

Auto-recognition of surfaces and auto-generation of material removal volume for finishing process

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Abstract. Auto-recognition of a surface and auto-generation of material removal volumes for the so recognised surfaces has become a need to achieve successful downstream manufacturing activities like automated process planning and scheduling. Few researchers have contributed to generation of material removal volume for a product but resulted in material removal volume discontinuity between two adjacent material removal volumes generated from two adjacent faces that form convex geometry. The need for limitation free material removal volume generation was attempted and an algorithm that automatically recognises computer aided design (CAD) model's surface and also auto-generate material removal volume for finishing process of the recognised surfaces was developed. The surfaces of CAD model are successfully recognised by the developed algorithm and required material removal volume is obtained. The material removal volume discontinuity limitation that occurred in fewer studies is eliminated.

Keywords: material removal volume, regional segmentation, lofting, finishing layer.

1. Introduction

The 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. The delta volume was decomposed into large and simple maximal volumes and then maximal volumes were transformed into maximal features, by using a 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 [1]. A hybrid feature recognition method (face pattern approach + volumetric decomposition method) was developed to recognise non-interacting parts and interacting features respectively. The developed algorithm was used only for cast-then-machined parts [2]. The author developed an algorithm to recognise parts of regular and freeform surfaces. The method recognised all forms of surfaces and also generated material removal volume for the finishing process and roughing process. However, the material removal volume of finishing process bore discontinuity between them and the percentage error obtained was greater than 1% [3]. An algorithm was developed for automatic recognition of only non intersecting machining features directly from 2D CAD input instead of converting 2D to 3D model 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 [4]. 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. A 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 was able to identify the lost design features and machining features from a data exchange part model. Simple and compound features can also be identified [5]. Although many researches have been carried out on automatic feature recognition, there is a need for a more optimal feature recognition and material removal volume generation method.

2. Methodology

The flow adopted by algorithm to recognise surfaces and their finishing layer generation is shown in **Figure 1**.

