Process-oriented multidimensional 3D printer design based on IJP technology

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Abstract: At the early stage of industry development, China's 3D printing industry has problems such as an incomplete industry chain, immature raw materials, and confusing technical standards, but with the introduction and implementation of policies such as the "Made in China 2025" strategy in 2015, China's 3D printing industry has gradually developed and perfected, and the market shows a rapid growth trend. To respond to the government's policy call for the 3D printing industry and promote the industrialization of 3D printing technology. A process-oriented multidimensional printing device based on IJP technology for multiple fields is designed. First, the main functions and technical features of this process-oriented multidimensional printing device are introduced. Then the modularization of the process-oriented multidimensional printing device is introduced, which mainly includes modules such as an automatic material feeding module, fine grinding module, and printing drive module. Finally, the design of the temperature control system and remote control system used in the device is presented. The designed process-oriented multi-dimensional printing equipment for ceramics, glass, PCL, resin, and other materials is suitable for many fields such as education, medicine, and industry while integrating the functions of intelligent proportioning, high energy grinding, fine discharging and detailed printing, which effectively improves the product forming accuracy, shortens the forming time, broadens the complexity of forming and gives new life to the raw materials. This product has the advantages of high integration, and high intelligence, and can reduce human interference. It can change the status quo of scientific researchers and company employees who are bound by time and space and has a broad market prospect in the 3D printing equipment industry.

Keywords: 3D printer; IJP technology; Mechanical design; IoT technology; Automatic control

1 INTRODUCTION

With the rapid development of the Industry 4.0 era, 3D printing technology as a representative of strategic emerging industries has also received high attention from countries around the world. Nowadays, China's 3D printing technology is limited by the printing equipment[1], and there is a problem that the process application is not covered by the whole process. 2015 "Made in China 2025" issued by the State Council clearly in the academic, medical, industrial, and other fields to strengthen the research and development of additive manufacturing technology, to overcome the common technology of information design, process integration design, etc. 2021 additive manufacturing industry is included in the annual implementation of corporate standards The

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"leader" focus areas. This shows that the process application of 3D printing to achieve China's entry into the world manufacturing power must overcome one of the "problems".

Process-oriented multidimensional printing devices for multiple fields are still extremely important for research at present. At this stage, researchers have four main research directions for 3D printers based on IJP technology: raw material feeding and limitations[2], labor cost and efficiency[3], nozzle discharge and speed, molding accuracy and quality. Yang Minzhong et al. pointed out in "Rapid Development of Ceramic 3D Printing" that there are relatively few 3D printers applying IJP technology in China, and the printing nozzles, injection technology, molding accuracy and quality of the equipment are still lacking. Their research only stays at the level of problem identification and lacks specific solutions to solve practical problems. Shao Yuechen et al[4]. mentioned in "Machine vision-based monitoring system for FDM-3D rapid prototyping abnormal working conditions" can realize real-time monitoring of the whole process of 3D printing under unattended. This study explores the unmanned monitoring aspect of 3D printing in-depth, but no unmanned research has been conducted on the 3D printing equipment charging and grinding modules, resulting in less human-machine interaction in the overall control of the equipment and no complete closed-loop control. Among foreign studies, Elizabeth Loos[10] et al.'s defect analysis of 3D printed polymers and composites and exploratory research on the failure mechanism of raw materials in gear feeding provide important reference values for intelligent proportioning and highly energetic grinding of IJP-type 3D printing equipment. In addition, Edoardo Idà et al[5]. have conducted a detailed study of 3D printer nozzles, and the proposed new concept of CoreH-bot provides new ideas for the design of nozzle fixtures and print nozzle modules.

Although the existing 3D printers based on IJP technology are moving toward maturity, there are still problems such as low integration of devices, the rough surface of products, long time-consuming print monitoring, and frequent clogging of nozzles. In this paper, we conduct an in-depth study on 3D printers based on IJP technology and explore 3D printing devices mainly from the aspects of charging and grinding methods, nozzle, and fixture design, and software and hardware linkage based on the previous research. Starting from the mechanical structure, we also combine IoT technology, automatic control technology, and remote control technology to design the 3D printer unmanned, intelligent and remote, and propose a new vision of an IJP-type 3D printer with full process coverage for multiple fields[6].

