STANDARD TESSELLATION LANGUAGE IN RAPID PROTOTYPING TECHNOLOGY

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Abstract. *The growth of solid freeform fabrication (SFF) or layered manufacturing (LM) in biomedical applications has created the need for better technology in terms of model representation, accuracy and functionality. SFF models in medicine have been used mainly for assisting diagnosis, surgical planning, and manufacture of orthopedic implants. However, the technology has recently seen applications in the field of tissue engineering specifically in the fabrication of tissue scaffold structures. Traditionally, LM process involves the conversion of the 3D models into STereo-Lithography (.STL) format, a tessellation procedure where the model is approximated by triangles, sliced and then fabricated by the machine. The procedure worked well in the manufacturing industry which used RP to evaluate product designs and aesthetics by producing actual prototypes of the proposed design.*

Keywords: *STL-Standard Tessellation Language,RP-rapid prototyping, 3D modelling, CT scanning, CAD, CAM, CAD/CAM, Rapid Prototyping*

1. INTRODUCTION

STL (STereoLithography) is a file format native to the stereolithography CAD software created by 3D Systems.

STL is also called as Standard Tessellation Language. This file format is supported by many other software packages; it is widely used for rapid prototyping and computer-aided manufacturing. STL files describe only the surface geometry of a three dimensional object without any representation of color, texture or other common CAD model attributes. The STL format specifies both ASCII and binary representations. Binary files are more common, since they are more compact.

An STL file describes a raw unstructured triangulated surface by the unit normal and vertices (ordered by the right-hand rule) of the triangles using a three-dimensional Cartesian coordinate system.

Figure 1. Segmented 3D body with and without planar triangles used by the STL files

History of use

Stereolithography machines are basically 3D printers that can build any volume shape as a series of slices. Ultimately these machines require a series of closed 2D contours that are filled in with solidified material as the layers are fused together.

The natural file format for such a machine would be a series of closed polygons corresponding to different Z-values. However, since it's possible to vary the layer thicknesses for a faster though less precise build, it seemed easier to define the model to be built as a closed polyhedron that could be sliced at the necessary horizontal levels.

The STL file format appears capable of defining a polyhedron with any polygonal facet, but in practice it's only ever used for triangles, which means that much of the syntax of the ASCII protocol is superfluous.
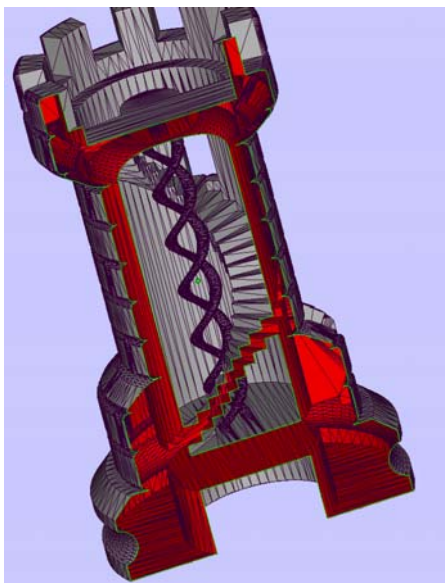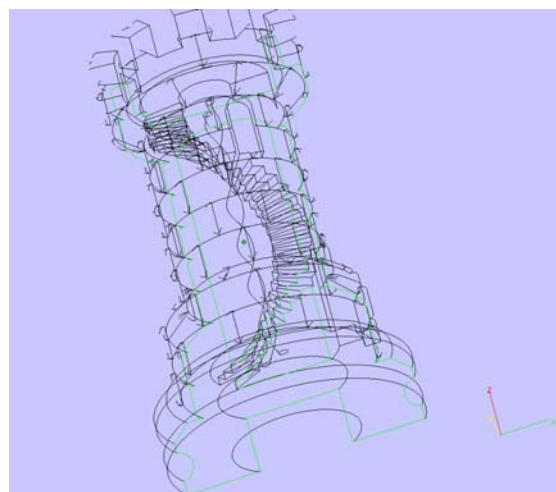

Figure 2. Section view (wireframe)

STL files are supposed to be closed and connected like a combinatorial surface, where every edge is part of exactly two triangles, and not self-intersecting. Since the

syntax does not enforce this property, it can be ignored for applications where the closedness doesn't matter.

