Identification of Freeform Depression Feature in a Part Using Vertex Attributes From Feature Volume

Pramod S Kataraki[a],
*Mohd Salman Abu Mansor[b,]**

[a, b] School of Mechanical Engineering, Engineering Campus, Universiti Sains Malaysia, Seri Ampangan, 14300 Nibong Tebal, Seberang Perai Selatan, Pulau Pinang, Malaysia
**Corresponding author.*
Telephone number: +604-5996385. Fax: +604-5996912.

**E-mail address: mesalman@usm.my*

ABSTRACT

The depression features can be of regular form shape (such as planar, cylindrical) or freeform shape (such as spline) and are found in parts of automotive, ships, aeroplanes like any other protrusion features. Recognition of features by methods like volume decomposition method, hybrid method (face pattern approach and volumetric decomposition method) and attribute based method has been applied in past research works to recognize regular form features of a part. The past research works also express about successful application of volume decomposition method to generate delta volume and recognize regular form volumetric features and application of attribute based method to recognize regular form features like hole, boss present in a cube while the research work on recognition of freeform depression features of a part is found to be inadequate. In this paper an effort is made to develop an algorithm that can recognize freeform depression feature of a part of any form by using vertex attributes of feature volume. First, the algorithm quantifies input part model's volume and identifies the faces having depression feature. Second, the inner loop of each face having depression feature is covered by generating a new face. Third, a lofting operation is performed between new faces to generate feature volume for the depression feature and fourth, the algorithm utilizes vertex attributes of feature volume to recognize feature type. The results obtained in .SAT file format show the algorithm generated feature

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volume, feature type and results obtained in .TXT file format show the quantitative values of features volume.

Keywords: *Freeform, Volume, Hole, Pocket.*

1. Introduction

The computer-aided design (CAD) and computer-aided manufacturing (CAM) are integrated by computer-aided process planning (CAPP). Automatic feature recognition play vital role in integrating CAPP with CAD/CAM. The methods applied in CAPP are feature-based, STEP compliant, knowledge based, genetic algorithm, internet-based method and neural networks [1]. The features of a part can be of regular form or freeform shape and feature obtained by performing operations (like forming, bending, beading, folding, louver) on a surface is called surface based feature for e.g., ridge, bump and peak [2] while feature obtained by part volume addition or subtraction on a surface is called volumetric feature e.g., hole, boss, pocket [3]. Author defined the single setup machinable feature volumes as maximal features and the volume resulting from the subtraction of part model from stock model, as delta volume. Decomposed the delta volume into large and simple maximal volumes and then transformed maximal volumes into maximal features, by using newly developed recursive maximal volume decomposition method. The recursive method consumes more time to decompose parts having feature intersections, and conversion of un-machinable maximal volumes into maximal volumes leads to generation of extra (unwanted) volume [4]. Developed hybrid feature recognition method (face pattern approach and volumetric decomposition method) to recognize non-interacting parts and interacting features respectively and algorithm developed is used only for cast-then-machined parts [5]. Author developed an algorithm to recognize parts of regular and freeform surfaces. The method recognized all forms of surfaces and also generated material removal volume for the finishing process, roughing process. But the material removal volume of finishing process bears discontinuity between them and the percentage error obtained is greater than 1% [6]. An algorithm was developed to automatically recognize non intersecting machining features directly from 2D CAD input instead of 2D to 3D model conversion for feature recognition. Methods were developed to determine the attributes of both isolated and non-isolated features. The developed algorithms are much simpler than the existing feature recognition algorithms that operate directly on 3D inputs [7]. An indirect extraction approach was applied to identify the lost design features and feature-related information of a CAD model from a data exchanged part model. Feature taxonomy was proposed based on the feature geometry and topological characteristics, from which design features were identified. The design features were classified into form features (convex, concave) and transitional features (generated by trimming and blending edges). The proposed approach is able to identify the lost design features and machining features from a data exchange part model. Simple and compound features can also be identified [8]. Developed an algorithm to detect the axis of cylindrical parts and rotate it as per user requirements to generate delta volumes, the work mainly concentrated on cylindrical parts [9]. Elements of B-rep and attributes of a feature were used to define a feature and rules that are simple, easy to implement and faster recognition were applied to recognize features. The method recognized boss or hole feature of a cube part only if total number of faces (TNOF) is equal to 8 [10]. Authors classified regular form features into (i) surface based features (ii) volumetric features, and further sub-classified volumetric based features into within faces, edge based and edge and vertex based features. Also regular form volumetric features of a part model were successfully recognized [11].

