Research Status of 3D Printing Support Structure Optimization

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Abstract. In today's digital era of rapid development of science and technology, 3d printing technology is undoubtedly the best for its superior production efficiency compared with those traditional manufacturing methods such as lathing, planning, milling, grinding, which has been widely used across various industries, capable of processing many complex parts. However, with the rapid development of this technology, it is inevitable to encounter some bottlenecks. The difficulty in removing the support structure is one of them. This paper mainly reviews the existing research in the past five years from three dimensions: improving the surface quality of 3D models, enhancing the performance of printed parts and reducing the support volume. These methods include optimized segmentation, flexible changes to the printing direction, development of new algorithms, and reasonable selection of printing materials.

Keywords: Support Structure, Surface Quality, Reduce Volume

1 Introduction

3D printing, also called Additive Manufacturing (AM), is the technique of producing multilayered or complicated geometric products by means of an adhesive material, for example, a powder or plastic. With the development of the times and the continuous maturity of technology, a variety of 3D printing processing methods have also been born. Nowadays, it is possible to utilize an amazing mixture of polymers, ceramics, metals, composite materials, and biological materials to produce the additive, including in cluster laser polymerization, laser melting or sintering, digital optical treatment, fusion deposition modeling, EBM fusion, and electrospinning. In the past two decades, people have also conducted a lot of interesting research on additive manufacturing. If the plane's normal vector is towards the negative, or if the plane is larger than the normal distance from the printer, the surface will be protruding, and the support structure needs to be added at this time [1]. The bearing construction is, however, a mechanical element which is manufactured as an integral part of the construction of the article in order to guarantee its structural integrity in the course of manual manufacture and is not designed for use as an article. The end product has to be discarded, often by hand. However, inexperienced users inevitably face technical difficulties. One significant

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challenge is the automatic generation and optimization of support structures. Therefore, the development of a systematic method for mechanically optimizing the support structure for additive manufacturing processes is a related issue, which will greatly affect the quality and production efficiency of the final parts.

The 3D printed model parts can be directly applied to actual production or physical assembly. Therefore, the surface quality of 3D printed parts determines its surface effect and overall quality, which is an important parameter for the quality evaluation of 3D handicrafts and must be paid attention to. For the majority of business 3-D printers, however, a uniform filling configuration is often employed to save building time and materials. In certain circumstances, however, those objectives cannot be met, for example, for a particular load. A solution needs to be found for specific application situations that will contribute to the improvement of 3-D printing properties in different ways, for example by increasing the structure strength and ensuring the image quality of the print [2]. Therefore, this paper must try to ensure that the quality and strength of the printed parts meet the requirements. In addition, when printing large volumes of solid objects or overhanging objects in the existing additive manufacturing technology, there is still a problem of waste of redundant supporting materials. Support materials may also be an important reason for the long production time and high energy consumption in the manufacturing process [3]. Therefore, it is also necessary to reduce the volume of supporting materials. In short, it is very important to optimize the support structure of the 3D model, which can ensure the stability and accuracy of the model in the printing process.

2 Literature Review

In order to improve the surface quality of 3D model: Li Rui, Peng Qingjin in 2021 proposed a subgraph data structure to pre-segment the three-dimensional model to build an application set, then, this paper apply the training of the deep learning system to extract the hidden features. Together with the Affinity Propagation Clustering Approach, a product model is split into multiple components [4]. he found that the spacing of the two bands was decreased from 2 to 0.2 mm for the segmentation model, but different 3d printers and materials can be further tried in the future. In order to overcome the influence of traditional printing process on the surface finish of the model structure, Pengfei Tang et al. first analyzed the problems of the existing unsupported printing methods, such as the inability to accurately locate the concave surface of the structure and the uneven thickness of the layer, and then proposed a five-axis unsupported printing method based on point cloud data set [5]. The multi-branch and overhang parts of the model are segmented or divided by adjacent voxels and skeletons respectively, and then the appropriate angle slice is sought based on the segmentation plane. This method can be used for unsupported printing of complex multi-branch structures and has been tested on a five-axis printer to prove the reduction of printing time and material consumption. More importantly, it also reduces the surface roughness of the structure.

W.M.Wang et al. in 2016, in order to reduce the demand for support structures in 3D printing and improve surface quality, the input model is decomposed into a set of parts, so that each individual component can be oriented in a way that reduces the surface normal-s deviation from the horizontal direction (assuming that the printing direction is vertical) [6]. For easy assembling, the sequence and orientation of mounting are also computed. The practical and robust performance of this approach is demonstrated by a lot of experiments. It is shown that this approach can greatly decrease printing mistakes or print time. In the future, however, further research on the relation of the quantity of components, the quality of the printing and the vision of the seam, so as to seek a balanced solution. In 2021, Rui Lee and his colleagues put forward a new approach to segment the triangle on 3D grid as nodes and consider the distance from the centre of mass of neighboring triangles to be the edges [7]. Based on the properties and characteristics of the three triangles, the similarity matrix is obtained, and the Laplace matrix is built. Then, the 3D grid is grouped into a number of groups, and the optimization results are obtained. It is found that the cutting process can greatly increase the surface quality and decrease the quantity of bearing material. In the future, the relationship between the number of parts, area, surface quality and support structure can be considered in detail, and different printers and materials can be tried to form a better solution.