Figure 3. Example of the complexity of the design

The closedness only matters insofar as the software which slices the triangles requires it to ensure that the resulting 2D polygons are closed. Sometimes such software can be written to clean up small discrepancies by moving endpoints of edges that are close together so that they coincide. The results are not predictable, but it is often sufficient to get the job done.

Use in other fields

Many computer-aided design systems are able to output the STL file format among their other formats because it's quick and easy to implement, if you ignore the connection criteria of the triangles. Many computer-aided manufacturing systems require triangulated models as the basis of their calculation.

Since an STL file output, of a sorts, is almost always available from the CAD system, it's often used as a quick method for importing the necessary triangulated geometry into the CAM system.

It can also be used for interchanging data between CAD/CAM systems and computational environments such as Mathematica.

Once it works, there is very little motivation to change, even though it is far from the most memory and computationally efficient method for transferring this data. Many integrated CAD and CAM systems transfer their geometric data using this accidental file format, because it's impossible to go wrong.

There are many other file formats capable of encoding triangles available, such as VRML, DXF, but they have the disadvantage that it's possible to put things other than triangles into it, and thus produce something ambiguous or unusable.

2. SOLID MODEL FOR RAPID PROTOTYPING

Rapid Prototyping, also called Solid Freeform Fabrication (SFF), or Layered Manufacturing (LM), automatically generates physical objects layer-by-layer directly from 3-D CAD data, without conventional manufacturing and tooling processes. Figure shows some

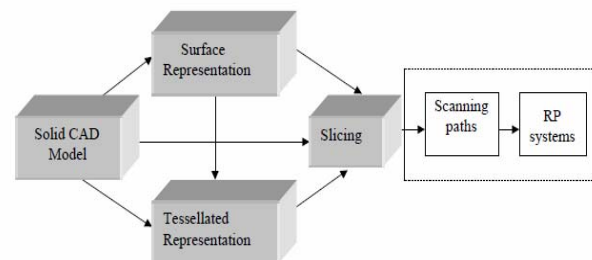possible transferring ways from the CAD model to the RP systems.

Figure 4. Transfer from the CAD model to RP systems

Geometric information processing for RP consists of two major steps: slicing the geometric description of the part into layers to generate the contours of the part for each layer, and then generating scan paths in each layer in a manner dependent upon the particular RP process. This paper discusses a novel approach to the former step (grayed boxes in figure).

In current RP practice, a 3-D CAD model is usually triangulated into an intermediate form, the STL file, which is then sliced in a uniform layer thickness.

Each slice becomes the input to algorithms for generation of the paths for material deposition /solidification. This process contributes to two important accuracy issues: tessellation and staircase effect.

Tesselation

Tessellation is concerned with the unordered set of planar triangles as well as the outward pointing normals of these triangles as found in the STL file. It approximates the surface of the CAD model (figure , left).
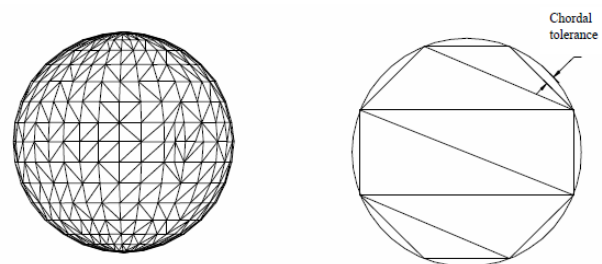

Figure 5. Tessellation of a sphere (right) and chordal distance (left).

