Research of 3D Printing Support Structure

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Abstract. This paper delves into the comprehensive analysis of support structures in the realm of 3D printing. It initiates by shedding light on the historical context and the profound significance of support structures within the sphere of 3D printing. Furthermore, it delves into an in-depth exploration of the diverse array of support structures, accompanied by a comprehensive examination of their respective advantages and benefits. Moreover, this paper meticulously reviews the ongoing research endeavors in optimizing the volume and strength of support structures in 3D printing, aiming to enhance the overall efficiency and effectiveness of the printing process. Additionally, it evaluates the latest advancements and breakthroughs in this field, encompassing novel techniques and methodologies that have been proposed to optimize the utilization of support structures. Lastly, this paper presents a forward-looking perspective on the future development of support structures in 3D printing. It explores potential avenues for further research and development, considering emerging technologies and innovative approaches that hold promise in revolutionizing the landscape of support structures in 3D printing.

Keywords: 3D printing, Support structure, Columnar supports

1 Introduction

3D printing is a technology based on digital model files that uses bonding materials such as powdered metal or plastic to construct objects layer by layer. The concept of 3D printing has existed for a long time, exemplified by the construction of ancient houses through the stacking of stones from the bottom up. In the 19th century, Frenchman François Willème applied for a patent related to multi-camera physical sculpture. Later on, American Joseph E. Blanther patented a method for layering to create three-dimensional maps. This method gradually approached the fundamental principles of modern 3D printing. In the 20th century, 3D printing technology developed rapidly. Prior to 1980, technicians from Europe and Japan made significant contributions to selective laser sintering technology and photopolymerization molding technology. Following this, the most representative technique in the field of 3D printing, known as fused deposition modeling, emerged. By the end of the 20th century, 3D printing technology began to enter the market, and 3D printers became accessible products for technicians. In the 21st century, personal 3D printers flourished, and 3D printers became more accessible to a wider range of users. As the

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consumption of 3D printed products continued to expand, reducing material costs and improving printing efficiency became increasingly important. Due to the influence of material gravity, the material will fall dawn and cannot be stacked according to the target, resulting in the need for support structures. Therefore, reducing support structures has become a significant breakthrough in reducing material waste.

2 Classification and Advantages of Support Structures

2.1 Self-supporting

The structure topology optimization method based on the SIMP model is used to achieve product structural design. The image is converted into a binary image, and post-processing is performed on the results of topology optimization. The structural boundaries and overhang angles are determined, and the printing directions for different printing sections are determined based on their types. The design undergoes an overall optimization with angle constraints. Structural information is extracted, and after partitioning the 3D solid model, slicing and printing paths are generated for multi-axis 3D printing without supports. The self-supporting technology enables the printing of objects with self-supporting structures without the need for additional support structures, reducing material waste and greatly improving the efficiency of 3D printing [1].

2.2 Tree-Like Supports

Tree-like supports are a multi-level support structure that offers greater material and time efficiency compared to columnar or other projection support structures. However, their complexity in structure can present challenges in the design and manufacturing process. The generation algorithm for tree-like supports is based on the constraint of critical tilt angle. It constructs a mathematical model to solve for the nodes of each layer in the support structure and approximates the optimal tree-like support structure through a greedy algorithm and iterative approach. For complex models with protrusions, a voxel-based method is used to optimize the tree-like support generation algorithm. Based on the voxel method, the position relationship between the support branches and the solid is determined to avoid direct interference between the support and the solid. The voxel-based interference detection algorithm not only generates a reasonable tree-like support structure but also enhances the robustness and applicability of the tree-like support generation algorithm [2].

2.3 Columnar Supports

Columnar supports in 3D printing are a design used to support the overhanging parts of printed objects. During the 3D printing process, if the printed object has overhanging parts, these parts need to be supported to prevent deformation or collapse. Columnar supports are typically generated automatically by software, printing a series of slender column-like structures within the area that requires support to hold up the overhanging parts. The design of columnar supports is crucial for the quality and appearance of the printed object, as well-designed support structures can reduce deformation and defects during the printing process while maintaining the accuracy and integrity of the printed object [3].

3 Volume Optimization of 3D Printing Support Structures

3.1 Automatic Generation of Support Structures

Many 3D printing software programs offer the functionality of automatically generating support structures. These algorithms are capable of generating minimal yet effective support structures by analyzing the geometry and overhanging parts of the printed object, which minimizes the volume of the support structures. Research proposes a algorithm to automatically generate the support structure focused on accuracy, efficiency, convenience, and generation speed. Besides, it can exactly determine an optimal build-up direction for the minimum volume of support structures. This provides high-quality support structure planning [4, 5].

