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Volume Modeling of Complex Mechanical Parts via Triple Dexel

K. Bouhadja, M. Bey, K. Sebti, H. Moulay, M. Bouaziz

Abstract—**The evolution of productivity and quality of manufacture mechanical parts with complex shapes on multi-axis machines is marked by the development of the machining simulation techniques that are used to: check the tool path, detect collisions and predict the cutting forces and the roughness of the finished surface, etc. For material removal simulation, three models of geometric representation should be considered: workpiece model, tool model and swept volume model. In this paper, an approach for modeling geometric parts of complex shapes is developed by using the Triple Dexel model from STL model and the use of the K-means algorithm for optimize the computation time.**

Index Terms—**Geometric Modeling, Triple-Dexels, STL Model; Virtual Workpiece, Material Removal Simulation.**

I. Introduction

The Production of mechanical parts passes through two important steps that are the designing and the manufacturing. During manufacture, the final shape of the part is obtained by three operations: roughing, half-finishing and finishing. These operations require the selection of several parameters (machining strategy, tool, feed rate, etc.). Before proceeding to the actual machining, it is necessary to simulate the manufacturing process, in order to verify the tool path, detect collisions, predict the cutting forces and predict state of finished surface, etc. According to these objectives, the machining simulation is distinguished in tool path simulation and material removal simulation. There exist several machining simulation techniques that touch various levels. For clarify and separate the difficulties of these techniques, a synthesis work proposing classification criteria related to the various problems of machining simulation is presented in [1].

The surface topography prediction problem is inserted through the material removal simulation where the quantification of the removed material is indispensable. Therefore, the geometric representations models that should be considered are: workpiece model, tool model and swept volume model. These models are distinguished by continuous and discrete models, these can range from the simplest, a series of points [2] to complex, faceted description of the surface [3] or volumetric: Dexel [4], Voxel [5] and the most advanced Triple Dexel model [6]. A comparative study between models of workpiece representation for material removal process is presented in [7], this study answer to the compromise between accuracy and computation time issue. The purpose of the present work is to propose and to implement a methodology discretization volume representing the complex mechanical part as closely as possible, using the Triple Dexels model by computing its intersections with STL model. The computation time is minimized thanks to the K-means method [8], applied before in an others fields like image processing [9]. In this work triangles group cluster, is used relatively to STL model.

This paper is organized into four sections: the first is an introduction by situating the present work-compared to the literature, the second is the description of solving approach, the third is a presentation of results and discussion and finally conclusion and future works.

II. RESOLUTION APPROACH

The approach used involves the following steps:

- Recovery STL model;
- Grouping the triangles in Clusters;
- Generation volume model in Triple Dexels;
- Discretization optimization.

A. Recovery STL model

STL model can approximate the object surfaces by a set of triangles whose number and size depend on the accuracy imposed (Fig. 1). Each triangle is defined by its unit normal $\vec{N}$ directed outwards and the coordinates of its three vertices oriented P1(X1, Y1, Z1), P2(X2, Y2, Z2) and P3(X3, Y3, Z3) (Fig. 2.a). In this model, each vertex is common to several triangles. To avoid this redundancy and reduce the memory space required to store all this data, two additional lists were created. The first contains the set of vertices without repetition while the second list contains all triangles where each triangle is defined by three addresses of its vertices (Fig. 2.b). By subsequently, from the coordinates of end points crude XMIN, YMIN, ZMIN, XMAX, YMAX, ZMAX, the minimum size of the crude (width, length and height) is calculated.

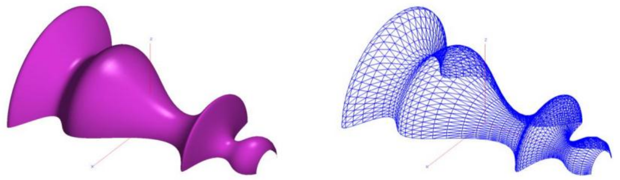
K. Bouhadja is with the Centre de Développement des Technologies Avancées, Baba Hassen B.P.17, 16303 Algiers, Algeria. (bouhadjakhd@yahoo.fr) and with the Ecole Nationale Polytechnique, Département de Génie Mécanique, Rue des Frères OUDEK, Algiers, Algeria.