The literature review elaborates feature recognition of intersecting machining features, interacting features of cast-then-machined parts by applying algorithm, hybrid method respectively and also express about volume decomposition method and indirect extraction approach applied to recognize features of a part. But the methods applied concentrate on recognition of regular form features and recognition of surface based features. The work on recognition of depression features that are of freeform shape is scant and in the present paper a new approach is applied to generate feature volume for a feature and then vertex attributes of feature volume is used to recognize freeform depression feature of a part.

2. Technical definition

The technical definition of freeform depression feature of a part model is expressed in this section.

2.1 Depression feature

The depression made of spline edges and vertices is called freeform depression feature (Figure 1) and the freeform depression feature is classified into two types based on the number of vertices it has

(i) Two-vertex hole
(ii) Multi-vertex pocket

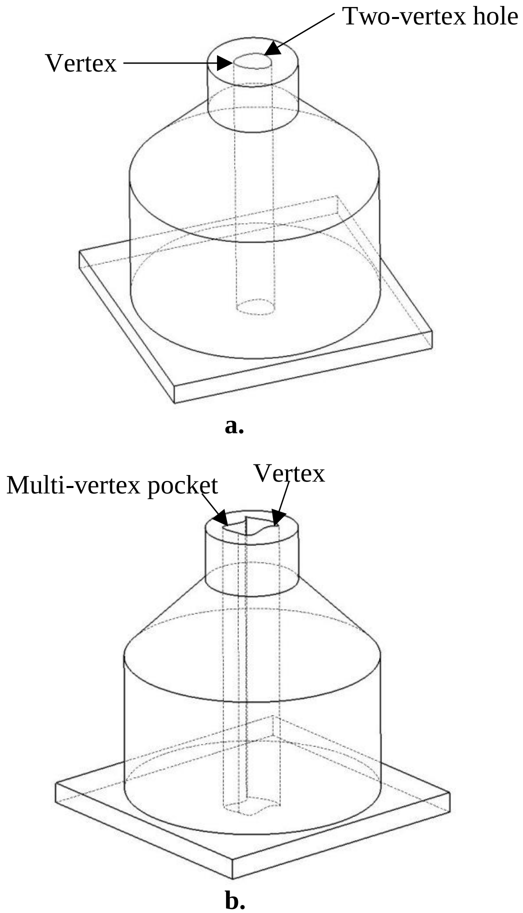


Figure 1: **a.** Part model having two-vertex hole **b.** Part model having multi-vertex pocket

2.2 Two-vertex hole and multi-vertex pocket feature

The freeform depression feature is said to be a two-vertex hole feature if it is made of only two vertices (Figure 1a) and a freeform depression feature is said to be a multi-vertex pocket feature if it is made of more than two vertices (Figure 1b).

Methodology

The steps followed by algorithm to recognize features of a part model are shown in flow chart below (Figure 2).

