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Five-axis FDM 3D Printing Device Design

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Abstract

Common 3-axis 3D printers need to add support to manufacture parts with overhanging structures, and printed surfaces with curvature will have obvious step lines. In order to solve the above problems, this paper designs a "3+2" five-axis 3D printing structure by adding B and C axes to the traditional XYZ three-axis 3D printer. The Reprap firmware and Duet2 control card were used to complete the construction of the five-axis 3D printer control system.

Keywords

Additive manufacturing; 3D printing; 5-axis printer.

1. INTRODUCTION

Additive manufacturing has played a huge role in promoting and subversive change in the manufacturing industry, and is widely used in aerospace, biomedical, mold manufacturing, automotive and other fields. The "Mainstreaming of the Development of Additive Manufacturing" released by McKinsey & Company in the United States discusses the 40-year development process of additive manufacturing and believes that additive manufacturing will become the mainstream manufacturing technology. Friday, October 7, 2022, is "Manufacturing Day" in the United States, and the U.S. Office of Science and Technology Policy released the latest version of the National Strategy for Advanced Manufacturing (NSAM) on October 7, 2022. The new strategy revolves around three related objectives; (1) Development and implementation of advanced manufacturing technology. (2) Cultivate advanced manufacturing labor. (3) Build manufacturing supply chain resilience. The new strategy provides a comprehensive summary of additive manufacturing, addressing the U.S. government's vision for additive manufacturing and its role in U.S. manufacturing. In the report, "additive manufacturing" is mentioned more than 20 times at a time, and areas such as additive manufacturing and "smart manufacturing" and the digital transformation of the supply chain overlap highly technically, such as nano printing and biomanufacturing.

2. RESEARCH REVIEW

Some scholars use multi-axis industrial robotic arms to carry out multi-axis 3D printing experiments of FDM process, install an extruder at the end of the robotic arm execution, the robotic arm executes G-code, moves according to a specific trajectory, and extrudes materials from the extrusion head to jointly complete the printing of the model[1]. Ding combines a six-axis robot system and two inclined rotating platforms to form a 6+2 multi-axis printing system, which mainly uses the multi-axis printing system to print the overhang structure by decomposing the model into the hanging structure and the core structure, and mapping the overhang structure to the printing platform through cylindrical coordinate transformation[2]. Jing [3] proposed a robotic 3D printing system consisting of a 6-degree-of-freedom robotic

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manipulator and a material extrusion system for multi-axis additive manufacturing applications. At the same time, the authors propose a method to calculate the amount of E-axis extrusion based on the accumulated arc length of the printed points, which is used to realize the synchronous motion between multiple systems[4]. Compared with the traditional three-axis printing system, the proposed robot 3D printing system can provide greater flexibility when printing complex structures, and can realize surface layer printing. Hunt [5] et al. combined the concept of additive manufacturing with drones, a device that uses polyurethane expansion foam to create structures in the air in flight. Frederik Wulle et al. [6] used a multi-axis 3D printing device combined with hydrogel materials to print the tibia, first processing the MRI scan data of the tibia to obtain a smooth bone surface, then entering the data into a surface slice and path planning algorithm to generate a print path for the surface, and finally testing it with a seven-axis printing robotic arm and a newly developed print head for printing hydrogels.

3. PROGRAM

3.1. Mechanical structure design

Common 3D printers on the market are classified according to the type of structure as follows: Cartesian structure, core, delta. The parallel 3D printer actuator adopts delta parallel mechanism, and its mechanical components are the parallel mechanism body, motor, aluminum alloy bracket, stepping belt, linear guide, hot bed, extruder, etc. Its disadvantages: it can print very high in the vertical direction, but the printing range on the horizontal plane is small, resulting in low space utilization; Since the delta mechanism is a coupling parallel mechanism, the three axes affect each other, resulting in higher difficulty in printer debugging than that of series printers; Its overall shape is a tall tower structure, and its stability is poor under high-speed operation; Observing the three chains connecting the print head, it can be seen that the horizontal stiffness of the print head is poor when printing at high speed on the horizontal plane. Advantages: Only the print head of the parallel printer can be moved, the accuracy of the three directions of movement along the coordinate axis is uniform, and its printing speed is about twice as high as that of the series printer.

