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Research on Key Technologies of 3D Printing Control System

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Abstract—**As an additive manufacturing technology, based on a computerized 3D design model, 3D printing is mainly composed of high-precision mechanical systems, numerical control systems, injection systems, and computer technology. The software is layered discretely and numerically controlled to create a physical product in a superimposed manner. The advantages and disadvantages of mainstream 3D printing technology are compared. The method of key printing technology was studied, including the improved performance of stepper motors, selection and optimization of stratified parameters, and optimization of structural topology. Finally, several high performance chips for the print control system were discussed.**

Keywords—3D printing; control system; microfluidics control chip; hierarchical agorithm; structural topology; stratified parameters

I. INTRODUCTION

The 3D printing is an emerging manufacturing technology that builds out physical materials by layering materials based on a digital model. 3D printing will have a profound impact on the traditional process flow, production line, factory model, and industrial chain combination. It is a representative subversive technology in the manufacturing industry and has been advertised as the leader of the third industrial revolution by many media and industry professionals. 3D printing is usually done using a digital technology material printer. It is often used in the manufacture of molds in the fields of mold manufacturing and industrial design, and is gradually being used for the direct manufacture of some products. The technology is used in the jewelry, industrial design, construction, engineering and construction (AEC), automotive, aerospace, dental and medical industries, education, geographic information systems, civil engineering, firearms and other fields. As an additive manufacturing technology, 3D printing is one of the rapid prototyping technologies. Based on the computer three-dimensional design model, through the software layered discrete and numerical control molding system, special materials such as metal powder, ceramic powder, plastic and cell tissue are stacked and bonded by laser beam and hot melt nozzle. Forming and manufacturing a physical product. Unlike traditional manufacturing, which shapes and cuts raw materials by means of machining, such as mold and milling, 3D printing transforms 3D solids into several 2D planes. By processing the material and stacking it layer by layer, the manufacturing complexity is greatly reduced. This digital manufacturing model eliminates the need for complex processes, large machine tools, and labor, and can produce parts of any shape directly from computer graphics data, enabling manufacturing to extend to a wider range of production people.

The materials used in 3D printing are specially developed for 3D printing equipment in the form of powder, filament, lamellar, liquid, and the like. Taking a powdery printing material as an example, the particle diameter generally ranges from 1 to 100 μm depending on the printing environment. ABS is one of the most widely used non-universal plastics. It combines the properties of butadiene and styrene with impact resistance, high and low temperature resistance, chemical resistance, non-toxic and tasteless. In addition, it is easy to process and can be processed twice. PLA is a new type of biodegradable material made from starch raw materials extracted from renewable plant resources. It has good compatibility, degradability, physical properties, gloss and tensile strength, and is suitable for various processing methods, especially blow molding and thermoplastic. Engineering-Plastics refer to industrial plastics used as industrial parts or casing materials. It is excellent in heat resistance, impact resistance, aging resistance and mechanical properties, and is mainly used in industry. The photosensitive resin is a gel-like substance composed of a polymer. Due to its low viscosity, low rate of curing shrinkage, high swelling, low light sensitivity, and the like, the product has a smooth appearance and a transparent to translucent frosted appearance. Rubber-based materials have a variety of grades of elastic materials, low hardness, and high elongation at break, high tear strength, and high tensile strength, making them ideal for applications requiring non-slip or soft surfaces. The metal powder used in 3D printing differs from ordinary metals in that it requires high purity, narrow particle size distribution, and low oxygen content. At present, metal powder materials used for 3D printing mainly include titanium alloy, cobalt chromium alloy and aluminum alloy materials. Ceramic materials have high hardness, low density, high temperature resistance and corrosion resistance, and are widely used in aerospace, automotive, biomedical and other industries.

The 3D printer is mainly composed of high-precision mechanical systems, numerical control systems, injection systems, and computer technology. In summary, the manufacturing process of 3D printers generally goes through four stages of three-dimensional modeling, layered cutting, print spraying and post-processing. 3D modeling is divided into scanning and manual modeling. Scanning is an automatic modeling method that acquires three-dimensional data of a scanned object through a scanning device such as GOSCAN, and automatically generates a three-dimensional model. Create 3D models in Cartesian coordinates using 3D modeling software such as Blender, AutoCAD, and C4D. Since the 3D printer cannot directly operate the 3D model, the model file needs to be processed into a printer-recognizable description by the professional software provided by the printer. The thickness of each layer is determined by the properties of the printed material and the printing accuracy. The printer sprays or fuses the printed material layer by layer into a three-dimensional space in a layered, cut blueprint. There are many ways to achieve this stage. The more common way is to spray a layer of glue first, then add powder, and cycle. After the printing and spraying, there will generally be some rough sections and material burrs, which will require post-processing of the model, including curing, trimming, sanding, and coloring [1].