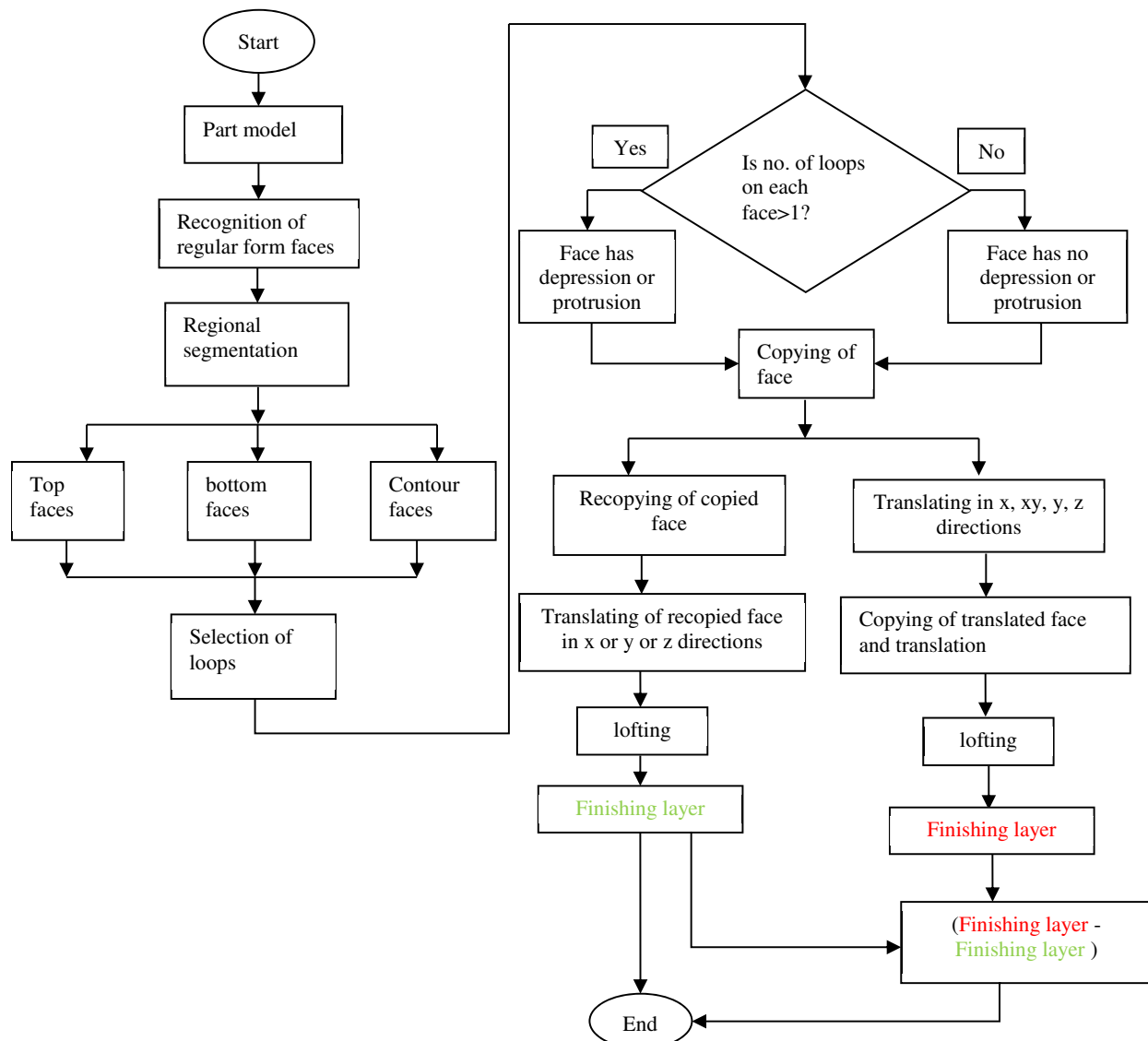


Figure 1 Flow chart of algorithm for recognition of surfaces and generation of finishing layer volume.

2.1 Part model

A part model, based on its geometrical shape can be of three forms: (i) regular form (ii) 2.5D form (iii) freeform. The part model having surfaces made of only straight and curve edges is said to be a regular form part model. The part model is said to be 2.5D form part model if its surfaces are made of straight, curve and spline edges, and part

model having surfaces made of only spline edges is said to be freeform part model. A solid body with 2-manifold boundary having CAD modeler file format extension must be input to algorithm.

2.2 Recognition of regular form faces

Surface is a superset of faces and is formed by joining of the set of faces. A component is formed by joining of these surfaces and geometrical evaluation application programming interface (API) functions. A surface recognition approach recognises the component 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.

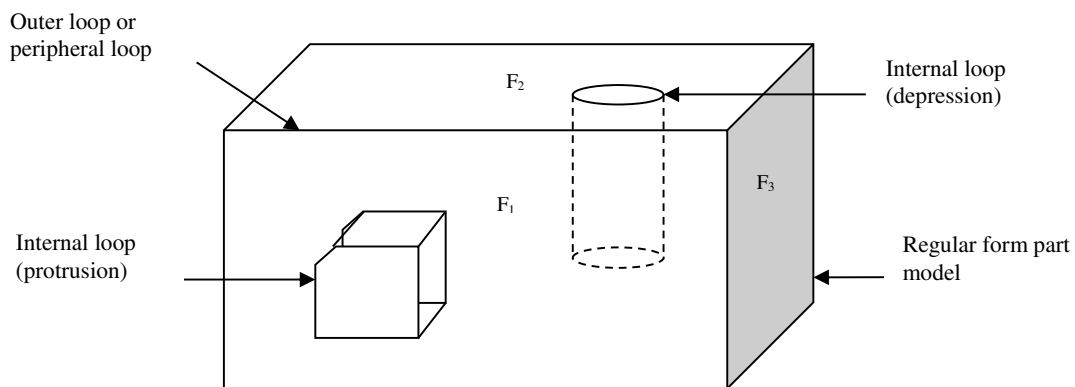


Figure 2 Geometric shapes of regular form part model

2.3 Regional segmentation

The segmentation of each face is achieved by considering its normal vector direction at midpoint. The three regions into which regular form faces are segmented: (i) top (ii) bottom (iii) contour. If a face's normal vector is greater than zero in z direction, then the face is segmented to top region. Similarly a face is segmented to bottom region if its normal vector is less than zero in z direction, and the face is segmented to contour region if its normal vector is equal to zero in the z direction and is less than or equal to 1 in x or y direction.

2.4 Selection of loops

The face is bound by loop and in turn loop is made of one or more co-edges. Each face is classified into face with depression or protrusion and face without depression or protrusion based on the following conditions (i) $2 > N > 0$; (ii) $\infty > N > 1$; ' N ' is the number of loops on the face.

