Reason- A Technical Journal
ISSN 2277-1654
Volume XIII • 2014

SCANNED DATA TRIANGULATION USING DELAUNAY TETRAHEDRALIZATION APPROACH FOR 3D POINT CLOUD DATA

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Paper received on: November 14, 2013, accepted after revision on: October 06, 2014

Abstract: Reverse Engineering (RE) is used to create surface models of existing products by capturing Point Cloud Data using either contact or non – contact scanners. Rapid Prototyping (RP) is used to fabricate the physical prototype of a product using a layer by layer additive technique. In this paper, a new method is suggested which creates a direct link between RE and RP. For RE process, 3D Laser Scanners have become more accurate and the speed of data acquisition has increased dramatically. However, handling of huge amount of Point Cloud Data is a major constraint. Rapid Prototyping (RP) demands solid model in Structured Tessellation Language (STL) format as a basic input. The three basic steps involved in creating a STL file from Point Cloud Data are as follows: 1) Data acquisition (Point Cloud Data), 2) Surface model and solid model development by using commercial software, 3) Generation of triangular mesh model using solid model and 4) STL file generation. This process is difficult; time consuming and laborious because gaps may appear in a surface model, being person dependent that may not allow the conversion of surface model into a perfect STL file.

To overcome these steps, some researchers have suggested a technique in which STL file can be crated directly from the Point Cloud Data to avoid surface modeling tasks. Conventionally Delaunay triangulation is used for triangulation of 2D Point Cloud Data obtained from 3D Laser Scanner. In this paper, a new approach, “Delaunay Tetrahedralization” is suggested which is suitable for 3D Point Cloud Data. The efficiency of the algorithm is validated and the results are included in this paper.

Keywords: Reverse Engineering, Rapid Prototyping, Point Cloud Data, Delaunay Triangulation, Delaunay Tetrahedralization, STL file.

1. INTRODUCTION

In order to meet challenges of today's rapidly changing business landscape, companies are taking a close look at their methods, adopting new techniques, and looking for ways to make production more efficient and cost effective. Among the recent technological advances, there is a growing interest in the availability of fast and affordable product. Both Reverse Engineering (RE) and Rapid Prototyping (RP) are emerging technologies that can play a promising role in reducing the product development time.

Reverse engineering refers to the process of creating engineering design data from existing parts. It recreates or clones an existing part by acquiring the point cloud data of a physical part using contact or non – contact instruments like Co-ordinate Measuring Machine (CMM) and 3D Laser Scanner. The major operation involved in reverse engineering is to develop a surface model from point cloud data, requires a great amount of time and operator skills and can also be subject to error.

Generally, in rapid prototyping, physical parts are manufactured layer by layer. It uses additive manufacturing processes, which do not require any tools or set-ups compared to the subtractive techniques used in the traditional machining operation. It allows one to manufacture features that are difficult or impossible to manufacture by machining operation. Different manufacturing methods exist for rapid prototyping, but nearly all use the same geometry input format, called STL. STL file consists of a list of triangular facet data to define the geometry of a product.

In conventional approach, four main steps are involved to generate STL file: 1) Data acquisition (Point Cloud Data), 2) Surface model and solid model development by using commercial software, 3) Generation of triangular mesh model using solid model and 4) STL file generation. But in order to develop rapid prototyping model, a completely watertight triangular mesh model is required, i.e., a mesh model without having any pocket or missing surface and zero intersecting surfaces.

The main objective of this paper is to present a methodology to convert a point cloud data into STL file without using conventional surface modeling techniques.

But to generate a STL file, a triangulated mesh model of point cloud data is required. Therefore, to generate triangulated mesh model, many approaches are available such as Delaunay triangulation, Constrained Delaunay triangulation, Conforming Delaunay triangulation, and triangular mesh constructor. Commonly Delaunay triangulation approach is used to get triangulated mesh model.

Delaunay triangulation approach is based on circumcircle criterion. Delaunay Triangualtion is a methodology developed so that no vertex from the entire point data set lies inside the circumcircle of any triangle which ensures non-intersecting and non overlapping triangulated network. Circumcircle criterion is shown in Fig. 1.