II. COMPARISON OF 3D PRINTING TECHNOLOGY

According to the available materials and the layers to create the parts, the printer process can be divided into the following five categories: Selective Laser Melting (SLM), Fused Deposition Modeling (FDM), Stereo lithography (Stereo Lithography Apparatus, SLA for short), Three-Dimension Printing (3DP), and Laminated Object Manufacturing (LOM).

Multi-Jet Fusion (MJF) is characterized by the use of two separate thermal inkjet arrays to create full-color 3D objects. When printing, one of them will move left and right, ejecting the material, allowing one to move up and down, spraying, coloring and depositing, giving the finished product the desired strength and texture. The two arrays then change direction to maximize coverage. Next, a refiner is sprayed onto the already formed structure. The portion that has been and is being deposited is then heated. These steps will cycle back and forth until the entire object is printed in layers.

The Continuous Liquid Interface Production (CLIP) works by manipulating light and oxygen to fuse objects in a liquid medium to construct a 3D model of the object. The projection device under the liquid pool causes the ultraviolet rays to illuminate the liquid surface according to the shape of each layer of the printed article. FIGURE I show the process of clip technique.

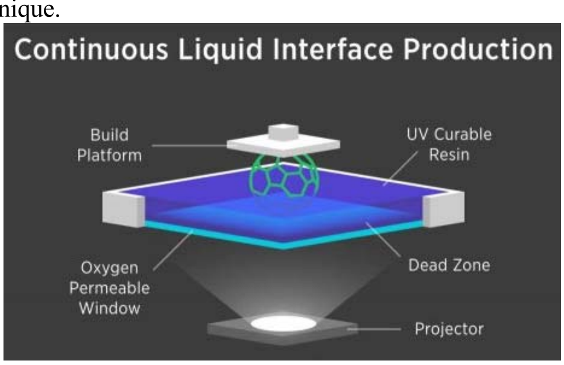

FIGURE I. CLIP TECHNICAL PROCESS DIAGRAM

At the same time, when a certain layer of printing is completed, the growth platform will be lifted up, and a new layer will be formed on the layer of resin that has just grown [2].

By using laser correction and oxygen curing processes, CLIP transforms traditional mechanical printing methods into tunable photochemical processes, superimposing layers into one molding. The raw material used in Nano Particle Jetting is liquid metal. At the beginning of the job, the printer first pulverizes the macromolecular metal particles into nano-sized technical particles. The pulverized metal particles are injected into the bonding ink developed by XJet. The metal does not melt in the ink, but instead forms a suspension that fills the entire cavity. The nozzle then extrudes the liquid mixture, solidifies it, and prints the product. Finally, the building chamber will evaporate excess liquid by heating, leaving only the metal part. Nano-metal jet technology can quickly print out metal parts. This technology has improved the speed and print volume of metal 3D printing by a step, and can achieve extremely high precision and surface finish. The vacuum environment is simple and safe to operate, and the support is easy to remove. However, temperature tolerance is lower than conventional metal 3D printing [3].

III. OPTIMIZATION OF KEY PRINTING TECHNOLOGIES

The 3D printing algorithm mainly includes the slicing algorithm, the path optimization algorithm and the optimization of the structure topology. In recent years, the results have focused on the geometric optimization problem in the field of computer graphics. The stepper motor is the drive component, and the 3D printer also has a hard requirement for the dynamic characteristics of the stepper motor.

A. *Improve the Dynamic Performance of Stepper Motors*

The stepping motor is the driving component. In order to ensure the steady state operation of the motor, the general printer will be set with its pulse width and other parameters when it is produced. The movement of the nozzle, in many cases, requires a quick response. The stepper motor that feeds the material has a poor dynamic performance, and the material is just too slow to spray, which affects the adhesion of the material to the work plane. This can cause curling, drifting, and so on. The dynamic performance of the motor that controls the movement of the nozzle or platform is not good, and the nozzle cannot quickly reach the target speed when doing rapid motion, so that the sprayed wire is pulled.