M. Bey is with the Centre de Développement des Technologies Avancées, Baba Hassen B.P.17, 16303 Algiers, Algeria (bey_mohamed@yahoo.com).

K. Sebti is with the Université Saad Dahlab, Faculté des Sciences, Département d'Informatique, Route de Soumaa, Blida, Algeria. (sebti.khaled1@gmail.com).

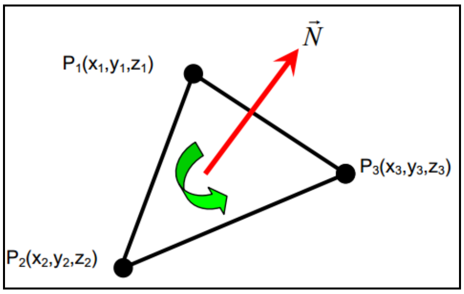
H. Moulay is with the Université Saad Dahlab, Faculté des Sciences, Département d'Informatique, Route de Soumaa, Blida, Algeria. (mly.hamid@gmail.com).

M. Bouaziz is with the Ecole Nationale Polytechnique, Département de Génie Mécanique, Rue des Frères OUDEK, Algiers, Algeria). (mbouazizdz@yahoo.fr).

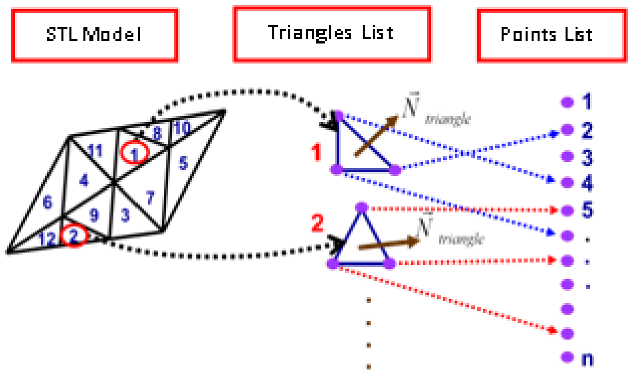


a. Theoretical surface. b. STL model

Fig. 1. Theoretical surface in Format STL



a. Triangle Parameters.



b. Structuring of STL model

Fig. 2. Parameters and structure of the STL model

B. *Grouping the triangles in Clusters*

Triple Dexels Model involves computation intersection points between lines and triangles in 3D. However, for a high accuracy STL model and a very precise volume discretization, the computation time increases considerably. So to minimize it, the triangles should be grouped into zones. These areas are called "Cluster" they are created using the K-means algorithm [8]. Each cluster is defined by a list of triangles and a specific point called the centroid of triangles which is the center of gravity (Fig. 3.b). The steps are:

— Introduction of the K number of clusters to create and the number of iterations I

— Computing the centroid of each triangle in the STL model.

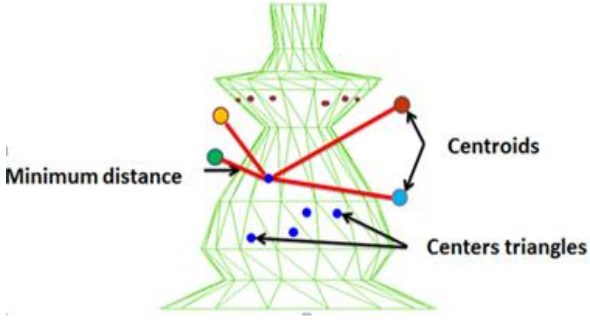
— Allocation of triangles Clusters based on the minimum distance between the centroids of each triangle and the centroid of cluster (Fig. 3.a).

— Updating the centroid coordinates of each cluster according to its triangles.

