

# AUTO-RECOGNITION OF CHAMFER FEATURES BY RULE BASED METHOD AND AUTO-GENERATION OF DELTA VOLUME

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**ABSTRACT:** Integration of computer aided process planning (CAPP) in CAD/CAM contributes to a successful product manufacturing and to achieve an automated process planning, auto-recognition of chamfer features of a product is necessary. An effort has been made (i) to automatically recognize the chamfer features of regular form and freeform computer aided design (CAD) models using rule based method and (ii) to auto-generate delta volume (DV) from stock model. Based on the conditions described the chamfer features of an input CAD model are successfully recognized and delta volume required to be machined in chamfering process is obtained from stock model.

**KEYWORDS:** *Regular Form; Freeform; Delta Volume; Chamfer Feature; Stock Model*

## 1.0 INTRODUCTION

The gap between computer-aided design (CAD) and computer-aided manufacturing (CAM) is filled by computer-aided process planning (CAPP) and methods such as knowledge based, genetic algorithm, feature-based, STEP compliant, neural network and internet-based method are major used in CAPP [1]. Automatic feature recognition integrates CAPP with CAD/CAM and following are the three methods of feature recognition applied by researchers.

## **1.1 Rule based method**

The elements of B-rep and attributes of a feature (such as depression, protrusion) were used to define a feature and rules applied to recognize features were simple, easy to implement and faster recognition, but the method failed to recognize intersecting features [2]. A review on rule based method for automated feature recognition explores contemporary recognition systems mainly dealt with orthogonal features and little attention was given to non-orthogonal features [3].

Surface based feature recognition approach was applied to recognize the geometric features of a freeform surface. The developed algorithm was implemented in a prototype system to recognize geometric features and the prototype system successfully recognized geometric features of cell-phone, automobile parts, cranks and monitors. The limitation of proposed approach is the part's orientation must be optimized before commencement of feature recognition [4]. Authors developed hybrid algorithm based on edge based and region based approaches to initially region segment the STL (Stereo Lithography) format of CAD model and then rule based technique was developed to recognize freeform features. Rules applied based on region geometry and region adjacency relationship successfully recognized holes, darts, dents, louvers, bends, dimples, and beads but needs user interaction in detecting complex freeform parts [5]. Authors applied equilibrium and concavity methods to recognize intermediate workpiece's roughing features. Features originated from convex inner loop were recognized by equilibrium method while concavity of edges, faces and vertices were used to recognize features by concavity method. But interaction between them but failed to preserve it. The faces of intermediate workpiece were compared with the faces of blank and faces that did not coincide were looked into for chamfer features using rule based method [6]. Edge boundary technique (EBC) was developed to recognize cylindrical and conical based features from B-rep models [7]. Authors developed slicing method to recognize 2.5D features in which the two sliced profiles of a workpiece were matched each other to recognize 2.5D features [8].

## **1.2 Hint based method**

Hint based method was applied to recognize machining features of 2.5D parts by generating delta volume. Concave cylindrical face subtending angles of concave faces of 2.5D part were used as hint to recognize linear slot, circular slot, hole, and pocket. The feature recognition is limited to parts entirely made of planar and cylindrical faces only [9]. Authors applied graph based method to generate AAG (attributed adjacency graph) and then decomposed the generated AAG to obtain concave sub-graphs which were used to recognize interacting features such as hole, slot [10].

## **1.3 Volume decomposition method**

Feature recognition method that can handle issues like multiple feature interpretations and lack of scalability very well was developed. Firstly, delta volume was obtained by subtracting the part model in stock model and then so obtained delta volume was decomposed to recognize machining features. The time taken to decompose the delta volume of a part model is higher if the part model has more feature intersections [11]. Authors developed algorithm to recognize regular form, freeform faces and generated material removal volume for finishing, roughing processes. All form faces were fully recognized but the amount of material removal volume generated by algorithm is greater when compared to material removal volume obtained by manual calculation [12]. A hybrid method, included of face pattern-based approach and volume decomposition method was developed to recognize features of cast then machined parts. The method recognized interacting and non-interacting features [13]. Volume decomposition method was applied to recognize machining features of cuboid and cylindrical shaped parts. The surfaces of delta volume obtained by volume decomposition were identified as open surface and closed surface, and a machining feature was identified based on the number of open and closed surfaces present in delta volume [14].

Literature review reveals feature recognition of machining features is performed using rule based, hint based and volume decomposition methods. Research works performed above either reflects only on feature recognition of regular form surface features or on feature

recognition of freeform surface features. Feature recognition of both regular form and freeform surface features under one research work is lacking, so an effort is made here to recognize chamfer features of both regular form, freeform surfaces and generate delta volume.