To improve the dynamic performance of the stepper motor, the following methods can be used. First we can adjust the current of the stepper motor. Some 3D printer manufacturers will provide current adjustment knobs, and some manufacturers will provide software to modify the pulse width of the stepper motor. In addition, too high current will not work, which will accelerate the heating of the motor, affect the life of the motor, and there will be a lot of noise and out of step. Second, we can reduce the speed of the stepper motor. The speed is too high, the adjustment time is too long, and then we can reduce the requirements a little. The feed rate of the material is related to the speed at which the spray head moves while spraying the material on one side [4]. The faster the nozzle moves, the faster the feed rate. Therefore, in turn, the feed rate of the spray material also affects the speed of movement of the spray head. These two speeds are coupled.

B. Selection and Optimization of Stratified Parameters

There is a certain step effect in the 3D printing process. Volume error is the main parameter to measure its impact. This parameter can be used to judge the difference between the theoretical model and the physical surface. In other words, the volume error can determine the closeness of the two, and at the same time, the accuracy and accuracy of the model can be effectively improved by reducing the volume error. For the control of volume error, layer thickness is an important factor. Reasonable control of layer thickness can reduce volume error.

Although the effect of the step effect can be reduced to some extent by controlling the layer thickness, it is not enough to achieve great results by technical limitations. Therefore, the introduction of the layering direction can further enhance the influence of the control ladder effect. A method of reducing volume error and build time from the perspective of stratification is used. The stratification direction selection should meet the following requirements. The sum of the surface areas that produce the step effect in the model is the smallest of the total surface area, that is, the volume error in the forming entity is the smallest. The number of layers should not be too large, so that the model is balanced and stable in the layered direction [5].

The premise of using the slice algorithm based on model topology information is to obtain the adjacent topology of the model, and then use the relevant technology to carry out layered processing. Set the Z axis to the layered direction and the layered plane to Zi. This algorithm is designed to calculate the 2D contour. First, the patch Ti intersecting the plane is found in the plane, and the coordinates of the intersection point are calculated, and the calculated topography is used to obtain the patch adjacent thereto. From this, the other Ti is derived and combined to obtain a layered two-dimensional contour. At the same time, the algorithm can be used to obtain the contour model of other planes, and then the hierarchical data is obtained. The application of this algorithm for 3D printing layered processing focuses on how to use the existing technology and conditions to calculate a reasonable topology, and then based on the topology to perform operations. First, calculate the vertices, edges, and faces of the model to obtain the corresponding data. Secondly, the data of the patch is calculated by combining the data of the vertex, the edge and the surface, and the patch information adjacent thereto is obtained according to the data, and the final data is derived by analogy. The advantage of the algorithm is that each intersection in the calculation process is carried out in an orderly manner, which directly improves the efficiency and quality of the calculation. However, the topology is more complicated, resulting in a lack of integrity of the resulting model and large memory consumption.

The slicing algorithm based on the position information of the triangle patch is mainly designed based on the characteristics of the STL model. The directional span of the stratification is proportional to the number of intersecting stratified planes. The height of the layered plane is linear with the height of the patch. According to the above two characteristics, the algorithm can effectively reduce the layering time and improve the efficiency of layered processing. In order to reduce the sorting time and improve the work efficiency, the number of classes should be reduced as much as possible in the process, and the number of levels should be increased. The number of patches should not be too much. The main advantage of using this algorithm is that it controls the number of patches reasonably, reduces the workload of calculations, and improves the efficiency of layered processing. The disadvantage of this algorithm is that it is not conducive to handling a large amount of patch calculations. Not only is the sorting workload large and the process are very complicated, the layering processing efficiency is low, and the objectivity of the final data is insufficient.

C. Optimization of Structural Topology

Compared with structural analysis, structural optimization makes people no longer limited to passively analyzing and checking a given structural solution in structural design, but actively seeking the optimal structure based on structural analysis. The main idea of topology optimization is to seek the optimal topology problem of the structure in the given design area.