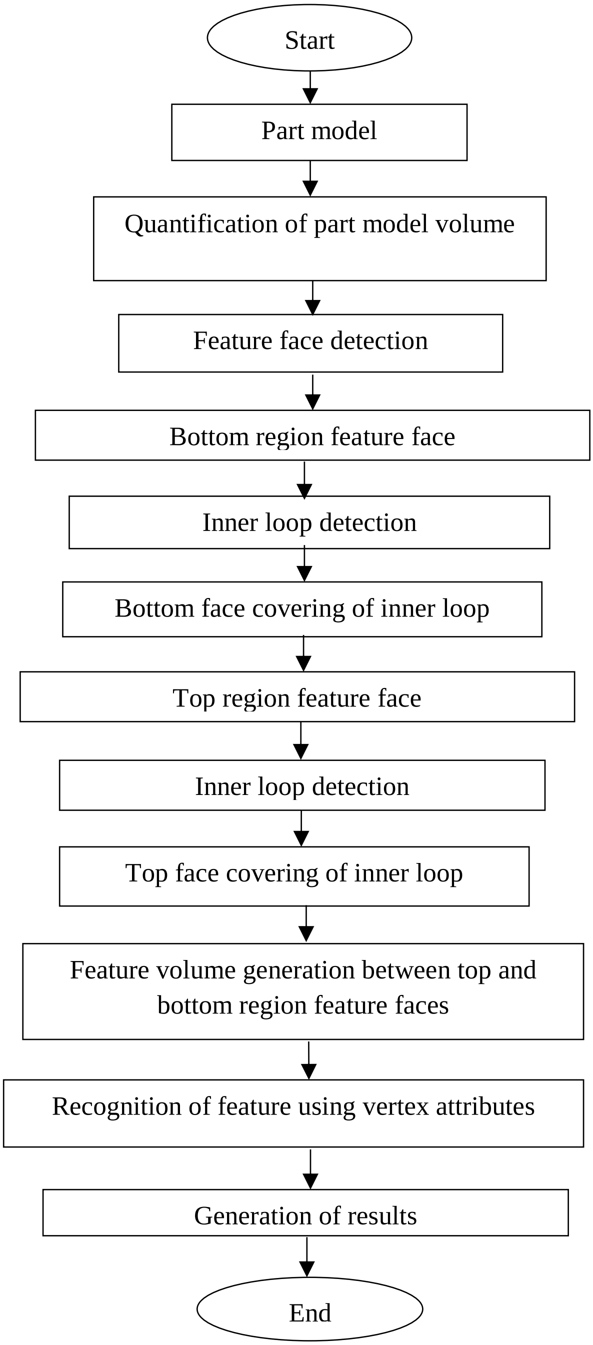


Figure 2: Flow chart of algorithm

2.3 Part model and quantification of its volume

The part input to algorithm is of B-rep CAD model containing attributes such as faces, edges, vertices. Figure 3 illustrates a part model represented with faces, edges, vertices and containing two-vertex hole feature. The algorithm quantifies volume of input part model which is shown in a .TXT file generated by algorithm.

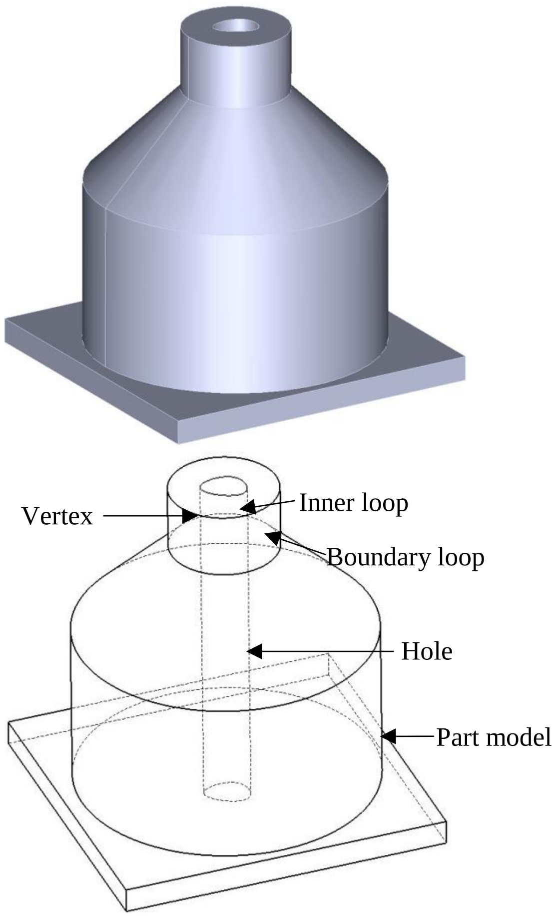


Figure 3: Part model with a two-vertex hole feature and its isometric drawing view

2.4 Feature face detection

The surface is a superset of faces and is formed by joining of set of faces. A part is formed by joining of these surfaces and the developed algorithm recognizes part face by face based on their geometrical shape. Faces having curve or NURBS patch or 3D B-spline surface are separated from the faces of cone, sphere, plane and torus geometrical shapes.

2.4.1 Top region feature face

The faces that form top surface of part model are detected by algorithm by identifying the face's normal vector direction at its midpoint. Figure 4 illustrates part model in a 3D space having x, y, z coordinates and normal vector of part model face pointing in z axis direction. The face is said to be in top region if its midpoint normal vector points in +z or +x or +y direction or a combination of any of these directions.