In 2023, Wang Liru et al. first analyzed and compared the existing research methods from the two main aspects of changing layer thickness and model direction forming and some other secondary aspects and found that most of them require special equipment and post-processing [8]. High cost and harsh environmental requirements cannot meet the needs of the UV-curable ink printing method they have studied. Therefore, the author explored the feasibility of printing multiple topographic map 3D models by changing the printing order of different layers by using the fluidity of UV ink before curing. The surface quality of the model was analyzed by means of the surface profile and slope of the model. The results show that the reverse printing can slow down the staircase effect and effectively improve the surface quality of the UV curing ink 3D printing model. In 2018, Han Xingguo et al. proposed a fused deposition 3D printing path optimization algorithm [9]. By selecting the angle, the filling area is merged to plan the filling path reasonably. In addition, this paper presents an algorithm of contour path planning based on ant colony algorithm. The probability formula of ants transferring from the starting point of one closed ring to the starting point of another closed ring according to the pheromone concentration is calculated and derived. The flow chart is drawn to determine the optimal solution of the printing order of the closed ring, and the printing order of each contour is reasonably planned. Experiments show that the implementation of this method can improve the dimensional accuracy and surface quality of printed parts.

For the above six articles, researchers have successfully improved the surface quality of 3D models by optimizing segmentation methods, developing new algorithms, changing the printing order, and employing machine learning analysis. These advancements have made 3D products more aesthetically pleasing and have pushed 3D printing technology forward.

In order to improve the performance of the printed parts :In 2023, Yi Liu and Peng Zhang et al. proposed a three-dimensional printing filling structure design method

based on parametric polyhedron units, which improved printing quality and mechanical properties by optimizing the wall thickness of the polyhedron the gap between the center of mass and the surface, as well as the filling structure [10].The method has been evaluated and compared on many 3D entities and various tests have proved the effectiveness of the method. However, the disadvantage is that the additional slice processing time and the discontinuity of the printing path bring a certain degree of limitation to the method.

Ning Lv, Yun Xulee and Yujing Qiao put forward that the first laying stage is the key point for obtaining good printing results and analyses the comparison between them and their respective strengths and weaknesses as well as their applicable ranges of Skirt, Raft and Brim [11]. This paper presents a new method to generate a new kind of platform attaching support, which not only decreases the influence of Brim's construction on the model's printing quality, but also decreases the amount of distortion. Finally, the experiment proves the effectiveness of the method. In 2023, Wang Jiang designed a more optimized laser 3d printing system [12]. The overall framework of the system is divided into three layers: upper, middle and lower computer layers. The model is reasonably selected according to the working performance and characteristics of different key hardware, and then controlled by computer. Finally, the control accuracy of the system is obtained by printing simple cuboids and cylinders. After testing, the control accuracy of the system can reach 99 %, and the printing error rate is low, which is 1 %. However, because the selected printing model is too simple, the printing accuracy and time obtained are not convincing enough, so more complex parts need to be simulated in the future. In 2017, Dong et al. carried out LS-SVM modeling based on statistical theory and introduced genetic algorithm for process parameter data and size error of SLA 3D printing model [13]. This method can predict the size error of the model under any process parameters, which provides a reference for printing users and can reduce the probability of printing failure. The model with the highest prediction accuracy of 92.6471 % is obtained by using HyperWorks finite element software to analyze the statics of the mechanism. It has guiding significance for the quality prediction of complex printing models, but it has limitations for some models with simple structure, incomplete parameters or narrow range. In 2019, Mao Yuxin et al.proposed a new design method of hybrid inner support structure [14]. Firstly, the diameter function (SDF) of each point on the surface of the model is calculated. According to the value of SDF, it is divided into cylindrical components (Vol) and non-columnar components (NCol). According to its mechanical properties, different internal support structures are generated for two different components: a columnar component support structure design based on skeletal muscle structure (MFS) and a NCol component support structure design based on tetrahedral crystal structure (TCS). For VCol component, MFS structure is adopted, while for N component, TCS structure is adopted. Col component adopts TCS structure. Finally, through the actual object printing test, it is proved that this hybrid support structure method is easy to achieve the optimization of the comprehensive index of material and strength.