3.2 Support Density and Shape Adjustment

Adjusting the density and shape of support structures can significantly impact the volume of the support structures. Increasing the density of support structures can provide better support but also increase the material usage. Optimizing the shape of support structures, such as using thinner support columns or adopting grid-like support structures, can reduce the volume of the support structures.

3.3 Directional Optimization

Considering the orientation of support structures during design can help reduce volume. Designing support structures along the primary load-bearing direction can decrease the number and volume of support structures while maintaining their effectiveness. The best quality military flask component can be obtained by forming along the Z direction. On the other hand, selecting the maximum allowed thickness layer and forming along the y direction can maximize the efficiency of forming the military flask component. Therefore, when choosing the forming direction for the part, it is necessary to balance the importance of forming quality and forming efficiency in order to meet the requirements for both forming quality and efficiency (Figure 1) [6].

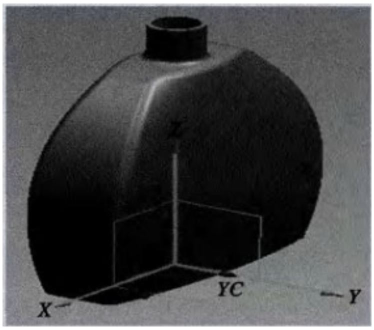

Fig. 1. Optimization of 3D printing forming direction and layer thickness [6].

3.4 Customized Support Structures

For specific printed objects, designing custom support structures may be more effective than relying on automatically generated ones. By manually designing support structures in 3D modeling software, the shape, position, and density of support structures can be adjusted as needed, maximizing the reduction of support structure volume. 3D food printing integrates 3DP and digital gastronomy technique to manufacture food products with customization in shape, colour, flavor, texture and even nutrition. This introduces artistic capabilities to fine dining and extend customization capabilities to industrial culinary sector [7]. It is meaningful in the area of 3D printing.

4 Optimization of 3D Printed Support Structure Strength

4.1 Increasing Support Density

Increasing the density of support structures can improve support stability and strength. A denser support structure effectively disperses forces, which reduces deformation and prevents the support structure from loosening. In one research ,Infill density is the amount of material used to fill the layer's inner area. This setting can make a part either fully or partially solid. The setting of the infill density is fed in the form of percentages like 25%, 50%, 75% or 100%. It again affects the build time, amount of raw material and strength of the FDM part [5].

4.2 Increasing the Diameter of Support Columns

Increasing the diameter of support columns can enhance the load-bearing capacity and stability of the support structure. Thicker support columns provide better support for overhanging parts, reducing the risk of deformation in the support structure. As stated in the literature, after obtaining the optimal location of the support structure, search for the radius of the self-supporting structure to meet the constraint of structural strength in the self-supporting structure optimization model, based on the searched support structure radius. So it is needed to adjust the support structure radius based on the requirements for the structural strength of the model.

4.3 Optimization of Support Structure Orientation

By optimizing the orientation of support structures based on the geometry and direction of forces acting on the printed object, the strength of the support structure can be improved. Designing the support structure along the primary direction of force maximizes its load-bearing capacity.

4.4 Grid Structure Design

Using a grid-like support structure can provide more uniform support, distribute forces, and increase the strength of the support structure. The grid structure can reduce the volume and `material usage of the support structure while maintaining its effectiveness. A 3D printing method based on simplified mesh models is proposed. Building upon existing algorithms for secondary error metric mesh simplification, this method combines the convex-concave nature of 3D spatial vertices and the cost of collapsing optimized vertices to ensure that folded vertices always simplify towards the interior of the model. While minimizing changes to the boundary features and physical properties such as rigidity of the mesh model, it reduces the number of triangular facets and decreases the model volume, thereby achieving the goal of reducing material consumption in 3D printing. The effectiveness of the method is validated by comparing the volume before and after model simplification [8].

4.5 Optimizing Support Connections

The connection between the support structure and the printed object is a critical point for support strength. Ensuring a firm and reliable connection between the support structure and the printed object is essential to avoid loosening or breakage. Additive manufacturing can be employed to produce structural components, including nodes for space frames, and potentially entire structures. The primary emphasis is placed on identifying optimal welding techniques and processing parameters [9]. Brilliant support connections are beneficial to enhance the strength of supporting structures.