The homogenization method is the first proposed continuum structure topology optimization method. The basic idea of the algorithm is to introduce the microstructure into the continuum, and to determine the optimal topology by increasing or decreasing the microstructure. The method uses the dimensional parameters of the microstructure as the design variables to transform the topology optimization problem into a size optimization problem that is easier to solve. The homogenization method is more rigorous in mechanics and mathematical theory, but the number of method design variables is large, the microstructure shape and angle variables are difficult to determine, and the optimization results are easy to produce porous materials and are not easy to manufacture. As an extension algorithm of the homogenization method, the variable density method introduces a hypothetical functional relationship between the unit density and the material elastic modulus, and does not involve the microstructure design and homogenization process. The program is simple to implement and computationally efficient. Common interpolation models include solid isotropic microstructures with penalization and rational approximation of material properties. The variables in continuum structure topology optimization methods are usually assumed to be continuously varying physical or mathematical variables. Evolutionary structural optimization is a topology optimization method based on discrete variables. The basic idea of the algorithm is to obtain the optimal structure by gradually deleting invalid or inefficient cells and making the remaining structure stable [6]. However, in order to ensure the stability of the remaining structure, it is usually necessary to perform multiple structural reanalysis.

Level Set Method uses Level Set Function to implicitly track dynamic interfaces. Figure 2 shows the level set description of the structure. The LSM-based topology optimization method can not only design the results with smooth boundaries, but also avoid the checkerboard phenomenon and the stress singularity. In order to realize the structural topology optimization design of multi-phase material structure, scholars have proposed a color LSM. In order to eliminate the dependence of the optimization results on the initial number of holes, we can combine the topological derivatives with the shape derivatives to achieve the purpose of automatically opening holes in the structure, and thus significantly improve the optimal convergence rate. The LSM-based topology optimization method uses discrete LSF, so the Hamilton-Jacobi equation needs to be solved in the optimization process. At this time, not only the speed field diffusion and initialization operations but also the optimization step size is required to satisfy the Courant-Fredric's-Lowy condition [7]. The research of LSM-based topology optimization method pays more attention to engineering practice. The two most popular research directions are to apply LSM to region topology optimization design and stress-related topology optimization design.

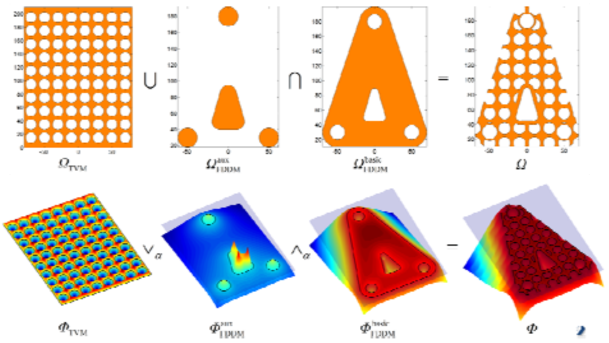

FIGURE II. LEVEL SET DESCRIPTION OF THE STRUCTURE.

Level Set Method uses Level Set Function to implicitly track dynamic interfaces. Figure 2 shows the level set description. The LSM-based topology optimization method can not only design the results with smooth boundaries, but also avoid the checkerboard phenomenon and the stress singularity in order to realize the structural topology optimization design of multi-phase material

IV. SELECTION OF MICROFLUIDICS CHIP IN THE CONTROL SYSTEM

The development and manufacturing of micro fluidic chip manufacturing has gradually introduced 3D printing technology. Polyjet 3D printing technology based on material ejection was first used. In the application, the mold was first printed by this technology, and then the micro fluidic chip was fabricated by PDMS material. The process of directly manufacturing a micro fluidic chip mainly includes a photo polymerization process and a material extrusion process, and the micro fluidic chip manufactured by these processes is mainly a polymer chip.

For the cooling of extruder heaters or electronic components, most 3D printers use some type of cooling fan. Many cooling fans use a 3-phase brushless DC motor. Although efficient, some extra work is required to rotate the motor at the proper speed. The DRV10983 simplifies 3-phase BLDC motors by integrating a senseless control system that allows the motor to start spinning in minutes.

One of the main requirements of a 3D printer system is to know the exact position of each axis. The most common method is to use a stepper motor with a limit switch. But we want to take the design a step further and achieve a contactless design. The DRV5033 Hall sensor detects when the magnet reaches a specific proximity of the sensor. The DRV5033 then sends a signal to the MSP430TM microcontroller telling it that the axis has reached the end of its motion path. In this case, the MCU now knows the absolute position of the shaft and uses a stepper motor to maintain the exact position of the shaft.

If the stepper motor driver is the backbone, then the MCU is the brain. The ultra-low power MSP430F5529 MCU allows you to control 3D printers. With the support of integrated USB, the MSP430F5529 can directly interface with the host PC. You can also load designs from storage media such as micro SD cards. A large number of peripherals allow you to easily control the different subsystems of your 3D printer while maintaining the low-cost nature of the MSP430 MCU family.

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