Improving volumetric accuracy of AM parts using adaptive slicing of Octree based structure

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Abstract

In Additive Manufacturing (AM) processes, the layer-by-layer fabrication of complex geometries may lead to stair casing and thus error resulting in volumetric inaccuracies in the model. Using thinner slices reduces the staircase error and improves part accuracy but there is a tradeoff between number of layers and the build time for manufacturing part. This paper presents a octree based structure to improve the accuracy as well as reduces the build time. In the current work, firstly converting STL file into a modified boundary octree data structure (MBODS) and then calculating the non-uniform slice thicknesses (adaptive slicing) from the octree representation. This slice thickness at any height is computed from the AM machine parameters and the smallest octree size at that available height. After the computation of the variable slice thicknesses has been completed, the part is virtually manufactured and the part errors are calculated. The virtually manufactured part and physical models are inspected to evaluate the volumetric errors. This algorithm uses an octree approach to improve the volumetric accuracy. And build time for the two different case studies are also done

Keywords: Additive Manufacturing, volumetric accuracy, octree structure, STL file, adaptive slicing.

Introduction

The Beauty of Additive Manufacturing is to build any complex geometry which is available in system . The Basic principle of AM is to build part layer by layer till part finishes [1]. The major advantage of this technology over conventional process to build complex shapes easily. If the design is available in CAD system then almost 100 times physical part can be produced though AM. In the recent years the demand for AM fabricated models are growing drastically. The major challenges with this technology is stair case effect occurs due to layered manufacturing principle, Which effects the surface quality and build time of the fabricating model [2]. The need to overcome this problems gave opportunity to develop various slicing algorithms. In traditional uniform slicing algorithms the layer thickness remains constant for single STL file. The major purpose of this STL file is optimum layer thickness along with maximum possible build quality and minimum build time, which is not easy to attain through uniform slicing. But in adaptive slicing there is opportunity to have variable layer thickness for the STL file, where layer thickness can be modified according to the geometry of the part. Adaptive slicing models comes out with better quality with less build time compared to uniform sliced part [3]. The layer thickness is one of the major parameter which effects on part quality. If the layer thickness is small then stair casing effect will be minimum and vice versa in case of curved and complex geometry. The layer thickness is also inversely proportional to the build time. Whereas in adaptive slicing the layer thickness is automatically defined on the basis of part geometry. This adaptive slicing gives a benefit of improved part quality and reduced built time in case of complex geometries also [4].

The primary objective of this paper is to compute AM part with variable layer thickness to satisfy desired requirements. N. Siraskar has developed a particular algorithm which adapts layer thickness depending on the geometry of the part and calculates the desired thickness. The major problem with these existing algorithms is huge time consumption and complex in design [5]. In most of the adaptive slicing algorithms, the slice thickness is determined on the basis of various parameters like upper limit of permissible Ra value or cusp height. The maximum allowable cusp height was introduced by Dolenc and Makela in 1994 [6], which is accepted by various researchers for various applications and they were successful in that some of them proposed slicing algorithms in which CAD model initially divides in to horizontal layers with allowable cusp height. Those layers do not satisfy this requirement will further divided in to finer layers of uniform thickness [7-10].

In the Local adaptive slicing also the part is divided into layers on the basis of allowable cusp height as discussed earlier [11, 12]. In this local adaptive slicing the initially it identifies the individual features are present in the part and then the slicing is done individually for the each feature. In most of the cases different features with same height will be present and those different geometries need different slice thickness to attain desired tolerance. Edge node in octree has been introduced, in which edge node is represented by singe edge rather than removing as gray, black or white. This work also consists of representing composed surfaces which consists biquadratic representation by extensive octree structure with help of edge, face and vertex nodes [13, 15].