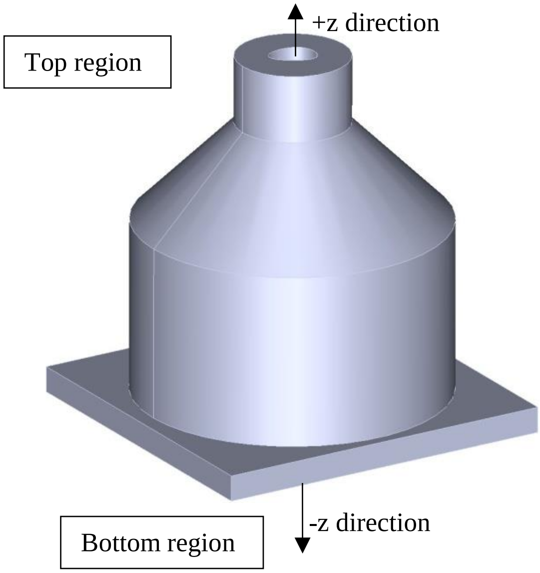


Figure 4: Part model with top and bottom region

2.4.2 Bottom region feature face

Similarly the faces that form bottom surface of part model are detected based on their normal vector direction at midpoint by the algorithm and a face is said to be in bottom region if its midpoint normal vector points in -z or -x or -y direction or a combination of any of these directions (Figure 4).

2.5 Inner loop detection

The face is bound by a boundary loop and in turn loop is made of one or more co-edges. Within the boundary loop an inner loop (Figure 3) may exist, for example if a part has depression or protrusion feature in it then the face containing this depression or protrusion feature will have inner loop within its boundary loop. The inner loop is identified by algorithm based on the following conditions

(i) $2 > N > 0$;
If the number of loops (N) on a face is always equal to 1 then the loop is identified as boundary loop and the face has no inner loop(s) (Table 1).

(ii) $\infty > N > 1$;
If the number of loops (N) on a face is equal to or greater than 2 then the face has both inner and boundary loops (Table 1).

Table 1: Conditions to identify inner loop

Number of loops (*N*)	**Conditions**	**Face without inner loop**	**Face with inner loop**
If $N = 1$	$2 > N > 0$	No inner loop	-
If $N >= 2$	$\infty > N > 1$	-	Inner loop

2.6 Face covering of inner loop

The inner loop of a face forms void region and needs to be covered by face, so the algorithm generates a face with same geometrical boundaries as that of inner loop and then covers the inner loop with the generated face. The face generated by algorithm covers the inner loop exactly and do not amalgamate with the adjacent faces.

2.7 Feature volume generation

The algorithm identifies the inner loop faces present in top and bottom region and generates feature volume between the identified faces by performing lofting operation. Figure 5 shows the algorithm generated feature volume for two-vertex hole feature of part model (shown in Figure 3).

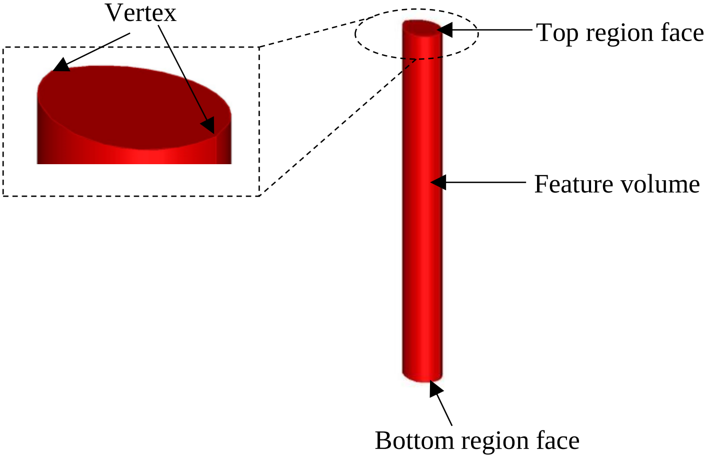


Figure 5: Feature volume for two-vertex hole

2.8 Recognition of feature using vertex attributes

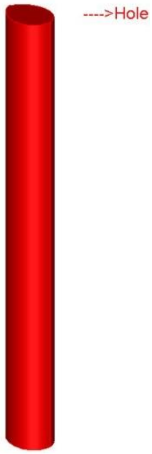
The algorithm identifies the feature type present in part model by recognizing the vertex attributes of face of feature volume obtained by lofting operation in the following ways

(i) If number of vertices of feature volume's face == 2;
Then feature type ∈ Two-vertex hole.