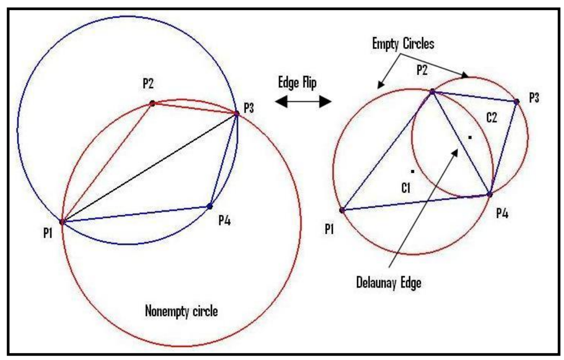

Fig. 1: Circumcircle criterion

This approach has some limitations such as: 1) Approach is used to convert planer type point cloud data into triangulated mesh model; 2) This method gives perfect result when the data is obtained from all the sides/ views. But in majority jobs data from all the sides is not required. In majority of the cases only critical surfaces are scanned and the side faces are attached to it later.

For attaching the side faces, a clean clear well defined boundary is required. By using Delaunay a clear boundary is not obtained rather dangling triangles are created near the boundary. No RP machine accepts the data with dangling surfaces, making the STL file invalid for product generation. To avoid such types of problems a new approach is evolved is Delaunay tetrahedralization.

Delaunay tetrahedralization approach is based on Delaunay Triangulation but instead of using circumcircle criterion, a circumsphere criterion is used. In this approach 3D point cloud data is considered to get triangulated mesh model of point cloud data. Circumsphere criterion is shown in Fig. 2.

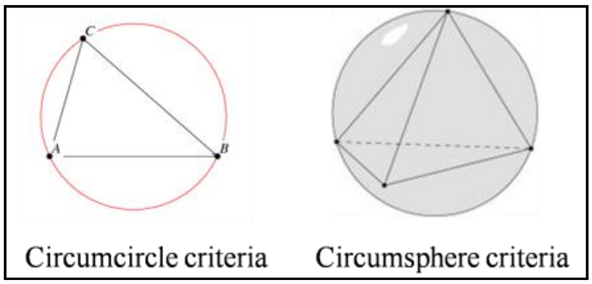

Fig. 2: Circumsphere criterion

2. RELATED RESEARCH

Rapid Prototyping demands a solid model in STL file format as a basic input. To eliminate this step, some researchers [1, 2] suggested techniques in which STL file is directly created from the Point Cloud Data, without having the need to create solid model.

Chen and Ng [1] proposed a method which constructs STL file directly from the CMM measured point cloud data which can be organized in matrix format. A method describes a vertex-to-vertex rule for generating triangulated mesh model from an organized 2D point cloud data. In this method the points are joined together on the basis of neighbouring criteria to get a triangulated mesh which subsequently leads to get a STL file.

Tyvaert et al. [2] developed a methodology and its translation into a software program to generate a closed STL file model from the point cloud data. The triangulation algorithm developed in the said paper uses the point cloud data which is obtained from CMM. The tessellation procedure works on two lines of data points at a time. This tessellation is performed from left to right.

From the above discussed papers, and work carried out by other researchers in this direction, it is shown that the point cloud data used for triangulation is obtained from CMM or contact type scanners, have some advantages such as the data is in an organized format, the storage space required is very less and hence computational time to compute the triangulated model is very less. But it has some disadvantages also, the data capturing time is very high, it requires contact – type scanner which inserts some errors at the time of scanning operation due to the material surface roughness.

To overcome these disadvantages, nowadays in digitizing process laser scanners are being used more frequently due to rapid measuring speed and high precision. Laser scanning technology provides non-contact type measuring device which can scan the parts with a very high speed, and a good accuracy can be maintained. The laser scanning machines enable one to capture the surface data of a part with freeform surfaces. The data obtained from the laser scanning process is scattered (unorganized) and enormous.

Lee et al. [3] addressed an approach to reduce the amount of point cloud data by segmentation which is obtained from laser scanner and 2D Delaunay Triangulation approach which is used to generate a triangulated mesh model.

A newly developed Constrained Delaunay Triangulation (CDT) [4] approach based on Delaunay Triangulation was proposed for getting an error free triangulated mesh model in which a new point is inserted as per the requirement in the mesh model to minimize the errors and to get a correct mesh model of the product. Often a CDT contains edges that do not satisfy the Delaunay criterion therefore a CDT is not a Delaunay triangulation itself.

From refereed papers it is concluded that mostly Delaunay Triangulation approach is used to generate a triangulated mesh model. But the Delaunay triangulation approach shows some disadvantages which are highlighted by Sangyoon Lee, Chan-ik Park and Chan-mo Park [5]. According to them large computation time is required to obtain the triangulated mesh model of the point cloud data. This time can be reduced by using more than one processor and several parallel algorithms. But after completing parallel triangulation of segmented point cloud data, a merging stage is required to combine segmented triangulation mesh. The process of merging is a very difficult task as it takes time to get an appropriate mesh model to generate the corresponding STL file and lastly Delaunay triangulation is mainly adapted for 2D point cloud data.