Methodology

In the current study a new approach is used in AM process to minimize the stare case effect without compromising in part quality and build time. Desired outcome is achieved with help of Modified Boundary Octree Data Structure (MBODS). The steps followed to achieve desired accurate STL with appropriate volume is as follows:

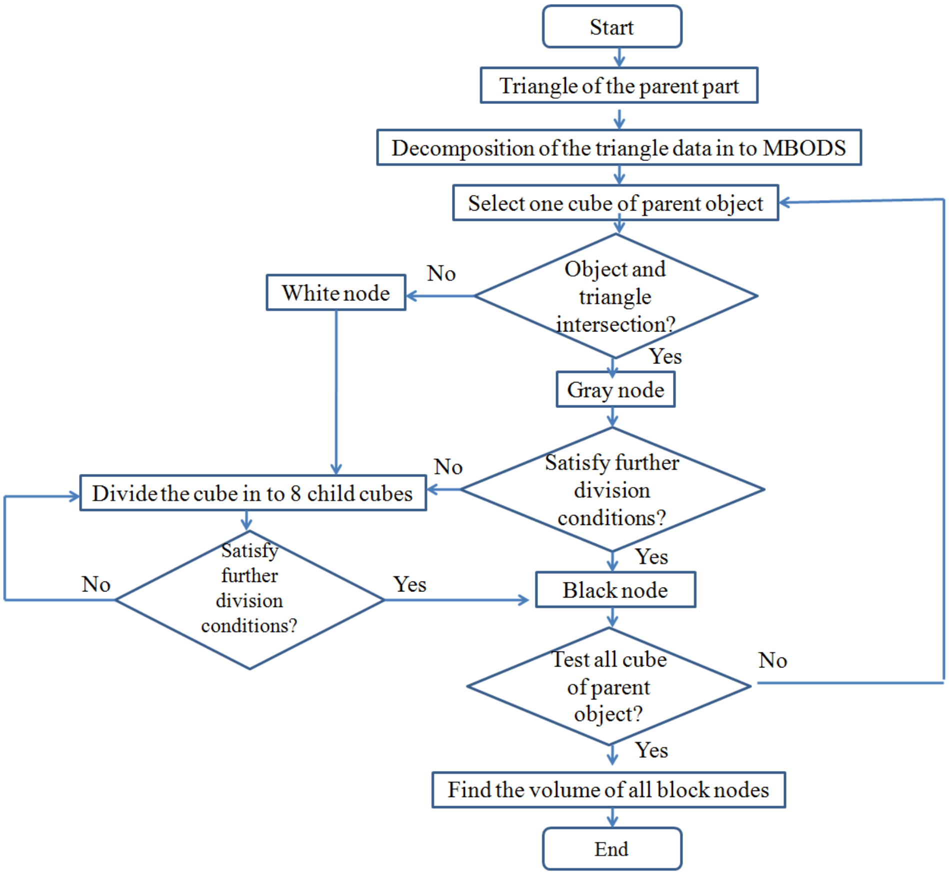

Fig 1. Flow chart of algorithm

Fragmentation of the initial STL File to required MBODS : Here in this octree representation the basic idea is to find the minimum and maximum values for the three axis. For example these calculated values are stored as X_{min} and X_{max} for the X axis and it continues same for the Y and Z axis respectively. Generally the STL file representation consists of only surface information and the name octree itself indicates a number eight. In the MBODS the part geometry is fragmented in to eight parts in all the faces of the geometry. These fragments are further classified in to the category of gray, white or black nodes. The formulas used in this fragmentation are as follows:

Calculate x_{max}, x_{min}, y_{max}, y_{min}, z_{max}, and z_{min} from the STL vertices (1)

Calculate the scalar quantity, $l_s = \max((X_{max} - X_{min}), (Y_{max} - Y_{min}), (Z_{max} - Z_{min}))$ (2)

Calculate the cube depth, $N = \text{ceil}(\log_2 (l_s/T_{min})$, where T_{min} is the minimum slice thickness (0.1 mm considered, it is minimum slice thickness of SLS) (3)

Calculate the size of the root cube is $L = T_{min} \times 2^N$ (4)

Initializing the gray, white or black values: The color of the node is represented on the basis of the specific property or identity of the node. The assignment of the white color represents that there was the presence of geometry and no overlapping is present. The gray color represents that the geometry is present in particular fragment and also there was overlapping of the geometry. The representation of black color means that there was no geometry present in this area and it is an empty or support area.

Further finer division gray node: The gray color node indicates that the overlapping of geometry is present and which needs to be further fragmentation. This further division of fragment is required till the overlapping issue is resolved and there are no more gray nodes present or when node value attains to the level of layer thickness (0.1mm). Which means that in the final geometry there are no presence of gray nodes or gray node with less than or equal to the size of layer thickness.

Octree calculation for the gray nodes: The STL is the representation of the boundaries and here even though it is in octree representation still it is a STL representation, hence there will be no information about the volume. So some separate technique is required to calculate the volume of the gray node. Here Ray casting algorithm is used to calculate the volume of the required gray node. For this ray casting to calculate the gray nodes and divided in to finer squares with number of N×N matrix.