4.6 Material Selection

Choosing the right material that meets the requirements of the printed object is also crucial for improving support structure strength. Some high-strength and heat-resistant materials can provide a more stable and reliable support structure. In a particular study, four distinct materials were analyzed, among which two were poly (lactic acid) (PLA) and the other two were poly (ethylene terephthalate glycol) (PETG). These materials underwent comprehensive evaluation from thermal, mechanical, rheological, and morphological perspectives. The primary goal of this research was to discern how the properties of these materials influence the performance and quality of a 3D-printed object. Test samples were extracted from 3D-printed semi-circular structures at varying orientation angles. Findings indicate that the samples crafted from PETG exhibited superior mechanical characteristics, especially in terms of elastic modulus and stretchability at the point of failure. In contrast, the PLA samples exhibited a more brittle nature, with stretchability at break significantly lower, roughly an order of magnitude less. Impact testing revealed that PETG samples excelled in energy absorption qualities. Additionally, PETG samples from 3D printing showed enhanced surface quality and more consistent inter-fiber bonding. The study concludes that selecting the right material is crucial for optimizing 3D printing outcomes [10].

5 Conclusion

This article revolves around the theme of support structures in 3D printing. It begins by introducing the historical background and significance of support structures in 3D printing. Then, it discusses various types of support structures and their advantages. Subsequently, it reports on the current research status of volume optimization and strength optimization of 3D printing support structures. (1) Discovering more high-performance printing materials. Such as soluble supports: some 3D printing materials support soluble support structures. These support structures can be dissolved by immersing them in specific solvents after printing is complete, avoiding the manual removal of support structures and reducing waste generation (2) Optimizing planning algorithms for printing paths and directions. In the future, it's feasible to conceive a sophisticated path planning platform. This advanced tool will possess the capability to autonomously select the optimal path planning methodology by analyzing specified input characteristics. It will maintain a comprehensive understanding of every path planning technique's strength and weakness, as well as their suitability for different additive manufacturing processes. Upon receiving user-defined objectives, like time efficiency, the platform will promptly present a list of feasible strategies, highlighting the most recommended approach along with a detailed breakdown of its merits and shortcomings.

References

1. Ye Jun, Wang Zhen, Zhao Yang, et al: Optimization Design and Manufacturing Method of Self-supporting Structures based on Multi-axis 3D Printing. CN202211307783.9 [2024-03-23].
2. Chen Jun, Zhang Qilin, Xie Buying: Research and Application of Tree-like Columns in Large-span Space Structures. Steel Construction 3(2), 42-58 (2010).
3. Li Zhongtang, Xu Rubin, Lu Wenlong, et al: Design and Research of Adaptive Columnar Support Algorithm for Melting Deposition Forming. Machine Tools and Hydraulics 49(10), 76-80 (2021).
4. Deng Hao, Guan Keliang, Chen Jin, et al: A Method for Automatic Generation of Self-supporting Structures for 3D Printing Geological Formations. CN201910023636.0 [P]. CN109741452A [2024-03-23].
5. Hur, Junghoon, and Kunwoo Lee: Efficient algorithm for automatic support structure generation in layered manufacturing. Journal of Manufacturing Systems 29(4), 154-162 (2010).
6. Yu Shihao, Zhou Sheng: Optimization of 3D Printing Direction and Layer Thickness. Journal of Plastic Engineering 22(6), 5-13 (2015).
7. Sun, Jie, et al: A review on 3D printing for customized food fabrication. Journal of Food Engineering 128, 74-85 (2014).
8. Dong Fangmin, Wang Jieyu, Sun Shuifa: A 3D Printing Method Based on Mesh Model Simplification. In: 12th International Conference on Advanced Computational Technologies, pp. 115-120. IEEE, Paris (2023).
9. Lange, Jörg, Thilo Feucht, and Maren Erven: 3D printing with steel: Additive Manufacturing for connections and structures. Journal of Constructional Steel Research 172, 106-115 (2021).
10. Ronca, A.; Abbate, V.; Redaelli, D.F.; Storm, F.A.; Cesaro, G.; De Capitani, C.; Sorrentino, A.; Colombo, G.; Fraschini, P.; Ambrosio, L: A Comparative Study for Material Selection in 3D Printing of Scoliosis Back Brace. Prosthetics and Orthotics International 44(5), 250-260 (2020).