## 2.0 METHODOLOGY

The flow adopted by algorithm to recognize regular form, freeform faces and their chamfer edges is shown in Figure 1.

### 2.1 Part model

The input part model must be solid body with 2-manifold boundary and its file format extension must be of a CAD modeller file format. The delta volume is obtained from stock model and the dimensions of input part model are used by algorithm to develop stock model.

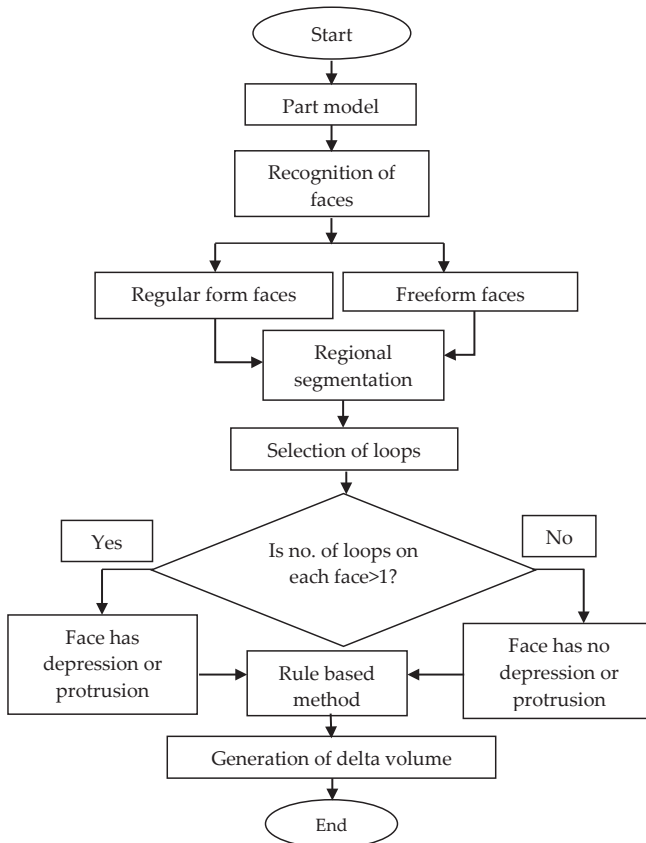


Figure 1: Flow chart of algorithm for recognition of chamfer edges and generation of delta volume

## **2.2 Recognition of regular form and freeform face**

Faces are the subset of a surface and joining of these surfaces together makes a part model (Figure 2). The surface recognition approach recognizes a part model face by face based on their geometrical shapes using geometrical evaluation application programming interface (API) functions. Each face of part model (Figure 2(a) & 2(b)) is evaluated and face entity having geometrical shape of 3D B-spline surface or curve or NURBS (Non-Uniform Rational Basis Spline) patch is separated from the face entity having geometrical shape of plane, cone, sphere, and torus.

## **2.3 Regional segmentation**

Each face's mid position is found by obtaining face parameter and then face's normal vector at the mid position is obtained. Based on the so obtained normal vector direction regional segmentation of the face is performed [15]. Two regions into which all the regular form and freeform faces are segmented are (i) top (ii) bottom. A face is segmented to top region if its normal vector in Z direction is greater than 1 and if its normal vector in Z direction is less than 1 then the face is segmented to bottom region.

## **2.4 Selection of loops**

A loop consists of one or more co-edges and is used to bind a face. A face may have more than one loop and so each regular form and freeform face are classified into regular form and freeform face without depression or protrusion, regular form and freeform face with depression or protrusion based on the following conditions (i)  $2 > N > 0$ ; (ii)  $\infty > N > 1$ ; 'N' is number of loops on the face, and face (F3) without depression or protrusion (Figure 2(a)) satisfies first condition since it contains only one loop. Faces (F1 & F2) with depression and protrusion respectively (Figure 2(a)) satisfy second condition since they do have more than one number of loops. Once number of loops is selected, algorithm identifies number of edges (E1, E2, E3, E4, E5 ... and En, where  $n = 1,2,3,4,\dots$ ) on the face.

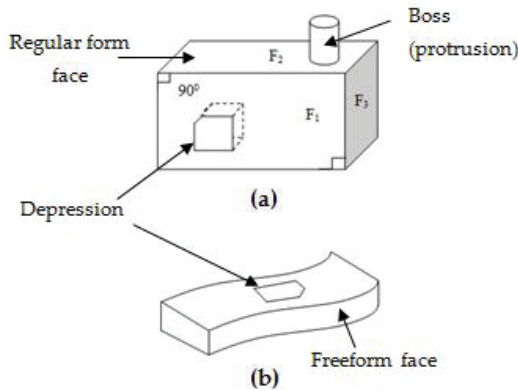


Figure 2: Geometric shapes, (a) Regular form rectangular part model with cylindrical boss and pocket and (b) Freeform part model having regular form and freeform faces

## 2.5 Regular form and freeform faces with and without depression or protrusion

The face without depression or protrusion consists of only peripheral loop and no internal loops of void region and extruding volume exists within the peripheral loop, for example face  $F_3$  (Figure 2(a)). The face with depression or protrusion contains minimum one internal loop within its peripheral loop, for example faces  $F_1$  and  $F_2$  contain inner loop of depression and protrusion respectively. The surface recognition system will properly recognize the faces of a CAD model that are joined together with  $G_0$  continuity.