With the goal of reducing the support volume:

Jiang Xiaotong et al. analyzed that the existing literature did not theoretically explain the calculation of the printing direction corresponding to the minimum support volume

required for 3d printing, so it filled this gap [15, 16]. They use the ray tracing algorithm to process the concave model. Aiming at the non-differentiability of the theoretical support volume function, a calculation method for the optimal direction based on spherical coordinate sampling and derivative-free optimization algorithm is proposed. Finally, according to the results of the algorithm in this paper, the feasibility of the algorithm is confirmed from the aspects of calculation accuracy, time and step size.

Shen Zhenhong, Dai Ning, and others have presented an algorithm to generate tree-support structure using critical slope restriction to solve the problem of big size and long printing time. It is proved by experiments that this approach is effective in decreasing the size of the carrier and cutting down the printing time in order to guarantee the stable printing. However, this study still cannot achieve support minimization for areas where support needs to be added, so local optimization is the key to future work.

Ruiliang Feng1, Xianda Li et al. in order to reduce the support volume and reduce the cost, firstly, the literature on the optimization of the support structure with fixed construction direction, such as the honeycomb structure and the tree structure mentioned in it, is mainly reviewed [17]. Then, an improved algorithm is proposed for the two-level support structure (Figure 1) generation strategy proposed by Jiang et al., considering the influence of the printing path, and a set of tree structures with good topology is obtained, which reduces the volume of the support structure. By comparing the printing results of models U, O, A, T with the latest research of jiang, it can be concluded that this method achieves a larger volume reduction of about 17 % -31 %. However, the limitation is that the support generation requires a long simulation time, and the blade combination method is random in the process of tree support generation. Therefore, in the future, the combination of blades in a more intelligent way may further reduce the support volume.

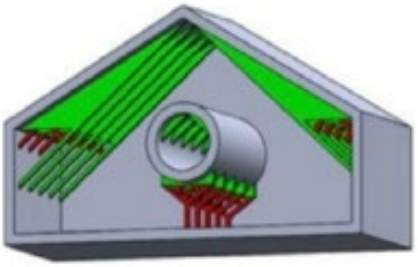

Fig. 1. An Improved Two-Level Support Structure for Extrusion-Based Additive Manufacturing [17]

In 2023, in view of the shortcomings of traditional 3D printing technology, inspired by the current five-axis 3D printing algorithm, a five axes 3-D printing algorithm is presented in this paper [18]. The model can be decomposed by a simple model data format (such as STL), so that the required support structure can be reduced to reduce material and time consumption. Through the establishment of the mathematical expression of the model, the model decomposition and collision analysis are carried out, and

the model printing of the auxiliary support reduction is realized, which reduces the printing volume.

In 2019, Sun Huichao et al. designed a 3D printer with a reversible working platform to solve the problems that it is difficult to ensure the surface finish of the specimen, the free-form surface is difficult to process, and the hollow structure strength is low [19]. They hope to reduce or even remove the support through the reversal of the working platform, save time and reduce the consumption of printing consumables. The experimental results indicate that this system can turn the 3-D printer's worktable and the connecting link of the jet machine to realize the turning of the 3-D printer so as to decrease the load of the carrier or even eliminate the carrier and increase the efficiency of printing. In 2016, Wei et al. proposed a tree-shaped sparse support structure with fuse as the support unit, aiming at the defects of existing support structure generation algorithms, such as unstable structure or many consumables [20]. The characteristics of scanning fuse structure in fuse deposition manufacturing were fully analyzed, and the support areas were classified. According to the characteristics of each type of support, the corresponding support structure forming algorithm was designed, and the optimal calculation model was established to calculate the minimum support structure that met various constraints. The printing quality was ensured, and the printing consumables were saved. In summary, reducing the support volume of printed parts is of great significance for reducing printing time, reducing material waste, and improving production efficiency. It is also the most direct and fundamental embodiment of optimizing the support structure. The existing literature has more research on mainstream 3d printing methods such as FDM and light curing printing methods, but rarely involves powder spraying and powder laying. Therefore, the future research direction and focus can consider some 3d printing methods with less application.

3 Conclusion

Above all, there are so many kinds of trials and possibilities in improving the 3d-printing support structure. In the future, the work of 3D printing to support needs to consider a variety of complex factors such as printing materials, gravity influence, printing platform, printing parameters, print head interference and so on. Although there are many teams or individuals in the world have made innovative breakthroughs in the optimization of supporting structure for a specific printing method, there are still many limitations. In the past five years, the literature on 3d printing has been collected and increased year by year, indicating that researchers are paying attention to this field. If the future can truly realize 3d printing without support, it will realize the manufacturing industry real zero loss, for enterprises to save huge energy, material and time cost.

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