Figure 1. Structure of delta

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The tandem 3D printer actuator adopts a series mechanical structure, and its mechanical components mainly include: light rod, hot bed printing platform, drive motor, synchronous belt, synchronous pulley, external frame, etc. There are two kinds of shape structure, as shown in Fig. 2 and Fig. 3. It can be seen from Figure 2: the short-range extruder is installed at the printing nozzle, and the printing nozzle moves together, resulting in increased system inertia, reduced power performance, and continuous printing in a short period of time makes the drive motor heated, which greatly reduces the service life of the parts; The hot bed and nozzle are driven by two motors respectively, resulting in inconsistent running accuracy and reducing printing accuracy; Later printer leveling installation is complicated and cumbersome. Figure 3 is the common Prusa i3, belongs to the RepRap open source series of 3D printer more mature structure, deeply loved by DIY enthusiasts, vertical use of double brackets, increase the rigidity of the system, the motion structure is simple, easy to maintain and modify, low cost of use.

Figure 2. Tandem 3D printer

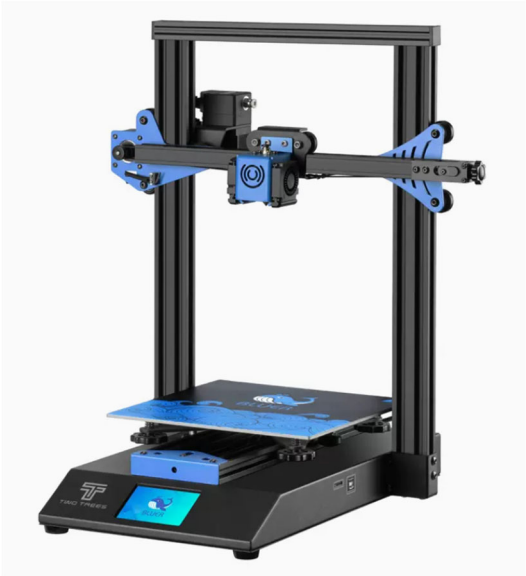

Figure 3. Prusa i3 3D printer

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By analyzing three typical traditional three-axis printers, from the volume point of view, Delta type 3D printers are large, and the series 3D printers are compact and easy to install and maintain. The structure of series 3D printer In terms of printer maintenance and modification, Prusa i3 has a simple structure, rich reference cases, and high stability of dual Z axis, so this paper uses this structure as the basic structure of the five-axis 3D printer, and establishes the mechanical structure of the five-axis 3D printer by re-adding the additional axis structure.

The five-axis 3D printer adds two rotation axes, and the design of this paper adds B and C axes, where the B axis rotates around the Y axis and the C axis rotates around the Z axis. C axis as an infinite axis can continue to rotate around the Z axis without interference, stepper motor directly installed in the center of the rotating platform to drive the C axis printing platform to do rotation movement, because the C axis in the process of motion only drive and printed parts contact with the printing platform rotation, does not involve static analysis calculation, only consider the size, weight, step angle and drive current of the stepper motor and other related parameters. The rotation of the B axis is driven by a side stepper motor to rotate the rotating platform, and the stepper motor driving the C axis is installed on the rotating printing platform, so it is necessary to calculate the driving torque of the stepper motor to ensure that the stepper motor of the B axis loses steps and slips during the printer movement.