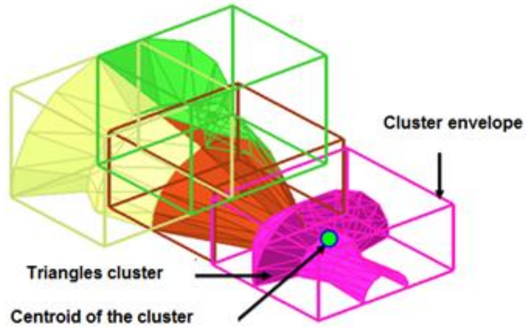
— Computation differences between the old and the new centroid of each cluster to check process stability (convergence).

— Stopping the process if the stability is reached (no change of the coordinates of centroids) or the number of iterations is reached.

Computation the envelope limits of each cluster (Fig. 3.b).



a. Distances Centroids to a summit



b. Cluster Parameters

Fig. 3. Grouping of triangles in Clusters by K-means method

C. *Generation volume model in Triple Dexels*

Model generation in Triple Dexels requires the generation of the Dexels model along the three main directions (X, Y and Z). The Dexel along the Z axis is a material column parallel to this axis, which is defined by the center (X0, Y0) of height H (Zmin and Zmax) and square or rectangular base (ΔX and ΔY) (Fig. 4). Depending the shape of the object to be modeled, several Dexels can be created on the same straight line.

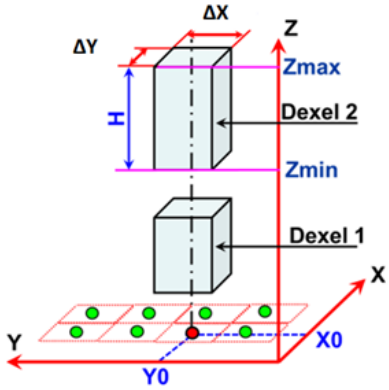


Fig. 4. Dexel Parameters

Creating grids of cells on three planes

This step is to generate three grids of cells in three perpendicular planes. The first grid is generated in a plane parallel to the XY plane and passes through the horizontal face of the crude of coordinate ZMIN. The second grid is generated in a plane parallel to the XZ plane and passing through the vertical face of the crude of coordinate YMIN.

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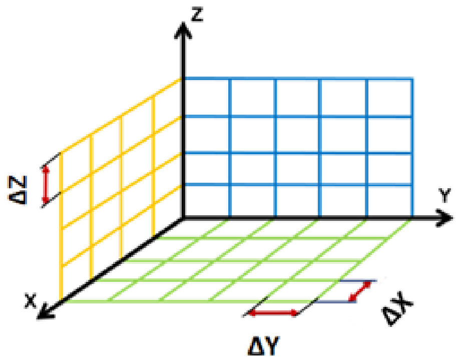
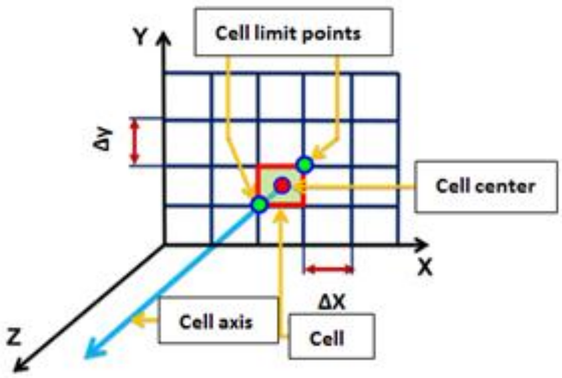
The third grid is generated in a plane parallel to the YZ plane and passing through the vertical face of the crude of coordinate XMIN. The creation of these grids requires the specification of the step discretization ΔX, ΔY and ΔZ on the three axes X, Y, Z (Fig. 5.a). These cells represent the bases of Dexels to create. The number of cells along each axis depends on the discretization step and the dimensions of the crude. Each cell is characterized by its limit points, _ its center and its axis perpendicular to the plane of the cell directed inwardly to crude (Fig. 5.b). These parameters are calculated in terms of dimensions of the crude and the discretization step.



a. Creation of the three grids of cells



b. Creating the grid cell in the XY plane

Fig. 5. Creating cell grids

Calculation of intersection points

The Dexels creation requires the calculation of points of intersection between each cell axis with the set of triangles; this calculation goes through the following steps:

— Identify clusters that overlap with the cell axis.

