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Technical Paper

Geometric approaches to input file modification for part quality improvement in additive manufacturing

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ABSTRACT

Additive manufacturing (AM) machines use the Stereolithography (STL) file as standard input file format to build parts. STL model is a triangular faceted approximation of a CAD model, which represents a part with less accuracy than the CAD model. Commercial softwares have the ability to convert a CAD file into an STL file based on a user defined threshold value to uniformly convert the entire part body into triangular facets. Increasing the geometric accuracy of STL models is typically accomplished by decreasing the user defined threshold value, which results in an increase in STL file size. In this research, a Surface-based Modification Algorithm (SMA) that adaptively and locally increases the facet density of an STL model is presented. The Surface-based Modification Algorithm is an error minimization approach to modify the STL facets locally based on chordal error, cusp height and cylindricity error for cylindrical features and is typically able to achieve a smaller file size compared to uniform export option. A novel bounding box based algorithm is developed to calculate cusp height error from the point cloud generated from the part by slicing the STL facets or from the CAD surface. Final results show a distinct improvement in the part error of the STL model using Surface-based Modification Algorithm (SMA) when compared to the original STL file.

1. Introduction

Additive manufacturing (AM) refers to the manufacturing of parts by building thin slices and layering the slices on top of each other, as shown in Fig. 1. The *Z* axis is usually considered the build direction. AM machines use the stereolithography (STL) file [1] as an input file format to build parts by different additive manufacturing processes.

Generally, three main stages exist in the additive manufacturing process planning. Modeling takes place in the first stage in which the geometric features of the part to be built are created and finalized virtually. The actual manufacturing process takes place in the second stage while the third stage concentrates on final finishing and post processing of the manufactured part such as external machining, hot isostatic pressing and heat treatment.

Despite the reporting of modified STL file formats with curved-edge triangles [2] and recently introduced Additive manufacturing file format (AMF) [3], current commercial AM machines still use STL files as standard input file. The STL file has planar triangles tessellated from the CAD surface, which introduces an approximation error, known as chordal error. Parts manufactured with STL file may also not satisfy Geometric Dimensioning & Tolerance (GD&T) requirements due to the approximated geometry. To increase the accuracy of CAD to STL conversion, there is a need to improve the quality of the existing STL file formats. Existing CAD packages export an STL file by globally increasing the density of STL file facets to reduce the CAD to STL approximation error. The denser STL facets leads to a substantial increase in the overall STL file size, resulting in more computational burden, more pre-processing time and unnecessary increase in accuracy of some unimportant features. In order to minimize the CAD–STL approximation error, increasing the density of STL facets selectively and locally will result in minimizing geometric errors without unnecessary increase of file size.

This paper presents an approach to densify STL facets in areas that have critical GD&T error values, based on new patterns of facet formation that replaces the original STL facets. The modified STL file is then used to virtually build the part and verify that the part errors have been minimized per the GD&T callouts. The GD&T improvement is verified by collecting the point cloud data from the virtual build based on the modified STL file after the application of SMA.

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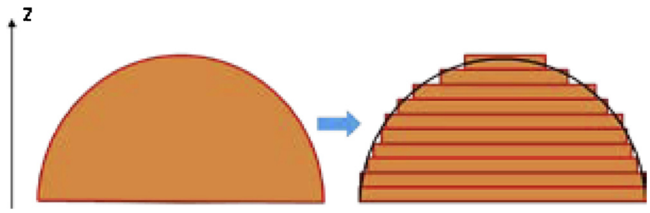

Fig. 1. Slicing and part building in additive manufacturing.

2. Literature review

2.1. Additive manufacturing

Additive manufacturing (AM), more commonly known as 3D Printing, refers to the manufacturing process which evolved from rapid prototyping (RP) techniques [4]. The fundamental principle of additive manufacturing process is creating parts by generating contiguous layers on top of each other. An STL file generated from a CAD model is used as an input file for building a part during the AM process.

2.2. STL file format

The STL file format is supported by many software packages and is a standard input format for contemporary AM machines. STL file consists of triangular facet data (three vertices and an associated normal), which represents the 3D surface geometry of an actual CAD model. The basic rule used to check the correctness of the STL file is to ensure that each edge of a triangular facet is shared by only two facets at most [5].

As we can see, in Fig. 2a, one edge of the upper facet is shared by two lower facets at the same time, depicting an invalid STL model while Fig. 2b represents a valid STL model. The modified STL models generated using the Surface-based Modification Algorithm (SMA), introduced in later section, are always valid STL models.