2.5 Regular form face with and without depression or protrusion

The surface recognition system recognises the faces of a CAD model that are joined together with a G0 continuity. The face with depression or protrusion will have a minimum of one loop within its peripheral loop, while a face without depression or protrusion consists of only a peripheral loop and no loops of void region, extruding volume exists within the peripheral loop. For example Face (F_3) contains no depression or protrusion (**Figure 2**) and satisfies the condition (i) as it contains only one loop. Faces (F_1 & F_2) contain protrusion, depression, respectively (**Figure 2**) and satisfy the condition (ii) as the faces contain more than one number of loops.

2.6 Copying, translation of face and lofting

The geometrical evaluation application programming interface (API) functions are used to copy segmented face. The copied face is recopied and translated in x or y directions for contour region, and in z direction for top and bottom regions. The table below shows the direction of translation for recopied faces. The copied face and translated face are lofted to generate finishing layer and the amount of thickness for finishing layer is given by the user as per the requirements.

Table 1 The face's translation direction based on its normal vector direction.

Face regions	Normal vector direction	Translation direction
Top	(Single direction) +z	+z
	(Multi direction) (+z) (+y)	(+z) (+y)
	(Multi direction) (+z) (-y)	(+z) (-y)
	(Multi direction) (+z) (-x)	(+z) (-x)
	(Multi direction) (+z) (+x)	(+z) (+x)
Bottom	(Single direction) -z	-z
	(Multi direction) (-Z) (+y)	(-Z) (+y)
	(Multi direction) (-Z) (-y)	(-Z) (-y)
	(Multi direction) (-Z) (-x)	(-Z) (-x)
	(Multi direction) (-Z) (+x)	(-Z) (+x)
Contour	(Single direction) +x	+x
	(Single direction) -x	-x
	(Single direction) +y	+y
	(Single direction) -y	-y
	(Multi direction) (+x) (+y)	(+x) (+y)
	(Multi direction) (-X) (-y)	(-X) (-y)
	(Multi direction) (+x) (-y)	(+x) (-y)
	(Multi direction) (-X) (+y)	(-X) (+y)

2.7 Boolean operation

The finishing layers of all region faces that are copied and translated only in single directions are Boolean subtracted from finishing layers of all region faces copied and translated into single and multi directions to obtain material removal volume for the discontinuity that exists between the two adjacent finishing layers generated from two adjacent faces that form convex geometry.

3. Results And Discussion

A regular form model with depression on one of its faces has been considered to validate the developed algorithm.

Figure 3(a) shows the regional segmentation of part model and top region face contain depression, while contour and bottom region faces contain no depression and protrusion.

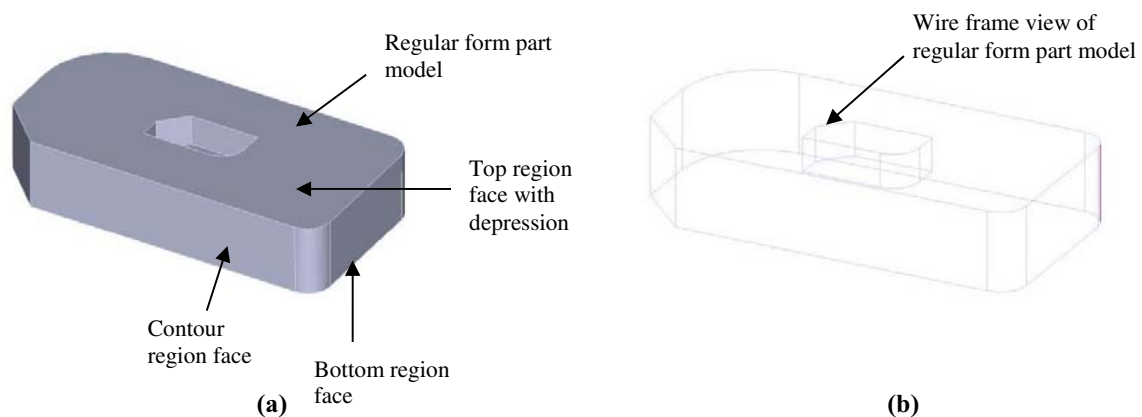


Figure 3. (a) Regular form part model with depression and regional segmentation. **(b)** Wire frame view of the regular form part model.