— For each identified cluster, determine the triangles that overlap with the cell axis.

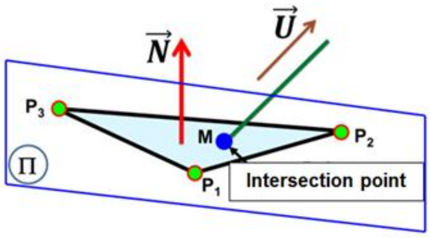
— For each identified triangle, calculate the intersection point between the cell axis and the triangle.

— If there is a valid intersection point, add it to the list points intersection of the cell axis.

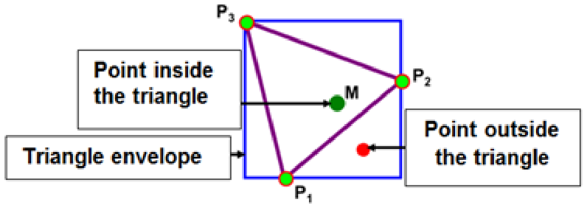
— For computation the intersection point between the cell axis and the triangle, two cases are considered:

1st case: a single intersection point between the cell axis and the plane of the triangle called Π (Fig. 6.a), this point is valid only if it belongs to the triangle of vertices P1, P2 and P3 (Fig. 6.b), and verifies the condition expressed by the following relationships:

$$\begin{cases} (\overrightarrow{P_1P_2} \wedge \overrightarrow{P_1M}).(\overrightarrow{P_1M} \wedge \overrightarrow{P_1P_3}) \geq 0 \\ (\overrightarrow{P_2P_1} \wedge \overrightarrow{P_2M}).(\overrightarrow{P_2M} \wedge \overrightarrow{P_2P_3}) \geq 0 \\ (\overrightarrow{P_3P_1} \wedge \overrightarrow{P_3M}).(\overrightarrow{P_3M} \wedge \overrightarrow{P_3P_2}) \geq 0 \end{cases} \quad (1)$$



a. Intersection of axis with the triangle 3D



b. Point inside the triangle

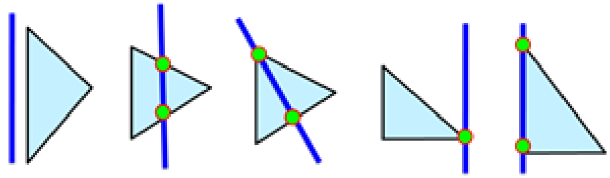
Fig. 6. Intersection of cell axis nonparallel to the triangle

2nd case: the cell axis and the plane of the triangle Π are parallels, and then they can be disjoint or coincident (Fig.7.a)

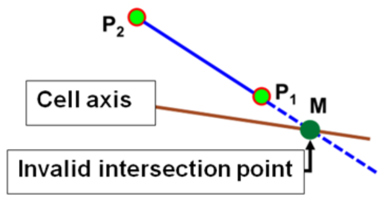
— If they are disjoint, then no intersection points exist.

— If they are coincident, then should be computed the intersection points between the cell axis and the three straight lines passing through the segments of the triangle.

- ➢ If the intersection point belongs to the segment, then it is a valid point and it is inserted in the list of intersection points (Fig. 7.b).
- ➢ If the intersection point isn't in the segment, then this point is invalid and it isn't considered (Fig. 7.c).



a. Various configurations of intersection between cell axis and triangle



b. Valid intersection point

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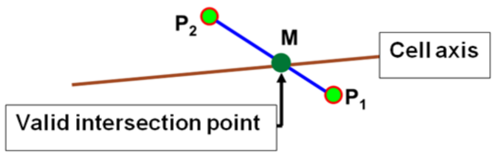


c. Invalid intersection point

Fig. 7. Intersection of cell axis parallel to the triangle

For each intersection point, the projection of the normal of the triangle on cell axis is calculated and is stored. This information will be used in the location of the material.