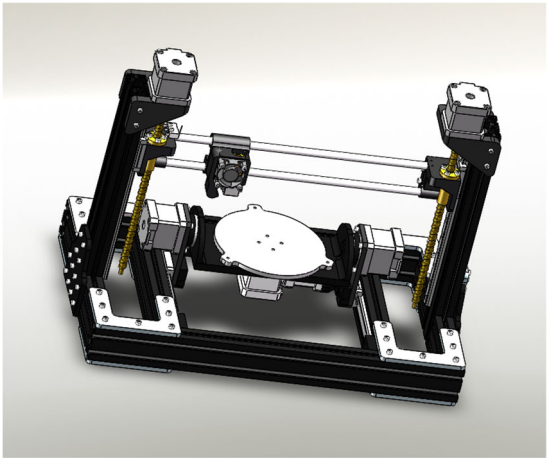

Figure 4. 3D model

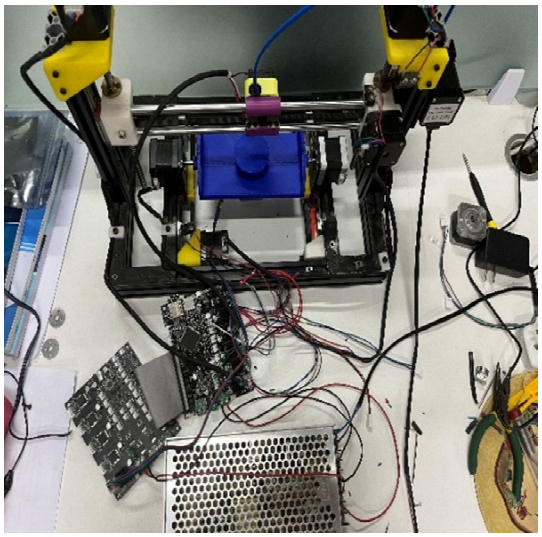

Figure 5. Physical model

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3.2. Control system

RepRap's electronics are based on the most popular open source Arduino platform and other boards that control stepper motors. Current versions of electronics use Arduino-derived Sanguino motherboards and other self-defined Arduino extruder controller boards. This structure allows the expansion of other extruders, each with its own extruder controller. Arduino are single-board microcontrollers that design electronics that are easier to use for multidisciplinary projects. The hardware is made up of simple open source hardware, designed primarily with 8-bit Atmel AVR microcontrollers, now available in 32-bit Atmel ARM. The software consists of a standard programming language compiler and a bootloader executed by a microcontroller.

The main chip of the Duet2 WIFI motherboard uses the ARM Cortex-M4 ATSAM4E8E to run clocked at up to 120 MHz. With RepRap firmware, configuration files are configured directly on the web page. Unlike other open source hardware, there is no need to modify the configuration in the source code, only need to configure the target printer in the config file, generate an executable file after configuration, and finally flash the file into the hardware. The G-code of the configuration file has high flexibility to adapt the G-code configuration file of the file system to the target printer on the web interface.

Since Duet2 reserves more extruder motor interface, the expansion board is connected to the motherboard through the cable, so add additional shafts to connect the drive motor of the B and C axes to the E1 motor interface and the Dux5 expansion interface, adjust the stepper motor line order to access the circuit board, because the Prusa i3 mechanical structure is selected to drive the extrusion head in the Z-axis direction of movement, so it is necessary to connect the two Z-axis stepper motors in the same stepper motor terminal, and the dual Z-axis drive makes the movement stable.

Duet2WIFI board is through the LAN to make the motherboard and the computer communication, after the board is connected to the computer hotspot, the computer assigns an IP address to the board, enters the IP address of the board in the computer browser and operates on the five-axis 3D printer on the computer side, such as uploading printing files, controlling the movement of each axis, controlling temperature rise, etc. The control interface is shown in Fig. 6.