The generated material removal volume for finishing layer of all the faces of the regular form part model is shown in green and material removal volume that fills the discontinuity between the two adjacent finishing layers generated from two adjacent faces that form convex geometry is shown in red color. **Figure 4** shows finishing

layers of all the faces and discontinuity filled material volume. The finishing layers of all region faces generated only in single directions are shown in **Figure 4(a)** and layers generated in both single and multiple directions are shown in **Figure 4(b)**. The Boolean subtraction of layers of **Figure 4(a)** from layers of **Figure 4(b)** eliminates discontinuity problem, and a new layer of material volume is generated that fill all the discontinuity, as shown in **Figure 4(c)**.

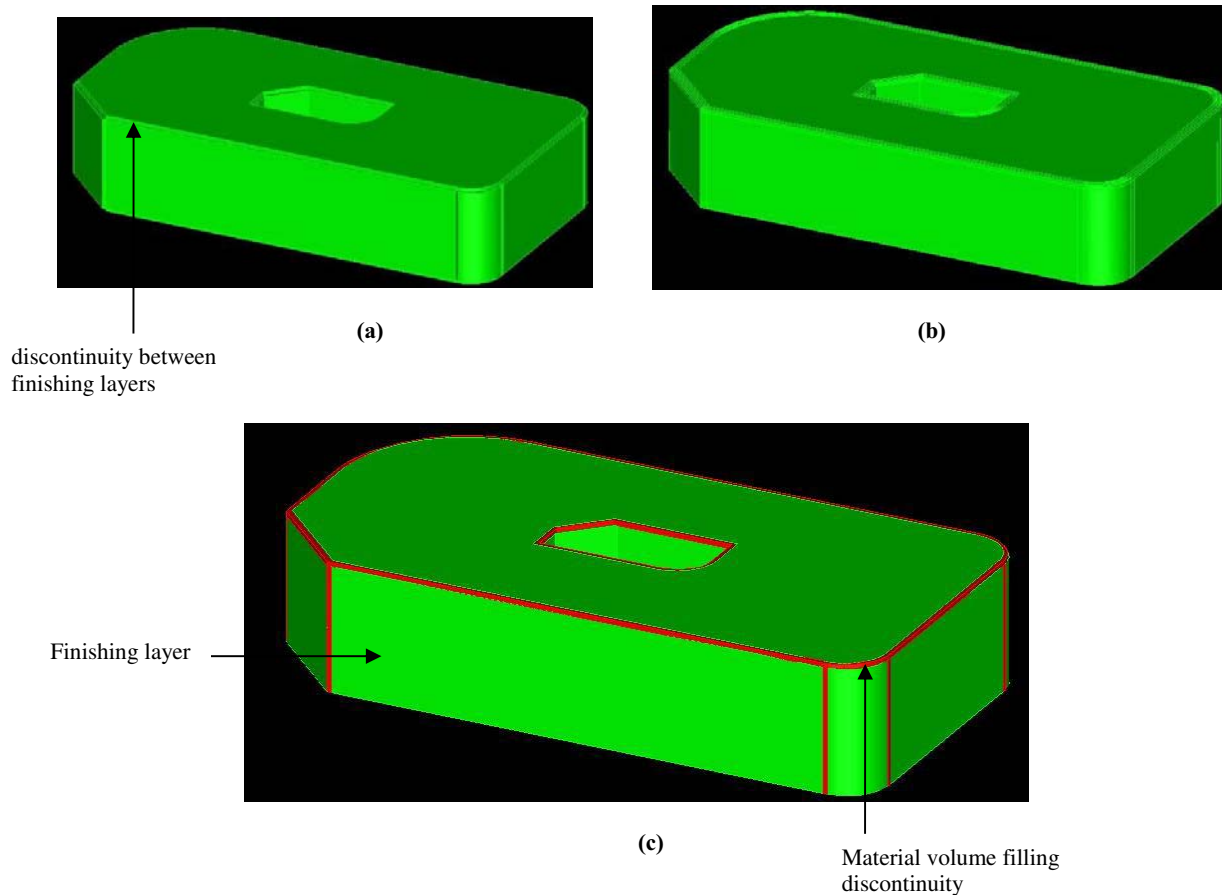


Figure 4. (a) Finishing layers (green color) of part model faces generated in single directions. (b) Finishing layers of part model faces are generated in both single and multiple directions. (c) Finishing layers and material removal volume (red color) filling the discontinuities.

Conclusion

The discontinuity that used to occur in previous research works is now eliminated and a new material volume is generated that fills the discontinuities between finishing layers. The current results show that a continuous tool path can now be maintained during machining process. The finishing layer thickness can be of any value as per users' requirements and with that, even a thickness of 1mm can be generated.

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