Identification of the material and the void areas

Creating Dexels necessarily involves the identification of areas representing the material and the areas representing the void. Since the points of intersection of each cell axis are unstructured, the process of creating Dexels involves the following steps:

— Sort the list of intersection points in the direction of the cell axis (Fig. 8):

- If the cell is in the XY plane, then the sorting direction is the Z axis.
- If the cell is in the YZ plane, then the sorting direction is the X axis.
- If the cell is in the XZ plane, then the sorting direction is the Y axis.

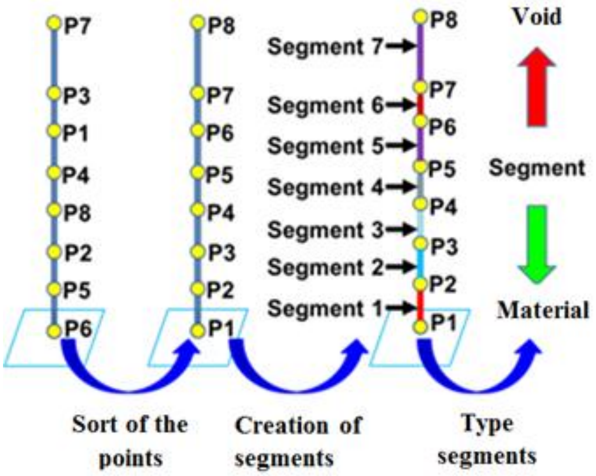


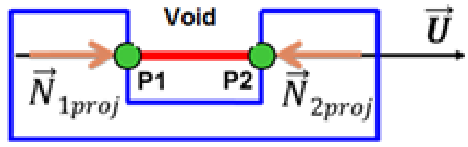
Fig. 8. Sorting intersection points and segments creation

— Initialization list segments:

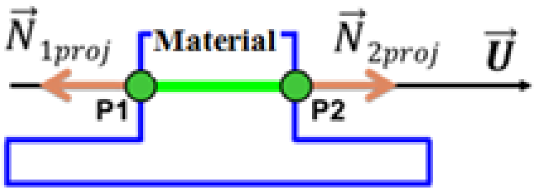
- Browse the sorted list of intersection points and create segments by taking the points two by two in the direction of sort.
- Initialization of the Type of each segment at «void» (Contains No material).

— Identification of the type of each segment: two situations are considered:

- The segment lies in the plane passing through one of the triangles:
  - ✓ If the two points of segment belong to the triangle, then the segment type is "material".
  - ✓ If the two points of segment are not in the triangle, then the segment type is "void".
- The segment doesn't belong to the planes of triangles: the segment type identification is done through the scalar product computation between the projections normal triangles points of intersection $\vec{N}_{1proj}$, ,with the direction vector of the cell axis $\vec{U}$:
  - ✓ If $\vec{N}_{1proj} . \vec{U} < 0$ and $\vec{N}_{2proj} . \vec{U} > 0$, then the type of the segment is "material" (Fig. 9a).
  - ✓ If $\vec{N}_{1proj} . \vec{U} > 0$ and $\vec{N}_{2proj} . \vec{U} < 0$, then the type of the segment is "void" (Fig. 9b).



a. Segment type "void"



b. Segment type "material".

Fig. 9. Identification of the segment type

Creation of Dexels and Triple-Dexels model

A Dexel is a parallelepiped characterized by its section shown by the shape of the cell, its height represented by the length of the segment type "material". The segments type "material" forms the Dexels of the part in the direction of the cell axis (Fig. 10) and the total volume of the object is the sum of all Dexels.

