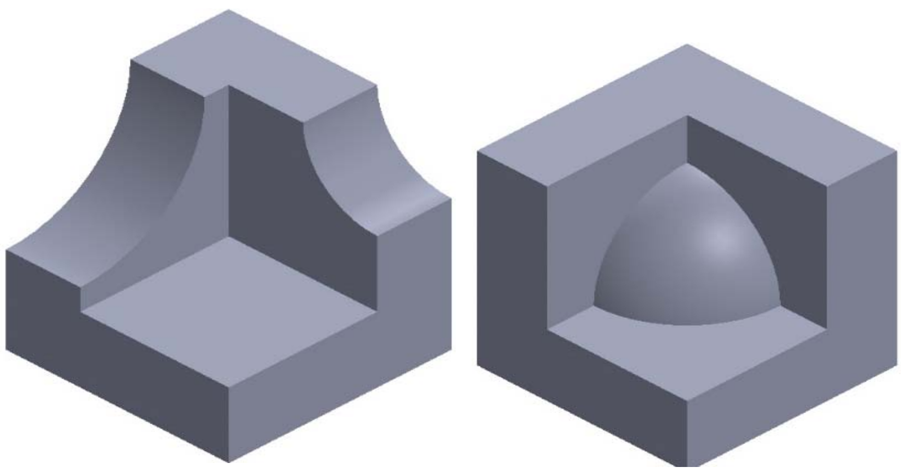

Fig. 14: Examples of some volumes which can be analyzed by proposed algorithm

And then define Eq. 11:

$$R(V(A_i))=R_1.R_2 \tag{11}$$

So, if any nonconformity between views, exists, R_1 or R_2 becomes 0 and then $R(V(A_i)) = 0$. Therefore, we can say our desired result obtained when $R_1 = R_2 = 1$ or $R(V(A_i)) = 1$. We are sure that there is one A_i so our desired volume earned, so we can say as shown in Eq. 12:

$$\exists \quad 1 \leq i \leq 2^N; R(V(A_i)) = 1 \tag{12}$$

It is clear that if A_i for example A_4 defined as Eq. 13 following:

$$A_4 = \{V_1, V_2, V_3, V_4, V_5, V_6, V_7, V_8, V_{10}, V_{11}\} \tag{13}$$

Then we will have our desired volume as shown in Fig. 13. Pay attention to this fact that mentioned algorithm satisfies for curved volumes too for example, sphere which its surfaces analyzed based on virtual vertices. Examples of some other volumes which can be analyzed by this algorithm, shown in Fig. 14.

The principal weakness of proposed algorithm is that, inner holes cannot be identified or hidden lines in orthographic views cannot be recognized. Example of 3D object which cannot be analyzed by mentioned method is shown in Fig. 15. To better perception, all steps of proposed algorithm are shown in Fig. 16 as a flowchart.