Finding the final volume of the geometry: The final volume geometry is calculated on the basis of the representation of the white nodes in the entire geometry. All the final black nodes are exempted from the calculation in finding the volume. All the rays represented with help of ray casting method are used to find out the rays that which are present inside or outside of the cube and the threshold value of the cubes are also taken in to consideration to perform whether further fragmentation is required or not and final volume of the geometry is calculated using the below formula:

$$VO_{cube} = \frac{\sum h_{out}}{\sum h_{tot}} \times V_{cube} \tag{4}$$

Here Σht_{tot} is the total sum of the height of all the rays and H_{out} is the sum of the lengths of all the ray segments which lie outside the part.

Build time calculation: Typically build time is means the time taken by machine to build the geometry. this was calculated on the basis how much time spend by laser (since SLS process is considered in this paper) on each layer to build the geometry and time taken to spread the powder for each layer. Here the time taken to spread the powder for each layer almost remains constant. In case of uniform slicing the layer thickness remains constant but in case of adaptive slicing layer thickness varies, thus build time will be reduced. Here the build timer and number of layers are inversely proportional to each other. the build time taken for the entire geometry is calculated by using the following formulas:

The time to build one layer is then Ti= Tp + Ai/(V_{laser} ×D) (5)

And the time to build the entire prototype is: Tb =T1+T2+T3……Tn ; (6)
where n is the layer number
The machine specifications considered in this work as follows:
Layer thickness of T_{min}= 0.1mm; Layer thickness of T_{max} = 0.2 mm
speed of the laser V_{laser} = 5 m/s; laser beam diameter D= 0.030 mm

Results

Here in this paper with help of the above procedure found out the volume for the two different case studies with irregular in geometry as shown in Fig 2. In the below two cases the overlapping of geometry is present and the results obtained with help of above procedure are compared with the uniform slice thickness of 0.1mm and 0.2mm. The comparison consists of the number of layers and the volumetric error when compared to the original CAD geometry.

Case 1:

Initially the volume for the below shown fig is calculated using the uniform slicing method with a layer thickness of 0.1mm and 0.2 mm. the part is divided by uniform slicing and the volume of the each layer is calculated to find the complete volume of the part and same procedure is done for both the layer thicknesses. In the next step the volume of each node is calculated and added to get the final volume with help of octree method and results are tabulated as below.

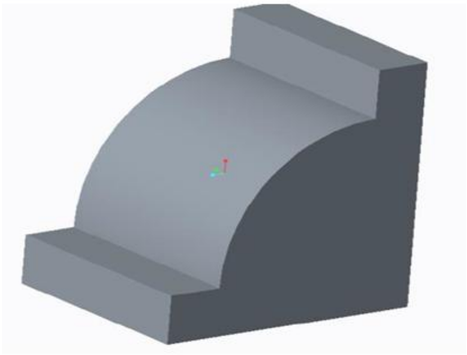

Fig 2. CAD Model of the object 1

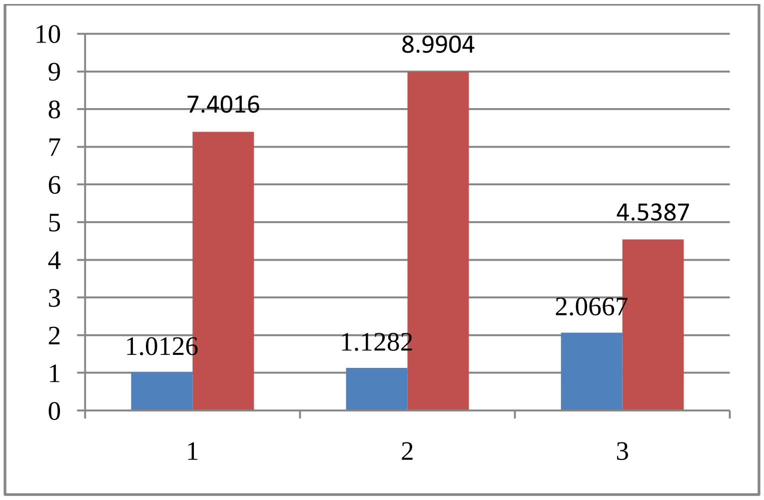

Fig 3. Volumetric error & Build time Vs slice thickness

Case 1 Part specifications:

Volume of the object =514.2 mm^3 The width of the part = 10mm
Breadth of the part = 8mm The Height of the part = 10mm

Calculated machine specification of AM:

Layer thickness of T_{min} = 0.1mm; Layer thickness of T_{max} = 0.2 mm
Speed of the laser V_{laser} = 5 m/s; Laser beam Diameter D = 0.030 mm

Allowable volumetric tolerance for used MBODS = 0.0003 mm^3

Table 1. The comparison results of CAD Model of the object 1

Slicing Method	**Adaptive Slice Thickness by MBODS**	**Uniform Slice Thickness**	
		0.1 mm	**0.2 mm**
Number of slices	83	101	51
Volume of CAD file	514.2	514.2	514.2
Volume of VM part	508.993	508.3986	503.573
% Volumetric error	1.01282	1.1282	2.0667
Build Time	7.4016 min	8.9904 min	4.5387 min

Case 2 Part specifications:

Volume of the object =1020 mm^3 ; The Min radius of the part = 3 mm
The Max radius of the part = 6 mm; The Height of the part = 16 mm
Allowable volumetric tolerance for used MBODS = 0.0003 mm^3

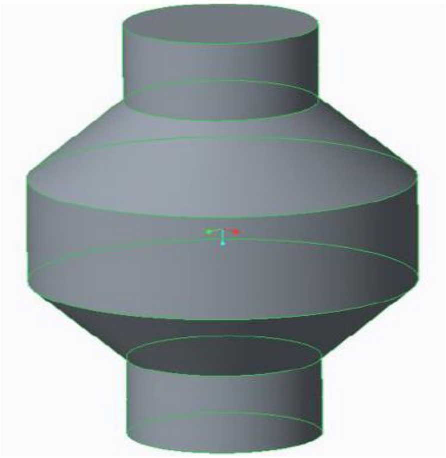

Fig 4. CAD Model of the object

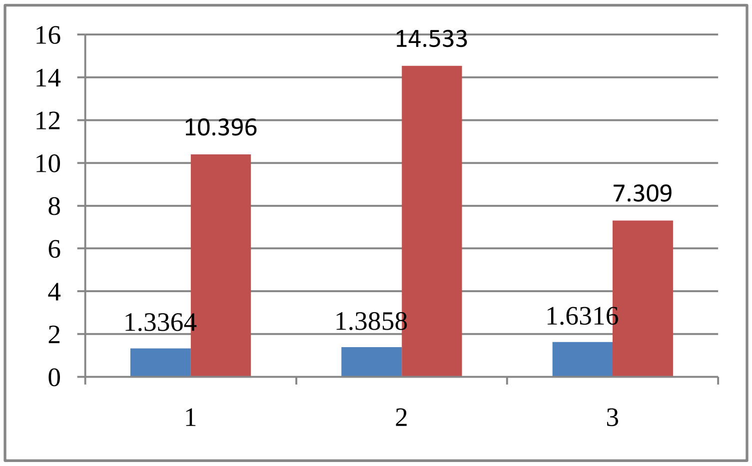

Fig 5. Volumetric error & Build time Vs slice thickness

Table 2. The comparison results of CAD Model of the object 2

Slicing Method	Adaptive Slice Thickness by MBODS	Uniform Slice Thickness	
		0.1 mm	0.2 mm
Number of slices	115	161	81
Volume of CAD file	1020	1020	1020
Volume of VM part	1006.368	1005.864	1003.357
% Volumetric error	1.3364	1.3858	1.6316
Build Time	10.396 min	14.533 min	7.309 min

Conclusion

With this approach the boundary data structure variable slice thickness is computed. Using this information part is manufactured virtually. This two test cases, in which boundary data structure of the part is calculated and these parts are then virtually manufactured using the computed slice thickness also inspected for volumetric error. Build time is also calculated to evaluate the effect of adaptive slicing on it. It is observed that with small amount of volumetric error can be achieved by short build time. In future this algorithm can be developed in such a way that it can extract the part data directly from CAD model. In this paper volume occupancy is used as a criteria for termination of division of cube. But in future other criteria can be used for cube termination and checking the accuracy of the AM part. Also to calculate volume of the part inside the cube is done by using ray tracing method. In future this can also be changed with other more efficient technique.

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