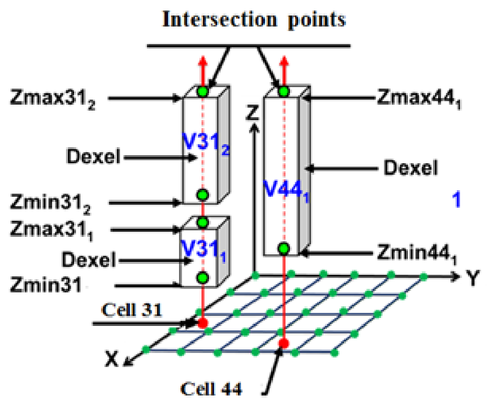


Fig. 10. Creation of Dexels along the Z axis.

According to [10], the creation of Dexels in the X and Y directions is performed by following the same process as the Z direction (Fig. 11), the model of the part in Triple Dexels is then obtained by combining the Dexels created in the three directions.

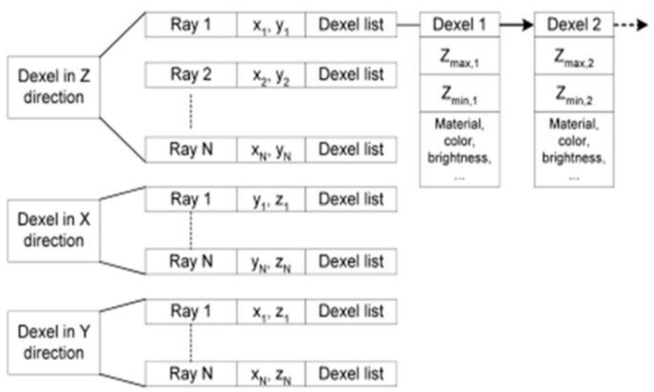


Fig.11. Creating the Triple-Dexels model [10]

D. Discretization optimization

To determine the optimum discretization ΔX, ΔY and ΔZ according to the three axes X, Y, Z at obtain a Triple-Dexels model with a given accuracy, a specific procedure is developed to automate this task. The ΔX, ΔY and ΔZ are calculated using the following steps

— Introduction of the initial steps ΔXinit, ΔYinit and ΔZinit and the required accuracy (error percentage);
— Grids generation;
— Dexels creation;
— Initial volume calculation of the material;
— Calculating the new steps ΔYnew, ΔXnew and ΔZnew by the divide of the steps previous by two;
— Calculating the new volume with the new steps;
— Error calculation between the two calculated volumes;
— If the error is smaller than the required error, then stop the process;
— If the error is greater than the required error, then divide the larger discretization by two and go to step 6.

At the end of this procedure, steps optimal initial ΔX, ΔY and ΔZ are determined.

III. RESULTS AND DISCUSSION

The proposed methodology is implemented in object-oriented Windows using C ++ Builder and OpenGL graphics library. The validation of the methodology is conducted on the STL model of a complex geometric shape of helicopter (Figure 12). The STL model consists of 18829 vertices and 34678 triangles. Helicopter envelope dimensions are 648.93mm X 1516.47 mm X 1976.31mm.

For grouping triangles Clusters, two values are selected (Figure 13). Greater the number of clusters is raised, the computation time of the intersection points is reduced. Figure 14 shows the model in Triple Dexels generated for step ΔX, ΔY and ΔZ equal to 3 mm.

IV. CONCLUSION

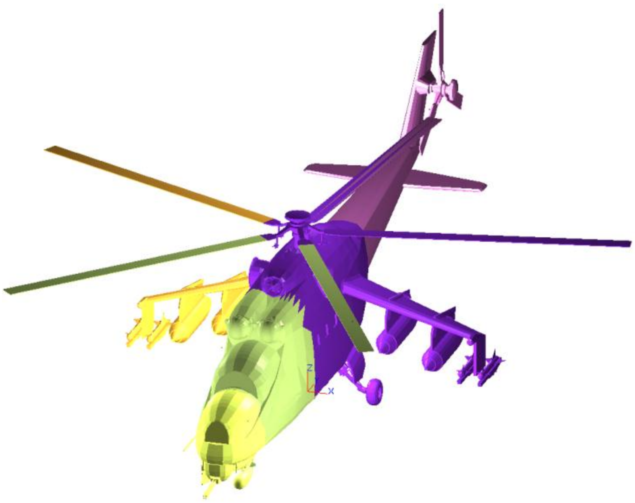
In this paper, an approach permitting the solid modeling of complex shapes based on Triple Dexels model generated from their STL models is developed to simulate material removal in 05-axis machining. Thus, the computation time of the intersection points is minimized thanks to triangles group clusters by the K-means method.