The disadvantages of tessellation are:

It is a first-order approximation of the original CAD model and often loses the intent of original design as well as any geometric and topological robustness that the original data might once have had.

It is a list of triangles with no topological information, which often induces errors such as: gaps, mixed normals, overlaps, etc. This format carries a high degree of redundancy since each triangle is individually recorded and sharedordinates are duplicated within a file.

There is therefore a need to recreate the topology of the CAD model. This has given rise to "verify and repair" software which needs more human intervention and slows the production cycle time.

The user needs to input the acceptable chordal tolerance (figure , right) which is the distance between the plane of a triangle and the surface it is approximating. Increasing the number of triangles smoothes the surface, but also leads to much larger data files. The user has to balance the accuracy issue with the file size issue, especially for highly non-linear surfaces such as turbine blades or manifolds.

The subsequent slicing of large STL files could take many hours and create numerous small segments to represent the contour of the cross section. These small segments are harmful to laser or nozzle scanning and result in low surface finish and low productivity.

Staircase effect

After tessellation, the model is usually sliced into a stack of layers with a plane parallel to the horizontal plane. The boundary of the RP part is then a stepped approximation of the boundary of the original CAD model. Each physical layer is generated as laser/forming head scans the planar profile on the interior of a 2-D slice. As a result of this, all RP parts exhibit a staircase effect along the vertical direction.
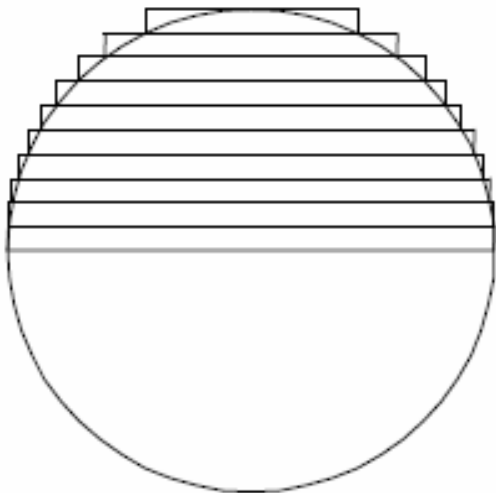

Figure 6. Staircase effect

The slicing procedure directly affects the extent of the staircase effect. The widespread uniform slicing procedure may result in a large staircase effect since it neglects the change in geometry curvature in the vertical direction of the CAD model. For controlling the accuracy of the model and for reducing the staircase effect, adaptive slicing needs to be performed.

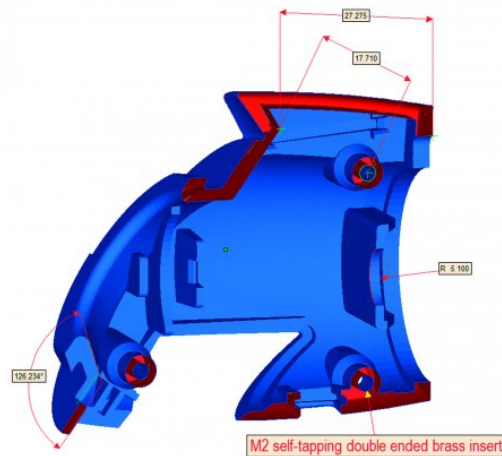## 3. MINIMAGICS: FREE STL FILE VIEWER. FAST STL INSPECTION AND COMPRESSION

Figure 7. STL section

MiniMagics offers:

- Import and save .STL, .magics or .mgx files
- Compress STL files up to factor 20
- View parts and rotate, pan or zoom
- Detect bad edges and flipped triangles
- Make a section
- Request part information, such as XYZ measurements, volume, surface area or number of bad edges
- Measure parts
- Add text annotations
- Create a print-out of parts
- See all information included in the .magics file (like pictures, annotations, etc.)
- Extended measurement options - precise measurements every time, using points, circles and planes.
- Enhanced visualization capabilities - quickly grasp complex projects
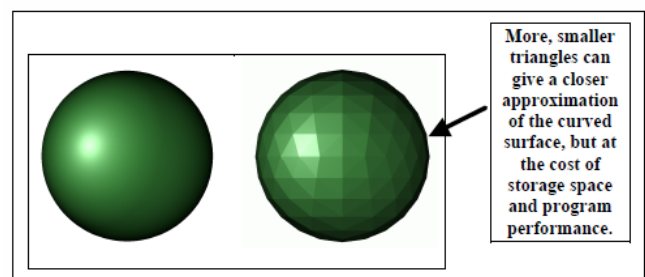- Easy silent server installation option - install on multiple computers with ease

Figure 8. Approximating a smooth, curved surface

Bounding Box

The bounding box of a part is a box defined by the minimal and maximal x-, y- and z-coordinates of the part. Those minimal and maximal coordinates can be found in the Part Information toolsheet.

The bounding box can be visualized via Menu/View/Part Dimensions or in the View Toolbar.
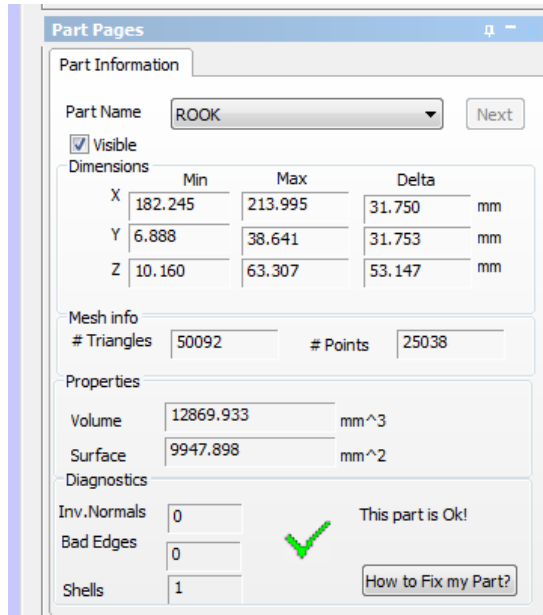

Figure 9. Visualisation of the Part Information

The standard surface representation used in industrial CAD systems are trimmed non-uniform rational B-Spline (NURBS) surfaces.The main advantage of this representation is the ability to compactly describe a surface of almost any shape. Recently, the introduction of T-Splines extended this surface representation further with hierarchical

concepts, making it even more attractive for design purposes.

Although much effort has been spent to build specializedhardware for rendering these surfaces (e.g. [Abi-Ezzi and Subramanian 1994]), no hardware implementation is available for this purpose so far. The main reason for this are the irregular mesh data structures required to generate a trimmed mesh (see Figure)
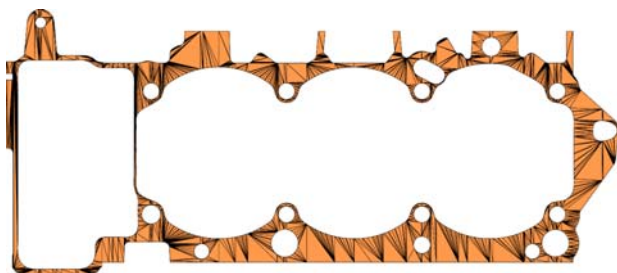

**Figure 10. Tessellation of a planar surface with complex trimming
(20 trimming loops) by explicit meshing**

4. DATA TRANSFER BETWEEN CAD SYSTEM AND RP SYSTEM

Rapid Prototyping (RP) is a technology that transform a design generated in Computer Aided Design (CAD) to a 3D model parts. CAD models are usually done on a CAD system and then transported into the RP system. A good interface between the CAD and the RP system is one of the key factors of producing a good quality prototype.

