Adaptive Layering Methods for Improving 3D Printing Accuracy

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Abstract. 3D printing technology realized the intelligent production of products. However, in the process of 3D printing, due to the limitation of production instruments, the thickness of each actual material layer can only change within a fixed range. It will cause ladder effect. Especially printing a large degree of bending, the 3D printing product manufactured through the traditional plane layered method has strong ladder effect and phenomenon named loss of character. In this essay, there are two approaches which are used in current society to solve the problems of 3D printing models accuracy. The approaches are named flat adaptive stratification and curing adaptive stratification. Based on traditional layering approach, people improved the algorithm so that the thickness of material layer can be adjusted. People named the approach flat adaptive stratification and use it to reduce the ladder effect of 3D printing models. Coordinating with other algorithms, flat adaptive stratification can also play a role in reducing models' loss and offset characters. With the development of 3D printer, people can use curving adaptive stratification to print models. Using curving adaptive stratification, people can remove the ladder effect from 3D printing models. In the feature, people can also use curving adaptive stratification to solve the problems named loss and offset of model character.

Keywords: Ladder Effect, Flat Adaptive Stratification, Curving Adaptive Stratification

1 Introduction

3D printing technology, is also called fasting modeling technology. Comparing to using some traditional manufacturing technology, people using 3D printing technology in process can cut down the time of products' production cycle.

3D printing technology are widely used on model manufacturing. Now, 3D printing technology are based on the CAD model data. The 3D printers build up material layer by layer to produce models and machine parts.

If people use 3D printing technology to produce models, they often could not get the productions as accurate as they want, because there is limitation in the algorithms. The main problems of these productions' accuracy are ladder effect, Loss of

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characteristics and characters' excursion. These problems will influence the productions' normal performance, which is very important. Adaptive stratification technology can solve problems such as the ladder effect and loss of characteristics.

With the developing of stratification approaches and printers, people have chance to solve the problem named characters' excursion. 3D printing technology would play a huge role in manufacturing industry if the accuracy of 3D printing productions have greatly improved.

2 Literature Review

During the process of converting 3D models to 2D pictures, people use computer vision technology to scan entities to obtain corresponding 3D model outlines and decompose these outlines into 2D slices.They use free surface approximation method to approximate 3D contours, therefore The degree of deviation in the overall dimensions of the 3D printed model is determined by the product's 3D structural complexity.Once the original solid has more curved surfaces and branches, the dimensions of 3D printing generated model would have a large deviation compared to the size of original entity.

What is more, the smoothness of the surface is also limited by the performance strength of production equipment. The traditional 3D printer can only print layers with limited thickness. Due to the thickness limitation, the appearance size of the overall model deviates from the original entity when the printer is printing multiple 2D layers. This deviation causes ladder effect.Due to the thickness limitation, the appearance size of the overall model deviates from the original entity when the printer is printing multiple 2D layers. This deviation causes ladder effect.

Dea Keon Ahn et al. proposed a feasible solution that tries to look for the best direction to print products to reduce the product's surface to be as smooth as possible.Besides, using this kind of direction to instead traditional printing direction, people can improve the productivity of 3D printers [1] .

Hong-Seok Byun et al. analyzed the model manufacturing direction relationship with the neatness of printed products, product manufacturing cost and product printing time to determine the best printing direction [2].

Zhanming Li et al. not only analyzed the product printing direction's relationship with the neatness of printed products and product printing time but also created new models to increase product cleanliness and speed up product manufacturing, so that they could find the best product printing direction [3].

Zhanli Li et al. analyzed the layer thickness for 3D printing relationship with the neatness of printed products, product manufacturing cost and product printing time and proposed the approach that determining layer thickness for 3D printing according to the Product dimensional accuracy, production time, and production cost of 3D printed products. The printer can adjust the layer thickness to print different parts of the model to ensure the 3D printing product is as accurate as possible without significantly extending the production cycle [4].

Except choosing the best printing direction of the model, choosing different thickness in areas of varying complexity is also a good approach to improve 3D printing efficiency. Using a thinner material layer to print parts with complex structures can improve the model's accuracy, and using a thicker material layer to print parts with simple structures can reduce the printing time. Using the attributes of STL document, which is the most popular kind of document in the filed od 3D printing, people can transfer the half-side numbers of discrete triangles on the model outline surface, the correspondence between twin halves and the normal vector of a discrete triangle. Connecting these information with the layer where the combined section is located, they can quickly found out the sheet layer outline data of 3D printed model. According to the angle formed by the normal vectors of the representative discrete triangles between layers they can get the slope of this position relative to the production direction and determine the most suitable layer thickness.