2 PROCESS-ORIENTED MULTIDIMENSIONAL 3D PRINTER DESIGN SOLUTION

2.1 Function design

The equipment developed in this paper, as shown in Figure 1, integrates three major functions: IoT-enabled remote control, customized raw material production, and precision multi-material printing. The addition of IoT technology provides the possibility of data interconnection and cloud transmission, getting rid of the hassle of hardware plug-ins. Meanwhile, the monitoring module assists with remote control to create an unmanned printing environment. The intelligent dosing system enables the automatic matching of paste components on demand to complete customized raw material production. The need for precision multi-material printing is well met with the installation of high-efficiency vane-type ball milling equipment, which makes the liquid material used more delicate and can further improve the product printing accuracy. The technology makes it possible to print large assemblies with diverse mechanical properties through independently innovative head-changing equipment to meet the need for co-printing of different materials so that multiple materials can appear on one component at the same time[7].

Figure 1. The diagram of the device model

2.2 Structural design

Overall, it is a case with external housing wrapping major modules, and the internal contains an automatic material feeding module, high energy grinding module, printing drive module, nozzle fixture module, printing nozzle module, finished product lifting module, and temperature control module, and wireless remote module. The external housing is a sheet metal part, mainly used as a frame to store and support the fixed components. The interior is modularly designed for each function, making the device compatible with material proportioning, fine grinding, and precision printing at the same time. The modules work closely together under the control unit to integrate the many functions into one. The modularity of each function and the overall connection of the unit allow for close use of space without oversizing the unit[8].

2.3 Electronically controlled design

The core control chip used in the hardware is STM32F103, the image acquisition adopts ESP32-CAM camera development module and OV2640 image sensor with 120-degree ultra wide-angle lens, the temperature detection adopts MC-SMD103J3950R temperature sensor, and the heating of the printing platform is done with a tracked ceramic heating pad, and the power supply module adopts 220V to 24V DC switching power supply to power STM32, 28/42 stepper motor, and GM6020 brushless motor respectively.

3 PROCESS-ORIENTED MULTIDIMENSIONAL 3D PRINTER MODULE DESIGN

3.1 Automatic dosing module

It consists of four filling jars side by side and a rack and pinion drive mechanism as shown in Figure 2(a). When the charging command is executed, the 42-step motor drives the gear to rotate while the rack on the slide rail slides, and the grinding jars fixed above the rack pass through the four charging jars in turn to complete the filling of raw materials. When the grinding jar moves to the bottom of the filling jar, the iris sealing mechanism at the upper end of the grinding jar works, and the 28-stepper motor drives the pinion gear to rotate in one direction, which in turn drives the sealing blade to move from the center position to the jar wall, making the filling port open. The program then calculates the amount of material needed to control the piston feed in each tank based on the amount of material needed, thus achieving the exact amount of material extruded from each tank to achieve the feeding.

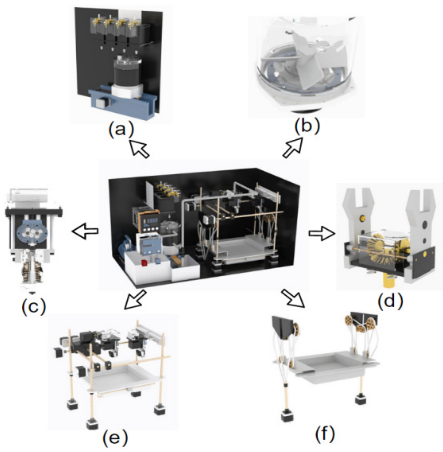

Figure 2. The General module diagram of the device

3.2 Fine grinding module

The self-researched high-energy ball mill is the core part of the fine grinding module. As shown in Figure 2(b), the internal rotating part consists of individual parts nested in layers and connected by screws and nuts. The internal rotating part is nested in the external fixed large bearing and finally, the whole part is fixed to the motor mounting block by the base plate.