This work can be extended to: modeling the swept volume, simulating the material removal in 05 axes machining with different types of tools, locating the contact zones tool-area, predicting cutting forces, predicting the 3D topography of machined surfaces and the adapting of cutting conditions.

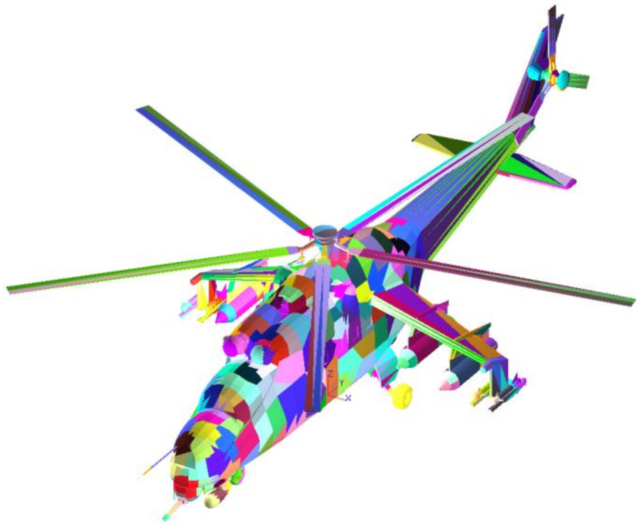
a. Representing wireframe

b. Representation in rendering mode

Fig. 12. STL Model of Helicopter.



a. Number of Clusters equal to 5.



b. Number of Cluster equal to 500

Fig. 13. Creating Clusters with multiple values.

Fig. 14. Triple-Dexels model helicopter

REFERENCES

[1] K. Bouhadja, M. Bey, "Classification of simulation methods in machining on multi-axis machines", Proceedings of the World Congress on Engineering WCE, Vol. 2, pp 992-997, 2014.

[2] D. Montgomery and Y. Altintas, « Mechanism of cutting force and surface generation in dynamic milling». ASME Trans.-Journal of Engineering for Industry, Vol. 113, pp 160-168, May 1991.

[3] Y. Mizugaki, M. Hao and K. Kikkawa, « Geometric generating mechanism of machined surface by ball-nosed end milling ». Annals of CIRP, volume 50, 2001

[4] T.V Hook. « Real-time shaded NC milling display ». In SIGGRAPH'86, pp 15-35, 1986.

[5] S. Ratchev, S. Liu, W. Huang and A.A. Becker. « Milling error prediction and compensation in machining of low-rigidity parts». International Journal of Machine, Tools and Manufacture, Vol. 44, pp 1629-1641, 2004.

[6] K. Weinert and A. Zabel. « Simulation based tool wear prediction in milling of sculptured surfaces». In Annals of CIRP, Vol. 53, pp 217-223, 2004.

[7] K.Bouhadja, M. Bey, "Survey on Simulation Methods in Multi-Axis Machining", Chapitre 25 inTransactions on Engineering Technologies: World Congress on Engineering 2014 published by Springer.

[8] J. Macqueen, "Some Methods for Classification and Analysis of Multivariate Observations", Proc. Fifth Berkeley Symp. on Math. Statist. and Prob., Vol. 1 (Univ. of Calif. Press, 1967)

[9] O. Lezoray , C. Charrier, « Segmentation d'images couleur par coalescence non supervisée d'histogrammes 2D et fusion de régions selon la théorie de Dempster-Shafer » traitement du signal 2004_volume 21_numéro spécial L'image numérique couleur.

[10] W. Zhang, «Virtual Prototyping with Surface Reconstruction and Freeform Geometric Modeling Using Level-set Method ». Missouri University of Science and Technology, 98-99 pages; 2008.