The STL part model is sliced by slicing planes that are perpendicular to part build direction and manufactured layer by layer by AM machines [6].

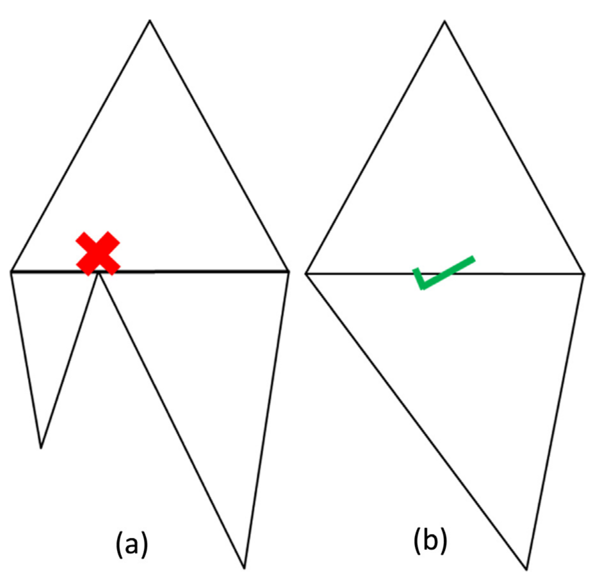

Fig. 2. (a) Invalid STL and (b) valid STL facets (adapted from [5]).

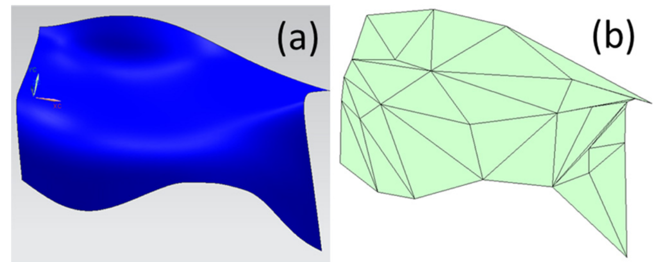

Fig. 3. (a) The original CAD model and (b) exported STL model.

2.3. Geometric error generated in CAD–STL conversion

Fig. 3 shows the difference between a surface defined by the original CAD file and the converted STL file using Siemens NX 8.5 and with a 0.3 error threshold. The CAD–STL conversion error is defined as chordal error [7–9], which is the Euclidean distance between a point on the STL facet and the CAD surface along the direction of the normal of the STL facet [10], as shown in Fig. 4. The length of the black arrows on the right side of the figure represents the chordal error of the point.

If P_{STL} is a point on the STL facet, $\bar{n_{STL}}$ is the normal to the facet and P_{CAD} is the corresponding point on the CAD surface based on the normal direction of P_{STL}, then the chordal error can be written as [11]:

$$\varepsilon_{ch} = \left\| P_{STL} - P_{CAD} \right\|$$

2.4. STL file local modification approaches

Previously a Vertex Translation Algorithm (VTA) [10,11] was proposed to selectively modify the STL format part model with the goal of reducing chordal error of certain STL facets. For each facet, the Vertex Translation Algorithm (VTA) finds a point on the CAD surface with the largest value of chordal error from the facet and then replaces the original facet with three new facets based on the point, as shown in Fig. 5.

The Vertex Translation Algorithm (VTA) was able to reduce the CAD–STL conversion error. Each iteration of VTA will reduce the error compared to the last iteration. However, quite a few iterations are usually required to satisfy some of the desired GD&T parameters and each iteration requires significant amount of computation time and results in increased file size.

The STL facetization pattern developed in Surface-based Modification Algorithm (SMA) performs better in decreasing GD&T errors and increasing overall part accuracy with lesser STL file size when compared to VTA.

3. Methodology

The application of SMA file modification algorithm is based on evaluation of average cusp height and average chordal error (and cylindricity error for cylindrical features) of individual STL surfaces.

In Section 3.1, a bounding box based cusp height calculation method is introduced. Section 3.2 introduces the method of obtaining average chordal error of an STL surface and the illustration of Surface-based Modification Algorithm (SMA).

3.1. Cusp height calculation using a bounding box approach

Cusp height is the staircase error generated in additive manufacturing process due to the 2.5D nature of layers (represented by the blue lines in Fig. 6). Cusp height also correlates with layer thickness.