## 2.6 Chamfer edge

The face of a part model formed by chamfering of certain amount of material from stock model is called chamfered face. An edge belonging to chamfered face is called chamfer edge. Rule based method [2] is applied to identify the chamfer features, wherein the algorithm recognizes chamfer edges of a chamfered face. If  $n$  of  $E_n$  is less than 5 then face has no chamfer edges and if  $n$  of  $E_n$  is greater than or equal to 5 then face may contain chamfer edges. A regular form or freeform face is said to have chamfer edges (Figure 3) if it satisfy the following conditions [6]: (i) number of edges of a face is equal to or greater than five. (ii) the edge ( $E_2$ ) and its co-edges ( $E_1$  and  $E_3$ ) are straight; (iii) the length ' $A$ ' of co-edge ( $E_3$ ) is less than the length ' $L$ ' of edge ( $E_4$ ) and height ' $B$ ' of co-edge ( $E_1$ ) is less than the

height 'H' of edge (E5); (iv) the angle between edge (E2) and its co-edges (E1 and E3) is between 90° - 180°.

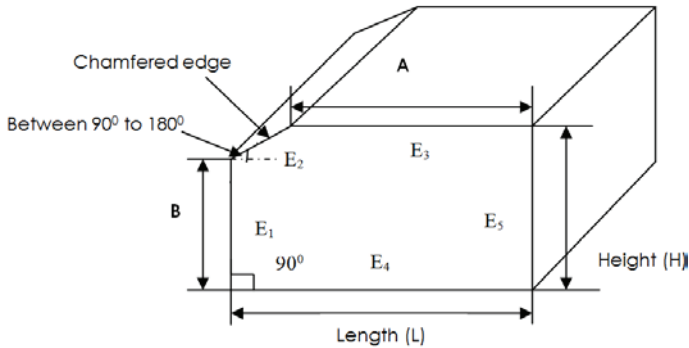


Figure 3: Regular form part model with chamfered edge (E2)

## 2.7 Delta volume

Delta volume (DV) derives machining features and is obtained by subtracting the part model volume (PV) from a cubic geometrical shaped stock model volume (SV) (Figure 4). The stock model volume without tolerances in x, y, z directions is called minimal stock model volume. The DV for a machining feature is obtained by Boolean subtracting the PV in SV (Equation 1) by applying Boolean subtraction API function by the algorithm.

The developed algorithm is implemented on a Solid modeller platform and Section 3 shows algorithm implementation on part model and the results obtained.

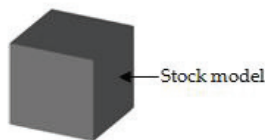


Figure 4: stock model

$$DV = (SV - PV) \quad (1)$$

### 3.0 RESULTS AND DISCUSION

#### 3.1 Case study 1

A chamfered regular form part model having depression and boss (Figure 5) is selected to test and validate the developed algorithm.

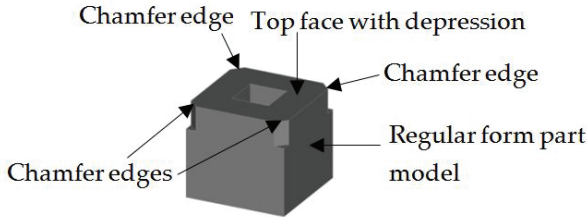


Figure 5: Isometric view of chamfered regular form part model with depression, boss

The developed algorithm recognizes all the 24 faces of input part model and segments each face to top and bottom regions based on their normal vector direction. Also recognizes chamfer edge(s) of face applying the rule base method. Results (Table 1) show that only top region regular form face [5] with depression has 4 chamfer edges.