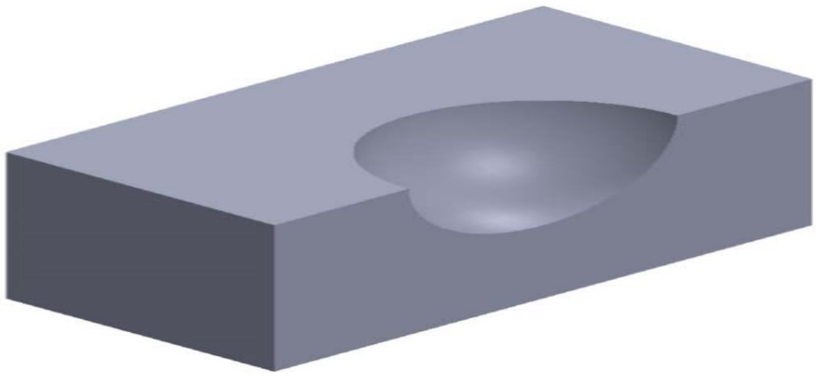

Fig. 15: Example of some volume which cannot be analyzed by proposed algorithm

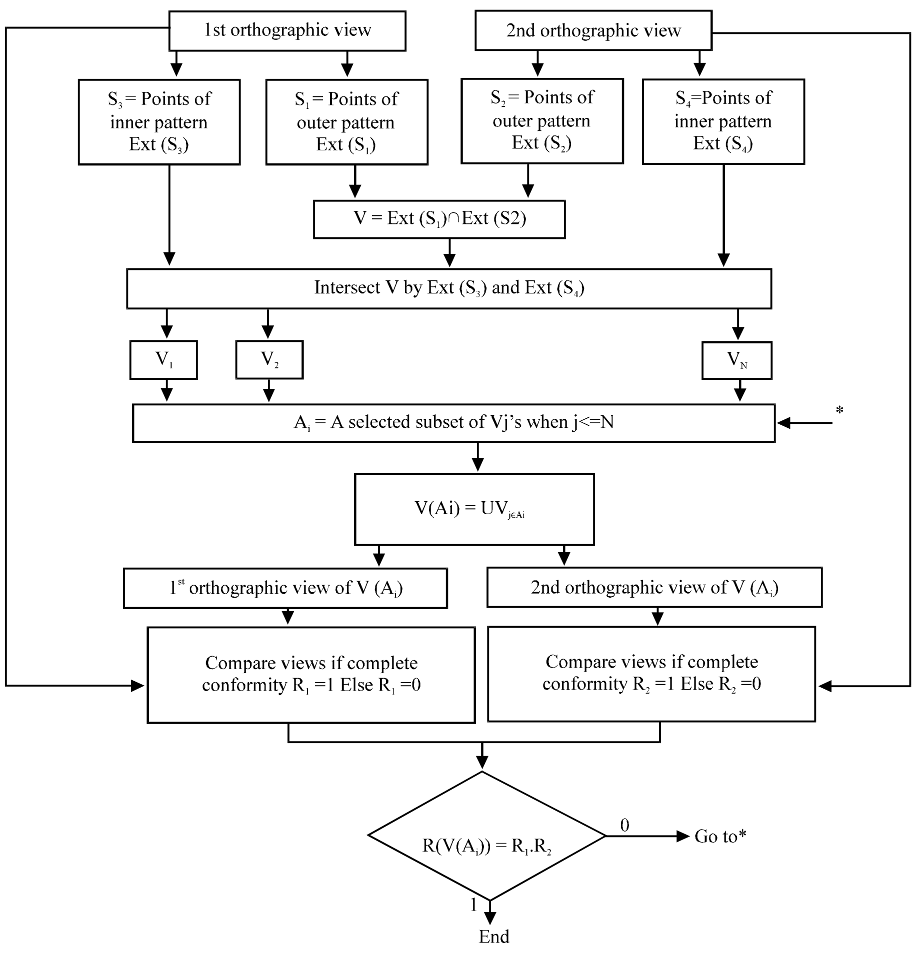

Fig. 16: All steps of proposed algorithm as a flowchart

CONCLUSION

Based on mentioned above and represented algorithm, we can say that, proposed method can cover some of weaknesses of CSG approach which is its limited domain because it can analyze non-geometric curved objects when previous methods only can analyze volumes which are obtained by extrude and revolve such as planar, cylindrical, conic, spherical and toroid shapes. So, this is a gait forward for CSG.

The other point is that this algorithm surely has an answer which has no vagueness. Of course, this is one of properties of CSG approach unlike B-Rep. The main weakness of this method is that, cannot analyze objects with inner holes or hidden lines in orthographic views which should be resolved in future works. Also, the other disadvantage of proposed algorithm is abound of calculations which regarding to usual today processors cannot be a serious problem.

REFERENCES

Aldefeld, B., 1983. On automatic recognition of 3D structures from 2D representations. Comput. Aided Des., 15: 59-64.

Cicek, A. and M. Gulesýn, 2004. Reconstruction of 3D models from 2D orthographic views using solid extrusion and revolution. J. Mater. Process. Technol., 152: 291-298.

Fu, Z.G., B.J. Zou, Y.M. Chen, L. Wu and Y. Shen, 2010. Reconstruction of intersecting curved solids from 2D orthographic views. Comput. Aided Des., 42: 841-846.

Gorgani, H.H., 2016a. Improvements in teaching projection theory using failure mode and effects analysis (FMEA). J. Eng. Appl. Sci., 100: 7-42.

Gorgani, H.H., 2016b. Innovative conceptual design on a tracked robot using TRIZ method for passing narrow obstacles. Indian J. Sci. Technol., Vol. 9, 10.17485/ijst/2016/v9i7/87857

Hwang, H.J., S. Han and Y.D. Kim, 2004. Mapping 2D midship drawings into a 3D ship hull model based on STEP AP218. Comput. Aided Des., 36: 537-547.

Idesawa, M., 1973. A system to generate a solid figure from three view. Bull. JSME., 16: 216-225.

Kuo, M.H., 1998. Reconstruction of quadric surface solids from three-view engineering drawings. Comput. Aided Des., 30: 517-527.

Lee, H. and S. Han, 2005. Reconstruction of 3D interacting solids of revolution from 2D orthographic views. Comput. Aided Des., 37: 1388-1398.

Lee, H.M. and S.H. Han, 2001. 2D design feature recognition using expert system (in Korea). J. Soc. CAD-CAM Eng., 6: 133-139.

Liu, S.X., S.M. Hu, Y.J. Chen and J.G. Sun, 2001. Reconstruction of curved solids from engineering drawings. Comput. Aided Des., 33: 1059-1072.

Nagendra, I.V. and U.G. Gujar, 1988. 3-D objects from 2-D orthographic views-A survey. Comput. Graphics, 12: 111-114.

Preiss, K., 1981. Algorithms for automatic conversion of a 3-view drawing of a plane-faced part to the 3-D representation. Comput. Ind., 2: 133-139.

Sakurai, H. and D.C. Gossard, 1983. Solid model input through orthographic views. Proceedings of the 10th Annual Conference on Computer Graphics and Interactive Techniques, July 3, 1983, ACM, New York, USA., ISBN:0-89791-109-1, pp: 243-252.

Shin, B.S. and Y.G. Shin, 1998. Fast 3D solid model reconstruction from orthographic views. Comput. Aided Des., 30: 63-76.

Shum, S.S., W.S. Lau, M.M. Yuen and K.M. Yu, 1997. Solid reconstruction from orthographic opaque views using incremental extrusion. Comput. Graphics, 21: 787-800.

Shum, S.S., W.S. Lau, M.M.F. Yuen and K.M. Yu, 2001. Solid reconstruction from orthographic views using 2-stage extrusion. Comput. Aided Des., 33: 91-102.

Soni, S. and B. Gurumoorthy, 2003. Handling solids of revolution in volume-based construction of solid models from orthographic views. J. Comput. Inf. Sci. Eng., 3: 250-259.

Wang, Z. and M. Latif, 2007. Reconstruction of 3D solid models using fuzzy logic recognition. Proceedings of the World Congress on Engineering, July 2-4, 2007, WCE, London, UK., ISBN:978-988-98671-5-7, pp: 37-42.

Wesley, M.A. and G. Markowsky, 1981. Fleshing out projections. IBM J. Res. Dev., 25: 934-954.

Yan, Q.W., C.P. Chen and Z. Tang, 1994. Efficient algorithm for the reconstruction of 3D objects from orthographic projections. Comput. Aided Des., 26: 699-717.