In the grinding stage, the GM6020 brushless motor drives the rotation of the internal rotating part, which drives the rotation of the ball mill blades embedded in the rotating part, and then drives the zirconia grinding balls of different sizes inside the grinding jar to move inside the jar. The friction and collision between the raw material and the blades, the raw material and the small balls, and the raw material and the jar body make the raw material put into the grinding jar further crushed and mixed fully.

3.3 Print Drive Module

As shown in Figure 2(e), the overall framework of the print transmission module is a four Z-axis MakerBot structure, high precision, stable structure, faster, more mature, and stable, and can carry multiple print-heads. The structure is mainly surrounded by sheet metal as the overall support, the filament rod through the coupling, and 42 stepper motor connection, the motor is embedded in the box and sheet metal sandwich. When the mechanism works, the filament rod through the coupling can drive the printhead module to move in the XY plane and the printing platform to lift in the Z direction according to the settings of the slicing software and the printing program.

3.4 Printhead fixture module

This module is a self-developed module, which mainly utilizes a multi-stage gear drive and a linkage mechanism, and is responsible for clamping and releasing the printheads when changing them. As shown in Figure 2(d), the structure includes a clamping assembly, a clamping drive assembly, and a power transmission mechanism. When clamping is required, a 42-step motor drives the filament rod in the clamping drive assembly to rotate, causing the nut on the filament rod to move inward along the filament rod, resulting in the relative motion of each linkage and pulling the clamping jaws serially on the light rod to move to clamp the printhead. At the same time, the cams on the jaws are inserted into the slot reserved for the nozzle. Subsequently, the bevel gear in the gearbox and the gear in the jaws at all levels of transmission, drive the rotation of the bump, the state of the bump from vertical to horizontal, and the nozzle to achieve the final lock.

3.5 Printhead module

As shown in Figure 2(c)， the slurry is transferred from the transport conduit to the printhead module by the air pressure difference of the air pressure pump and stored in the staging compartment above the printhead, which relies on the printhead clamping device to complete the fixation with the drive screw. During operation, the slurry enters the Roots pump by gravity through the pump tube, and the pump lobe speed is controlled by adjusting the output frequency of the 28-stepper motor, which in turn controls and records the flow rate and flow rate of the liquid. The liquid enters the multi-layer vane heat transfer frame through the output tube, and the rear fan facilitates the heat exchange at the heat transfer frame, and finally, the liquid is ejected on top of the printing platform[9].

Under the same working environment (diameter of pump pipe, atmospheric pressure), the program simulates the rotary cylinder method for the proportionally ground slurry according to the initial amount of raw material given, establishes a stable velocity gradient by balancing the external torque and internal friction torque, determines the viscosity coefficient of the slurry, then establishes a multivariate function according to the time required for the slurry to cure at the set temperature and other conditions, calculates the required extruded Then, the multivariate function is established to calculate the amount of slurry to be extruded per unit time, and the appropriate pump lobe speed is output to achieve the purpose of fine and stable slurry extrusion, and the appropriate extrusion amount, to realize the effect of instant extrusion, and maximize the precision of product production.

3.6 Finished lift module

As shown in Figure 2(f), the mechanism is mainly composed of the large pulley, small pulley, filament rod, filament nut, and so on. Among them, the two drive ropes on one side are connected to the screw nut through the fastening sleeve, and the drive ropes are tightly wound between the grooves of the pulleys at all levels. When the module enters the working state, the motor drives the filament rod through the coupling, and the drive rope fixed in the filament rod nut also moves, and through the transmission of force between the drive rope and the pulley, the multiple hollow platforms equipped with four small pulleys is lifted out of the printing support fluid, and the finished printed products are also fished out from the support fluid together.

Finally, the flow chart of the operation of the overall device containing the six modules is shown in Figure 3.