2.1 Existing Plane Adaptive Hierarchical Processing Ladder Effect Method

Science the surface roughness, dimensional accuracy and shape error of parts are mainly affected by the "step effect", people started from the molding system to reduce the surface deviation of the molding system according to the STL model, thereby reducing the volume deviation between the STL model and the final product. According to the above concept of optimization criteria, people can achieve this goal by changing the molding direction and adjusting the layer thickness of different slices. According to the criterion of improving the accuracy of the model as much as possible within a relatively fixed time, the system will set the total volume deviation between the STL model and the final formed product as Δv. P represents the direction of the printer printing model, N represents the normal vector of the selected discrete triangle in the STL model, h represents the corresponding material layers thickness, and the blank part framed by the black line represents the volume deviation between the STL model and the component. Δvi (as shown in Figure 1, Δvi is shown as the blank).

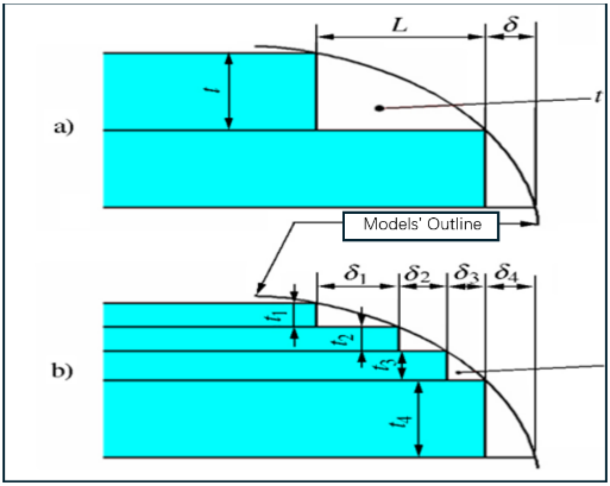

Fig. 1. The different Δvi between models using traditional stratification and adaptive stratification [5]

According to the characteristics, which is the models are composed by many triangles, of the STL files, the computer can use the angle between the normal phase $n_{i,j}$ (The normal vector of the j-th triangle in the i-th layer) corresponding to each discrete triangle and the manufacturing direction vector to determine the layers' thickness. Firstly, set the x-y resolution threshold value (L) of the 3D model voxel by themselves. Secondly, computers read STL model in ASCII code format and store the individual vertex coordinates, vectors, and surface angle values for each discrete triangle. Thirdly, the computer defines the height value of the lowest boundary of the model as 0, and uses the maximum layer thickness to try to layer. Among all the discrete triangles within this assumed layer, the computer takes the maximum value of $S\square\vec{n}_{i,j}\square\vec{n}$ ($|\vec{n}_{i,j}|,|\vec{n}|=1$) and records it as $L_{i-\max}$.

Fourthly, if $L_{i-\max}$ <L, the computer would performs a layering operation and starts layering the next layer at the upper boundary of the layer. If not, the compute would reduce the thickness of the assumed layer according to the step size set by the relative algorithm and preform the third step calculation again.

2.2 The Advantage of Curving Adaptive Stratification:

For some parts with small cross-section variations after computer laying, 3D printer using a layered approach with flat layers will print model quickly, because of the simple algorithms. However, for parts that have a large degree of change between cross-sections after layering or have many curved parts on the surface, the products' ladder effect is hard to eliminated after the process of 3D printing. Besides, when facing the small section size, materials can only be distributed in a fixed plane at a single level if the printer move along the path corresponding to the flat layering method. What is more, choosing flat ladder method to print the models with complicated structs, 3D printer need to spend additional time to move between different printing areas, which would cause the adhesion between layers decreased and the properties of 3D printed products reduced if the underlying material had been cooled before the upper material covered.

Using curving adaptive stratification, People can planned material laying path in the three axes of X,Y,Z, which means the nozzle can move along the curved surface. According to the topological relationship between the discrete triangles on the three-dimensional model surface in the STL file and the regional surface offset, computer can quickly split the three-dimensional model into curved sheet layers. 3D printing system, choosing curving adaptive stratification to replace flat adaptive stratification, not only can reduce the surface ladder effect as much as possible, but improve the product layer structure and the mechanical properties of the product.