Researchers in the past have shown that, a direct integration of RE and RP is possible via development of triangulated mesh model, therefore the bridge connection between RE and RP is at the generation of triangulated mesh generation step. As discussed there are several methods to convert point cloud data into the triangular mesh model. But various approaches have common weakness such as in all techniques a 2D point cloud data is used, large computation time is required to generate the triangular mesh model and even sometimes to improve mesh model a re – triangulation is done. To overcome these disadvantages a new approach is discussed which is called as Delaunay Tetrahedralization. This approach can be used for 3D point cloud data to get a triangulated mesh model and it is based on Delaunay triangulation, but instead of using circumcircle criteria here circumsphere criteria is used.

3. STEPS FOLLOWED IN DELAUANY TETRAHEDRALIZATION APPROACH TO DEVELOP RP MODEL

1. To obtain Point cloud data of available product by using 3D Laser scanner.
2. To generate a tetrahedral mesh model of point cloud by using the Delaunay Tetrahedralization appro-ach.
3. To generate triangulated surface mesh model from tetrahedral mesh.

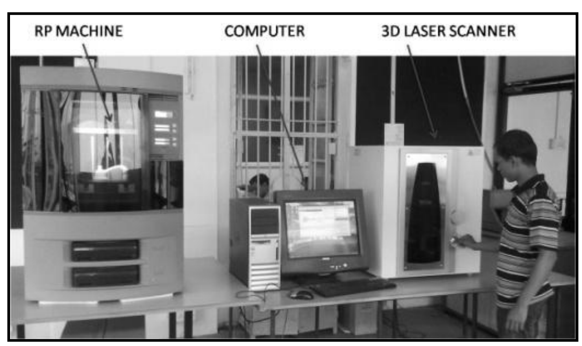

Fig. 3: Experimental setup

4. Validation of the surface mesh model using Euler's formula, Angle criteria.
5. Generation of STL file and RP model.

RP machine used in experimentation (Fig.3) uses Fused Deposition Modeling (FDM) method (Model: 768, Manufacturer: Dimensions).