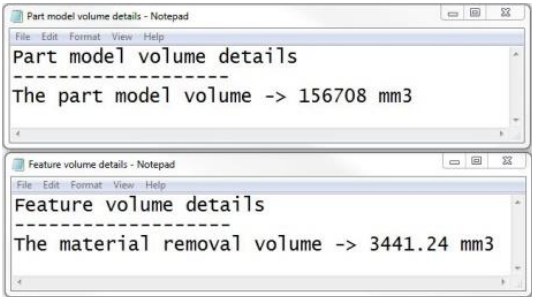
(ii) If number of vertices of feature volume's face >= 3;
Then feature type ∈ Multi-vertex pocket.

2.9 Generation of results

The algorithm generated feature volume and type of feature identification for two-vertex hole (Figure 6a) and multi-vertex pocket features are obtained in .SAT file format while the quantitative values indentified by algorithm are obtained in .TXT file format (Figure 6b).



a.



b.

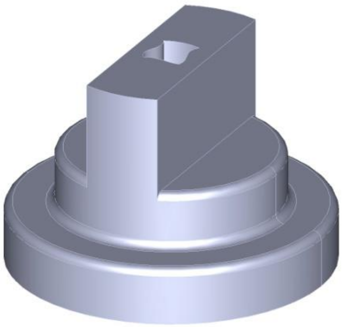
Figure 6: **a**. Feature volume and feature type **b**. Part model volume and two-vertex hole feature volume

4 Testing

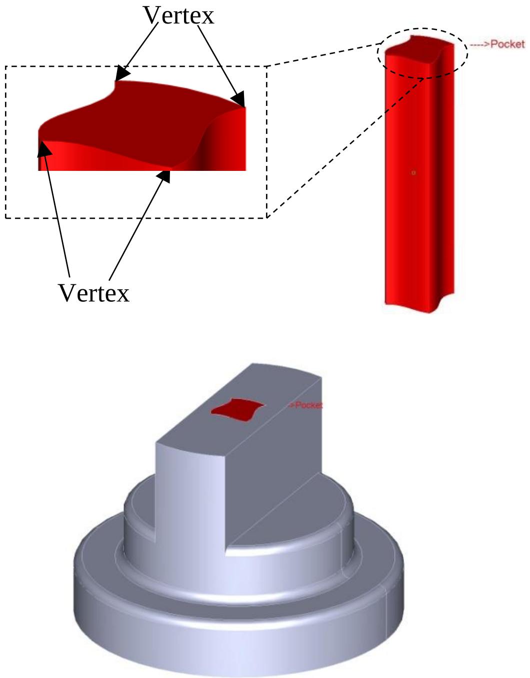
The developed algorithm is tested by input of two part models of different shapes in .SAT file format.

4.1 Example 1

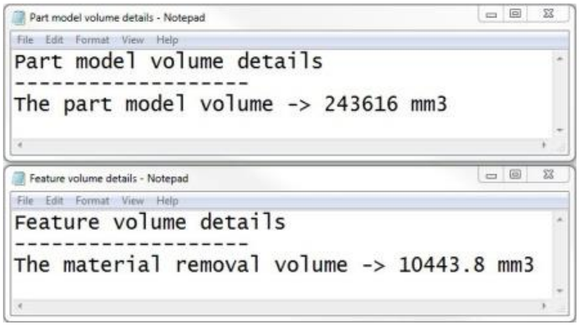
The part model with a multi-vertex pocket feature is considered to test the developed algorithm (Figure 7a). The algorithm recognized the face having inner loop and covered it by generating a face of same geometrical shape. The algorithm then generates feature volume for the feature and identifies feature type which is obtained in .SAT file format (Figure 7b). The .TXT file format show the feature volume, feature type, quantitative values of part model volume and feature volume (Figure 7c).



a.



b.