Wang Yu et al. established a relevant mathematical model by studying the surface roughness of products produced using fused deposition modeling (FDM) technology and the forming mechanism of parts when FDM technology is used to produce parts. They determine the key parts of the parts by analyzing the part structure, used computers to calculate the roughness of models printed at different printing angles, and selected the most appropriate printing direction on the principle of not significantly increasing product production time as much as possible. They reduced the material layer thickness in key areas as much as possible to reduce the roughness of the product, effectively predicting the printing quality of parts and improving printing quality [6].

Liu Wenyong et al. proposed a method of layering in the direction of the method vector of the discrete triangle in the STL file in the inside of the model. They determine the shape of the model to be printed before the layer and connect the separate triangles that can represent the discrete triangles in the STL file on the line of the STL file. The computer is connected to the endpoints of each line according to the algorithm to obtain the surface layers of each line. Finally, a complete curved layer is achieved through the spiral scan in the layer, and the additive manufacturing of complex biological tissues is achieved [7].

Chakraborty et al. earlier proposed the concept of curved layer melting deposition (Curved Layer Deposition Modeling (CLFDM)) They are based on FDM to allow the materials to deposit on the bending plane. By selecting the direction of the material filling and using additional materials between the same layer or different layers of material lines to ensure the smoothness and model strength of the model surface and control the number of layers of the material layer. Its team has used mathematical methods to prove the feasibility of the implementation of this production concept [8].

Although achieving curved layering requires more advanced printers and more complex algorithms than achieving flat layering, curved surface layering effectively solves the step effect problem caused by traditional plane layering and improves the production accuracy of 3D printing models with complex surface features. Currently, a hybrid hierarchical algorithm based on region segmentation has emerged. This algorithm divides the model into surface layered areas and flat layered areas, using different algorithms in different areas. Additionally, this algorithm can be used on current FDM printers.

3 Specific 3D Printing Surface Layering Method

People use computers to calculate the angle θ between the discrete triangle normal vector of the model surface of the STL file and the printing direction of the printer. People input into the algorithm the maximum angle value θmax and minimum angle value θmin to find out the discrete triangles whose θ is bigger than the θmin and smaller than the θmax. In the process of retrieving discrete triangles one by one, the computer can improve the retrieval speed by consulting the topological relationships of triangles in the STL file. Then the computer will together the captured triangles. The retrieval process is shown in Figures 2 and Figures 3.

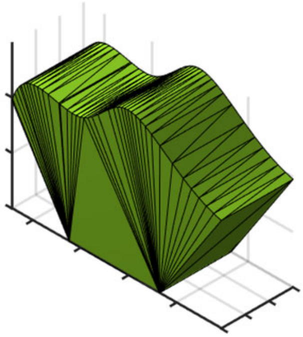

Fig. 2. The recognized model and the normal vector extension of each captured STL discrete triangle [12]

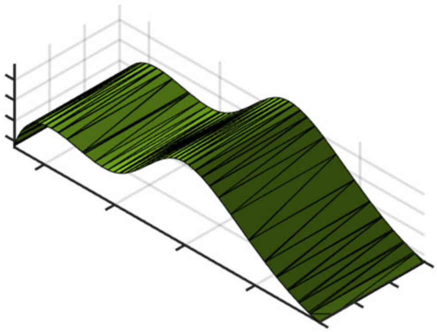

Fig. 3. The surface to be printed identified by the computer [9]

Firstly, people should set the number of delamination layers and delamination thickness in the algorithm. Secondly, the computer makes the retrieved triangles offset by the set distance and number of layers in the opposite direction of their normal vectors. Thirdly, the computer uses the surface obtained by the last offset to segment the 3D model into curved and flat layering areas. Fourthly, the computer calculates the intersection between the triangles on the surface being offset and the triangles on the side of the model during each offset. Lastly, the computer connects the line segments obtained in the fourth step end-to-end to form the contour of the surface. Models' feature loss and offset mean that, compared with the original design model, the actual model generated by 3D printing lacks the necessary features and features deviate from the original position.

As shown in Figure 4, the dashed lines represent the flaky layers generated by the traditional planar layering method and the distance between the dashed lines reflects the layer height of the material layer. Comparing the two pictures, it is obvious that using the traditional plane layering method to layer the model, there is a feature loss problem in parts 1, 2, 6, and 7 of the model, and a feature shift problem in parts 3, 4, and 5 of the model.