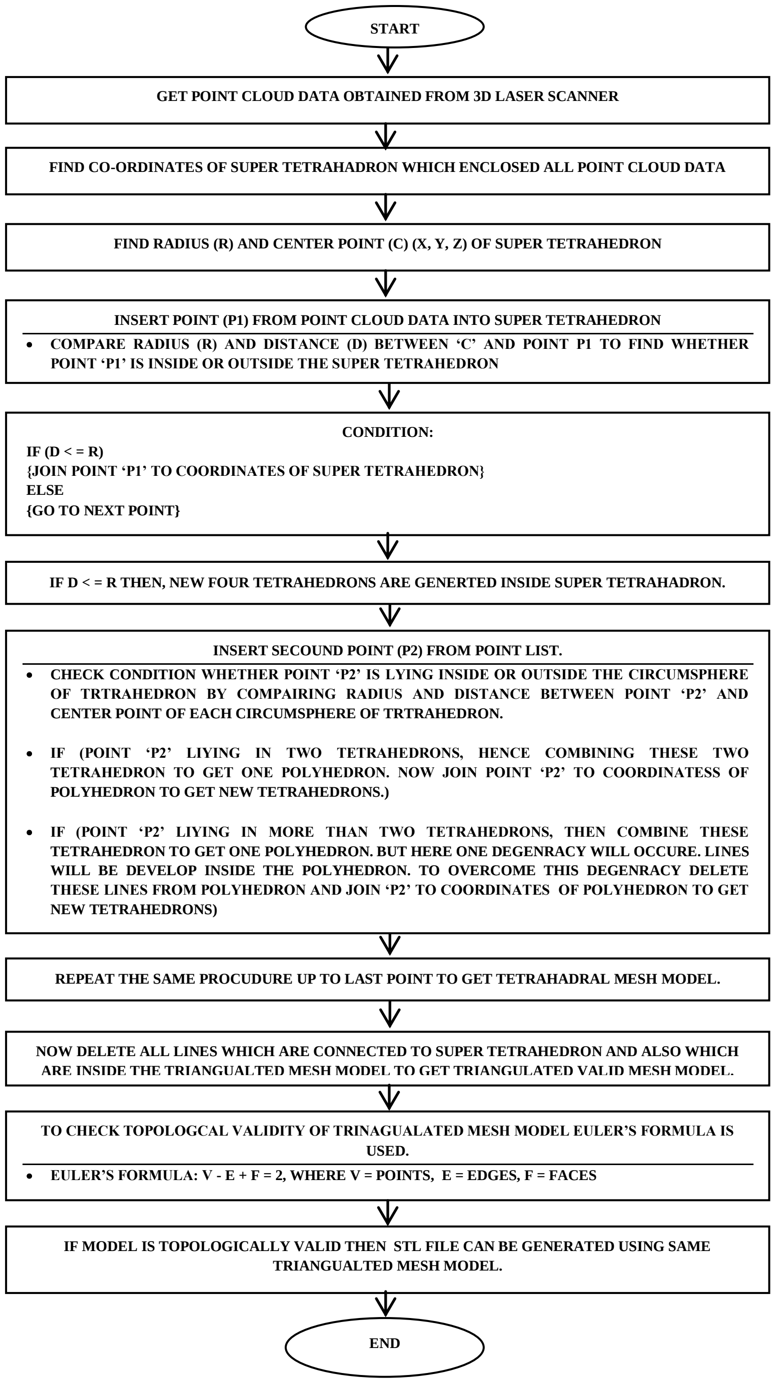

Fig. 4: Flow chart of Delaunay Tetrahedralization

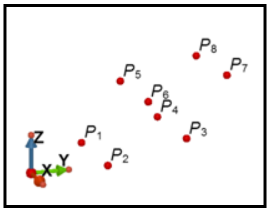

Fig. 5: Point Cloud Data

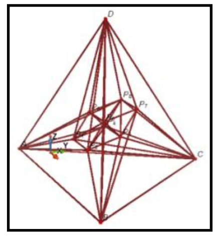

Fig. 6: Tetrahedral mesh model

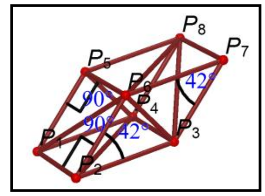

Fig. 7: Triangulated mesh model

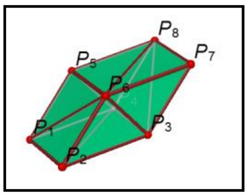

Fig. 8: Mesh Model of Product

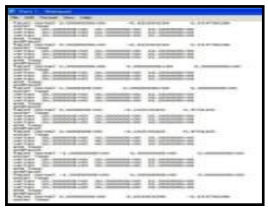

Fig. 9: STL File of Product

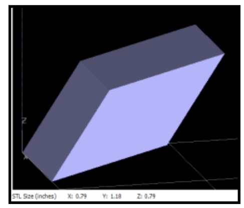

Fig. 10: File Load in CatalystEX 4.2 RP Machine Software

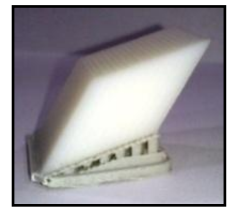

Fig. 11: Output from RP machine

A given flow chart (Fig.4) shows the actual steps in Delaunay Tetrahadralization approach to get STL file.

4. CASE STUDIES

To validate the Delaunay Tetrahedralization approach two case studies are carried out-1) Rhombus and 2) Water Tap.

4.1 CASE STUDY I – RHOMBUS

1. In the first case study, 8 points are considered in space, which define a shape of a rhombus with equilateral sides (20 mm in length). Point set is shown in Fig. 5.
2. By using point cloud data, a tetrahedral mesh model is generated using Delaunay Tetrahadralization approach shown in Fig. 6.
3. Delete, all lines which are connected to the Super – tetrahedron vertices A, B, C and D and also to delete lines which are inside the closed polyhedron to get closed triangulated mesh model shown in Fig. 7.
4. To avoid topological error in the STL file, it has to be validated by using Euler's formula [6-8] criterion.

   Fig.7 shows that the model contains:
   No. of Vertices (V) = 8,
   No. of Edges (E) = 18,
   No. of Triangles (F) = 12

   From Euler's formula: $V – E + F = 2$, and $8 – 18 + 12 = 2$.

   It shows that criterion is validated; hence STL file can be generated from triangulated mesh model to get Rapid prototyping model on RP machine. Fig. 8 to Fig. 11 show the actual steps followed to get RP model on RP machine.

5. To do physical validation of RP product. The object is re - scanned by PICZA 3D Laser Scanner LPX 600 to obtain the point cloud data.

Total scanned points obtained are 52724.