Table 1: Auto-generated table show algorithm recognized chamfer edges of top face with depression

Regular form face with depression (top region)
Edge [0] is a CHAMFER
Face [5] has a chamfer edge and the edge number is [0]
Edge [2] is a CHAMFER
Face [5] has a chamfer edge and the edge number is [2]
Edge [4] is a CHAMFER
Face [5] has a chamfer edge and the edge number is [4]
Edge [6] is a CHAMFER
Face [5] has a chamfer edge and the edge number is [6]



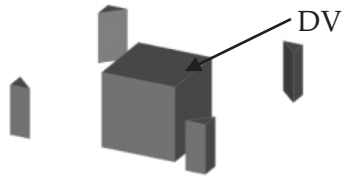


(a)

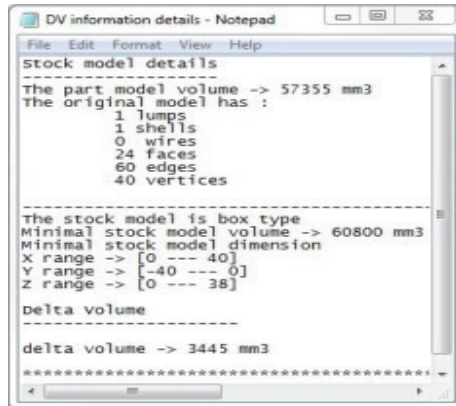
```
DV information details - Notepad
File Edit Format View Help
-----
stock model details
-----
The part model volume -> 57355 mm3
The original model has :
    1 lumps
    1 shells
    0 wires
    24 faces
    60 edges
    40 vertices
-----
The stock model is box type
Minimal stock model volume -> 60800 mm3
Minimal stock model dimension
X range -> [0 --- 40]
Y range -> [-40 --- 0]
Z range -> [0 --- 38]
-----
Delta volume
-----
delta volume -> 3445 mm3
-----
```

(b)

Delta volume for the input part model is obtained by subtracting part model volume from stock model volume (Figure 6(a)) using Boolean subtraction API function. The algorithm generated details of input part model and delta volume is shown in .TXT format file (Figure 6(b)).



(a)



(b)

Figure 6: (a) Algorithm generated delta volume and (b) Auto-generated details of input part model and delta volume

Firstly faces are recognized and separated into regular form faces, freeform faces, and then faces are segmented into top and bottom regions. Results (Table 1) show top region face [5] has a depression and consists of 4 chamfer edges having edge numbers [0], [2], [4], [6]. The DV is obtained by Boolean subtraction of PV from SV and Figure 6(b) display the numerical values of PV, SV, DV generated by the algorithm in .TXT file format.

### 3.2 Case study 2

A freeform part model having no depression and protrusion (Figure 7) is considered to test and validate the developed algorithm.

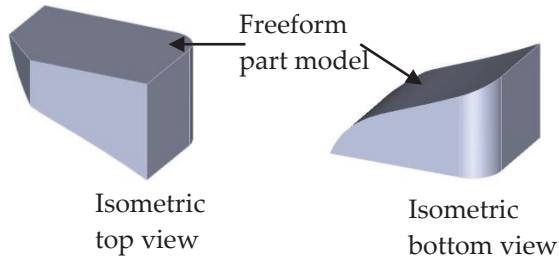


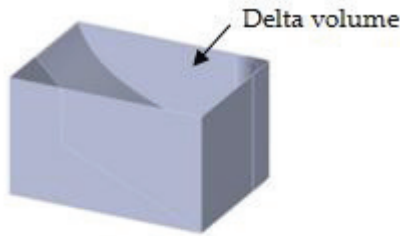
Figure 7: Isometric views of freeform part model [10]

All the 8 faces of input part model are recognized by the algorithm and each face segmented into top and bottom regions based on their normal vector direction. Each top and bottom region contains single face without depression or protrusion. Table of Result show only top region face [4] has a chamfer edge (Table 2).

Table 2: Algorithm generated table of result show the recognized top region face has chamfer edge

Regular form face without depression or protrusion (top region)
Edge [4] is a CHAMFER
Face [4] has a chamfer edge and the edge number is [4]

Subtraction of part model volume in stock model volume gives delta volume (Figure 8(a)), and detail of input part model and delta volume is shown in .TXT format file (Figure 8(b)).



(a)



(b)

Figure 8: (a) Algorithm generated delta volume (b) Details of input part model and delta volume

Firstly the algorithm recognizes and separates faces into regular form faces, freeform faces, and then faces are segmented into top and bottom regions. Results (Table 2) show top region face [4] has no depression or protrusion and contain a chamfer edge having edge number [4]. The DV is obtained by Boolean subtraction of PV from SV and Figure 8(b) displays the numerical values of PV, SV, DV generated by the algorithm in .TXT file format.

## 4.0 CONCLUSION

Compared to methods reviewed in section 1 the developed algorithm is simpler, successfully recognizes and segments each face of an input part model into top and bottom regions based on their normal vector direction. Novelty is, by the application of rule based method the algorithm can recognize chamfer edges of a regular form and freeform face. A face edge satisfying all four rule based conditions was concluded to be a chamfer edge. Generation of delta volume gives necessary information on amount of material to be machined (Figures 6(b) & 8(b)) to obtain the machining features.

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