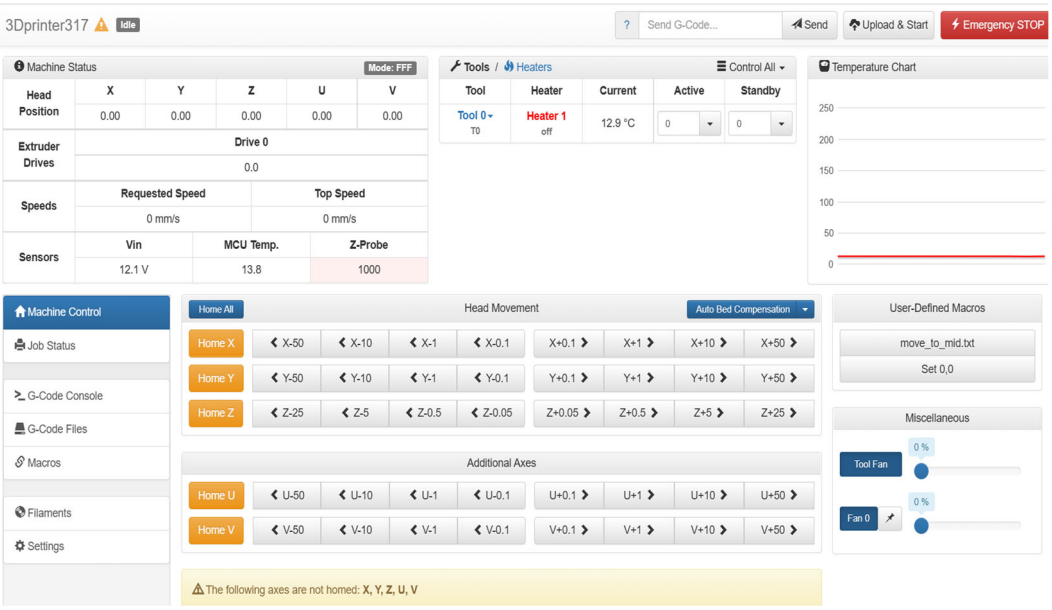

Figure 6. The interface of Control

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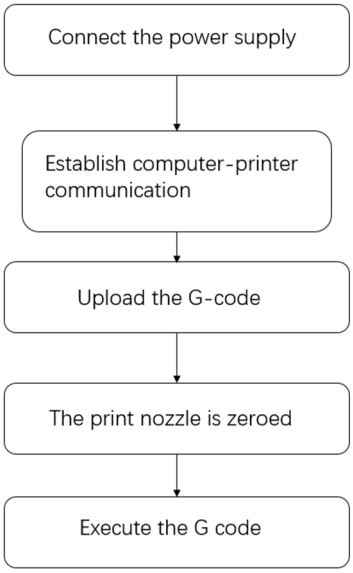

Figure 7. The Printing steps

4. TEST

Using the five-axis G-code for printing verification, the printed specimen is a bend with an inclination angle of 80 degrees, which is printed by the five-axis 3D printer built, without adding support, and has good surface quality. The printing model is shown in Fig. 8.

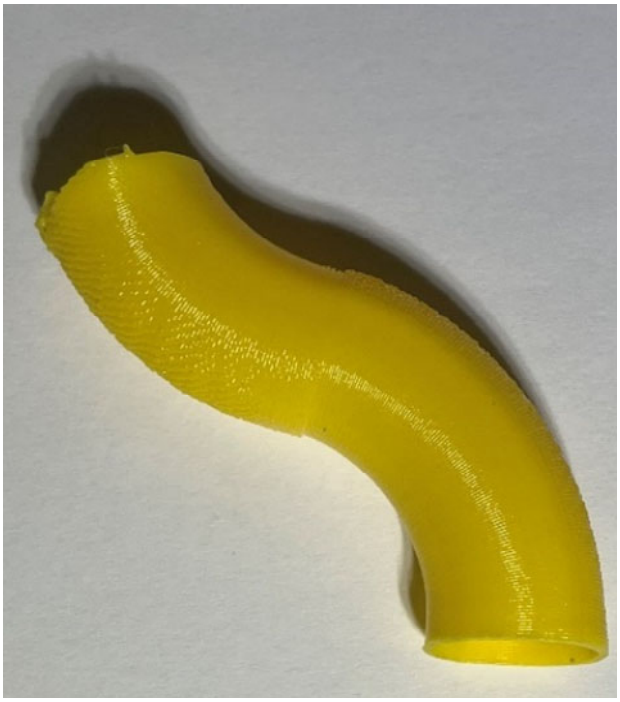

Figure 8. 80°Elbow model

5. CONCLUSION

By analyzing the structure of the traditional three-axis printer, a five-axis 3D printer is designed by adding two rotation axes. DUET2 open-source hardware and Reprap firmware

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were selected to form a five-axis 3D printing system, and the effectiveness and reliability of the five-axis 3D printer were verified through five-axis 3D printing experiments.

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