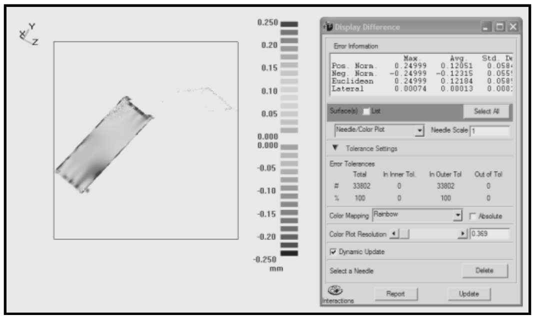

Fig. 12: Physical Validation

Obtained point cloud data is superimposed on the STL file for verification. Fig. 12 shows the deviation between the scanned data and the generated STL file. This comparison is done in Imageware which is dedicated software for surface modeling using point cloud data.

As noticed in Imageware verification, the difference between the surface model file and point cloud set gives average error in between + 0.12051 to – 0.12315 mm, which is within tolerance band of RP Machine.

4.2 CASE STUDY II – WATER TAP

1. The point cloud data of a water tap is considered for second case study which is shown in Fig. 13. The similar steps are followed which are discussed in previous case study.

2. To get surface mesh model of given point cloud, Delaunay Tetrahedralization approach is used Fig. 14 shows the triangulated mesh model of a Water Tap.

   Mesh model is tested under Euler's formula.

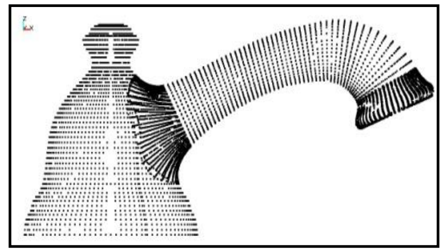

Fig. 13: Point cloud data

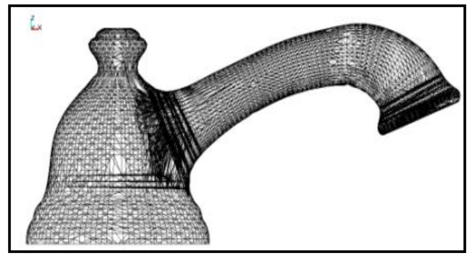

Fig. 14: Triangular mesh model of Water Tap

Output triangulated mesh model contains
No. of Vertices (V) = 8438,
No. of Edges (E) = 24581,
No. of Triangles (F) = 16145
Euler's formula: $V – E + F = 2$,
So, $8438 – 24581 + 16145 = 2$

This shows Euler's formula is validated; hence STL file can be generated from triangulated mesh model to get rapid prototyping model from RP machine, shown in Fig. 15.

3. Output of RP machine:

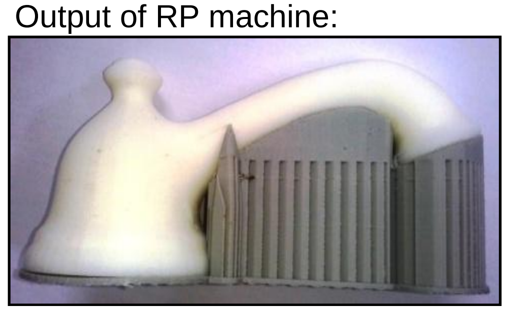

Fig. 15: RP product

4. To do the physical validation of the RP product, the RP product is re -

scanned by PICZA 3D Laser Scanner LPX 600. Total scanned points obtained are 702688.

To get the deviation between point cloud data and previously generated STL file, a point cloud data is superimposed on the STL file which is indicated in Fig. 16.

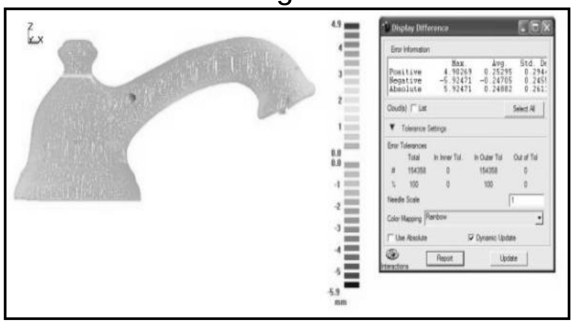

Fig. 16: Physical Validation

As noticed in Imageware verification, the difference between the STL file and point cloud set gives average error in between + 0.25295 to – 0.24705 mm which is within tolerance band of RP Machine.

5. CONCLUSION

A new approach to generate STL file directly from point cloud data is presented in this paper. The objective of Delaunay Tetrahadralization approach is to get prefect triangulated mesh model from 3D point cloud data and finally STL file which will be free from dangling edges, intersecting and overlapping surfaces.

After getting the results obtained from Delaunay Tetrahadralization approach, it is found that the average deviation reports between original point cloud data and developed STL file is within permissible limit of ±0.250 mm which is within tolerance band of RP Machine.

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