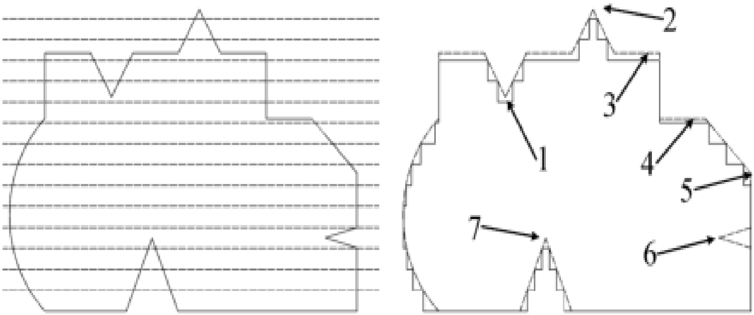

Fig. 4. Comparison of the original model to be printed and the actual printed model [10]

Siraskarn et al.used the improved boundary octopus data structure to convert STL files into geometric shapes, mechanical parameters and user definitions of multiple simple parts which is collectively referred to as Octree data structure in the text [11]. After that, the computer re -calculates the layered thickness and layers, and checks the sampling points of all manufacturing parts, and then evaluates the volume error and outline error of the actual product. This team used different slices to conduct layered experiments on each part. When the number of layers was small, the model's accuracy was higher.

Huang et al. used the curved layered method to layer the plane at the same time. The curved part was used in the model curved part. This method is based on the three -plane intersecting method, for the offset and consideration of the bending layer, as well as the residual height for adaptive slices. This method is called a curved layer adaptive slice (CLAS), which effectively captures the surrounding surface contour and other thinner parts. However, bending slices need to develop more complex shapes. Test facilities also need to be further improved so that they can be programmed to implement adaptive bending layer slices on various thickness. However, this method is mainly used to solve the problem of strong ladder effects when the model is manufactured [12].

Li Wenkang et al. In response to the loss and offset problem of the characteristic layer of the existence of the additive manufacturing model, a plane self -adaptation layer called the original model was selected to find the adjacent and the height difference than the minimum than the minimum. The two features of the layer thickness value are adjusted to the characteristic height of the adjacent features of each situation above the above situations. By adjusting the size of the manufacturing model, they ensure that the characteristics of the characteristic height of the adjacent level are not less than the minimum layer thickness of the printer of the 3D printer, thereby avoiding the problem of lack of characteristics and avoiding the issuance of the issuance of the positive offset [13].

4 Solution

Firstly, computer collects height data of all feature layers and place them in ascending order in a list. Secondly, the computer adjusts the heights of two adjacent feature layers whose height difference is less than the minimum layer thickness to ensure that feature are not lost. Thirdly, the computer adjusts the number of layers and the layer thickness of each material layer to ensure that the special front is on the upper or lower surface of the material layer. Fourthly, according to the result calculated by the algorithm, the printer print the model.

The details of the second step: Step1--Computer set the model's upper boundary height to highest and the lower boundary height to 0. Step2—computer adjust the height starting from the two adjacent feature layers in the middle of the arrangement. If the height difference is less than half of the minimum layer thickness, the two feature layers are merged. Otherwise, the two feature layers are translated in opposite direction by the same distance until the difference is equal to the minimum layer thickness.

Currently, there are few cases in China where the curved adaptive layering method is used to solve the problem of model feature loss and offset. This article refers to existing curved layering cases and makes the idea of using curved adaptive layering to solve the problem of model feature migration and loss. Firstly, the computer sets the model's upper boundary height to the highest and the lower boundary height to 0. Secondly, the computer looks for the pairs of adjacent feature layers whose height differences are less than the minimum layer thickness. Thirdly , computer adjust the height of different periods of other layers so that the outline layer is formed before the printer prints the feature layer.

5 Conclusion

At present, when using additive manufacturing technology, products have problems such as step effect, feature layer loss and feature layer offset. People can use adaptive stratification methods to alleviate or even eliminate the step effect of products, solve the problem of product feature layer loss, and alleviate the degree of product feature layer offset. Adaptive slicing can be divided into plane adaptive slicing and surface adaptive slicing. The plane adaptive layering algorithm is simple and has low requirements for 3D printers. Compared with traditional layering, it only adjusts the thickness of each sheet layer to improve the production accuracy of the product. The surface adaptive layering algorithm is complex and has high requirements for 3D printers. It can completely solve the problem of ladder effect in most 3D printed products. Curently, the domestic problem of feature layer offset in 3D printing models has not been solved through simple plane adaptive layering. In the next stage, the feature layer offset problem can be solved by developing surface layering methods.

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