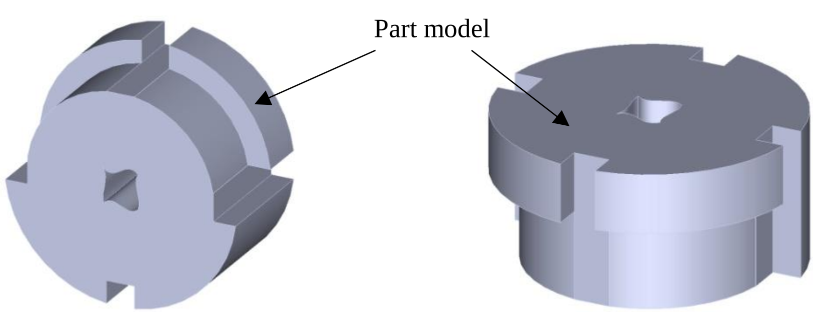


c.

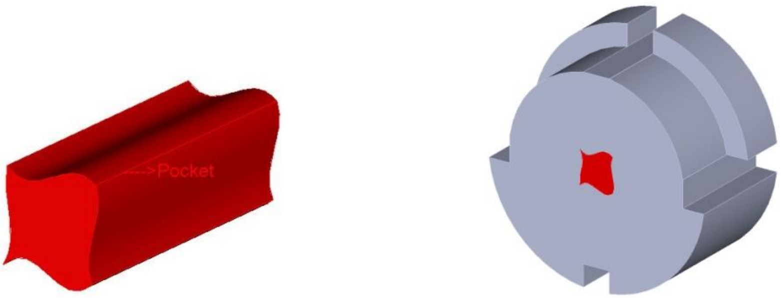
Figure 7: **a**. Part model **b**. Part model with feature volume **c**. Part model volume and multi-vertex pocket feature volume details

4.2 Example 2

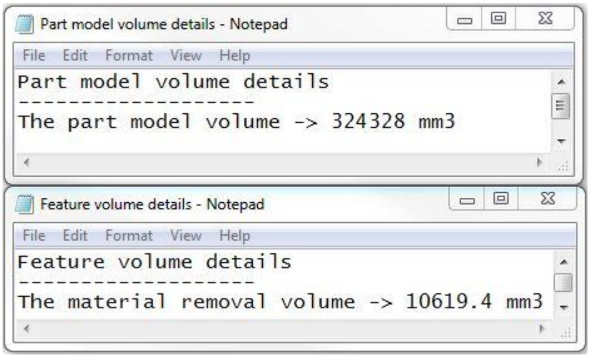
The part model considered to test the developed algorithm is taken from [12] and embedded with a multi-vertex pocket feature is (Figure 8a). The part model face having inner loop is identified by algorithm and a face is generated to cover the inner loop. Next, the algorithm generates feature volume for freeform multi-vertex pocket and identifies type of feature (Figure 8b). The quantitative values of part model and feature volume are generated by algorithm in .TXT file format (Figure 8c).



a.



b.



c.

Figure 8: **a.** Isometric views of Part model with multi-vertex pocket feature **b.** Part model with feature volume **c.** Quantitative details of part model volume and feature volume

4.3 Discussion

The developed algorithm automatically quantifies volume of part model input in .SAT file format and identifies faces having inner loop and covers the inner loop with a face generated. The algorithm then automatically generates feature volume, results. The part model considered in section 3 has a two-vertex hole feature and the generated results of section 3 show part model volume equal to 156708 mm^3, feature type identified is two-vertex hole and feature volume for two-vertex hole feature is 3441.24 mm^3. The part models tested in example 1 and example 2 contain a multi-vertex pocket feature and results show the part models volume equal to 243616 mm^3, 324328 mm^3 respectively. The feature type identified by algorithm in both part models is multi-vertex pocket and their feature volumes are 10443.8 mm^3, 10619.4 mm^3 respectively.

5 Conclusion

The developed algorithm is able to automatically quantify the input part model's volume and recognize faces having depression features. The algorithm successfully identified inner loop of face having depression feature and covered the loop with a new face. The algorithm successfully generated feature volume between new faces by performing lofting operation and recognized feature type by using vertex attributes. The developed algorithm is tested by input of part models having freeform depression feature and results obtained in .SAT file format show the developed algorithm can generate feature volume and identify two-vertex hole freeform depression feature, multi-vertex pocket freeform depression feature. The algorithm is able to present the generated feature volume in different colors as per the user requirements and results obtained in .TXT file format show part model volume, feature volume.

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