CAD is the creation and optimisation of the engineering design using the computer as a productivity tool. Computer Aided Manufacturing (CAM) refers to the use of computer to control the activities on the manufacturing floor. The integration between CAD and CAM is essential in order to improve the productivity in a manufacturing environment and also to ensure the quality of the product produced with shorter time and less cost. Rapid Prototyping (RP) system is one example of a technology that benefited from the integration of CAD and CAM. McMahon and Browne defined RP as a term used to describe a number of techniques which rapidly produce solid physical models of components and products using 3D computer data by a group of relatively new manufacturing technologies.
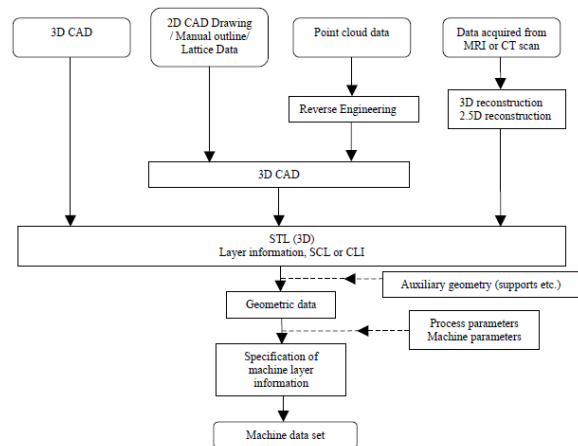

Figure 11. Generalized illustration of data flow in RP (after Gebhardt, 2003)

Basically, RP imports data or model from a CAD system and uses it to build the physical prototype of the model. This prototype of the model is useful in realising the conceptualisation of a design. RP can produce a real 3D physical model that can be physically checked or evaluated. The model can also be used to produce moulds and dies quickly thus, reducing time and cost of introducing new products.

However, to some extent the quality of the prototype produced is dependent on the quality of the interface between the CAD and the RP system. Any data lost or distorted during the interface between the systems will effect the quality of the prototype produced.

The main function of the interface is to handle and transfer the data of a given part from CAD systems to RP systems. An RP system uses the data from a CAD

system to produce a model or prototype of a part, component or product. However, an RP system cannot use directly the data from a CAD system. The data need to be converted to a suitable file format that can be read and understood by the RP system. Some of the file format that can be used in RP system are; HPGL (Hewlett-Packard Graphics Language), STL (Stereolithography Tessellation Language), IGES (International Graphics Exchange Standard), STEP (Standard of The Exchange ofProduct), and CLI (Common Layer Interface).

Figure 12. Classification of RP processes (after Gebhardt, 2003)

There are three basic steps in producing a prototype on an RP system:

1. A part is modelled on a CAD/CAM system and must be represented as closed surface to enable the system to create solid object.

2. The solid or surface model is then converted into a file format that the RP system can understand.

3. The RP system then analyses the file to generate the commands to fabricate the model on the RP machine.

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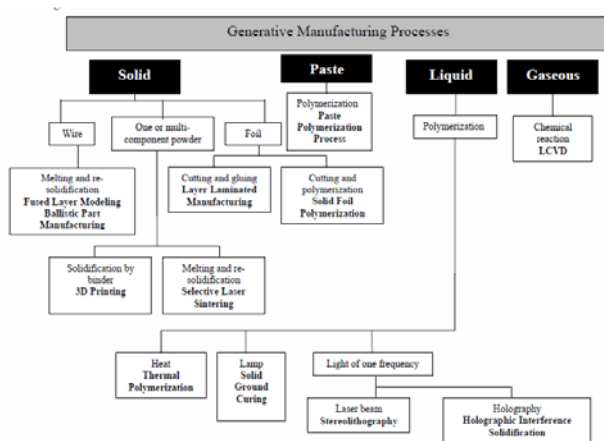[4] Dolenc, A., Makela, I., „ Slicing Procedures for Layered Manufacturing Techniques" Computer-Aided Design, Vol. 26(2) February, 1994 pp. 119-126.