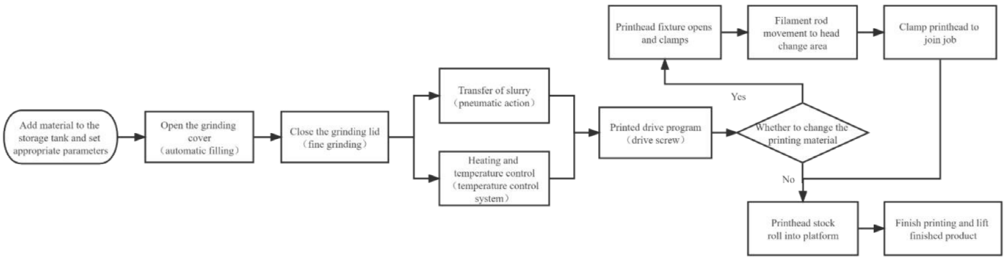

Figure 3. Flow chart of device operation

4 OVERVIEW OF TEMPERATURE CONTROL SYSTEM

4.1 Temperature information acquisition

The temperature information is collected mainly by the MC-SMD103J3950R temperature sensor implanted inside the printhead. It is an NTC thermistor with an effective operating range of (-40°C to 400°C), which can meet the needs of the actual printing process and has more mature technology and lower original cost.

Working principle: the sensor will be built into the internal circuit of the printhead, as the temperature of the printhead rises, the resistance value of the resistor will become smaller and smaller, and the current in the circuit will become larger, as electrical signal feedback to the chip in the main control area, the chip will be based on the pre-modulated program to calculate the real-time temperature of the printhead, and the temperature is displayed on the electronic display, while the user in its supporting APP can also be used to check the temperature of the printer in real-time.

4.2 Temperature self-regulation

It mainly relies on the STM32F103 chip inside the main control circuit to complete. It has two main roles, one can be used to calculate the temperature of the printhead in the temperature information collection, and the second is that it can be used for the printer to adjust the temperature. As shown in Figure 4, the printer self-adjustment principle of work is as follows:

at the beginning, the printer can be set in the APP or operation to display a working temperature range, in the printer work process, the stm32 chip will continue to receive changes in temperature information when the temperature is not set in a good working range, stm32 will be set according to the program to increase or reduce the working power of the material area heating equipment, and change the printhead working voltage so that the temperature is stable within the normal working range. When the system malfunction, the temperature change is large, and out of the adjustable range, the stm32 chip will use the alarm on the 3D printer to send an alarm, and will warn the user on the APP, at the same time, will send an emergency stop command to forcibly stop the printing process to achieve the purpose of protecting the components[10].

4.3 Product area temperature control

In the finished product area of the printer, due to the different printing materials or different requirements for the production process, we have installed a heating plate at the bottom of the finished product area to meet different production situations. The heating plate is a tracked ceramic heating plate, which has the advantages of high mechanical strength not easy to damage, long service life; high working temperature, fast heating, and adjustable temperature. Therefore, we can reserve a temperature to meet our needs in the actual printing process.

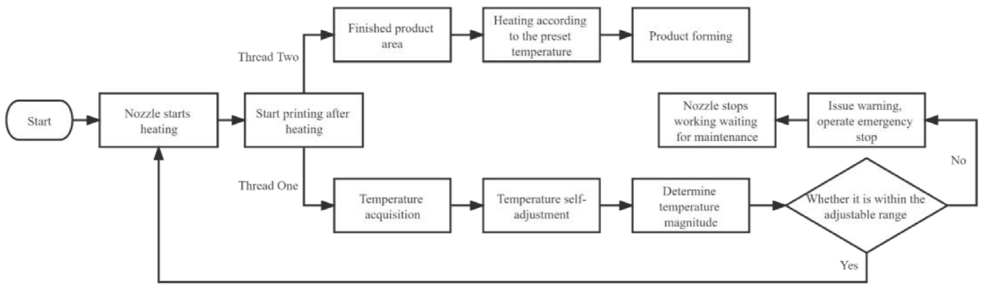

Figure 4. Temperature control system operation flow chart

5 REMOTE CONTROL SYSTEM OVERVIEW

5.1 Image acquisition

The hardware device is developed in C++ using the ESP32-CAM camera development module and the OV2640 image sensor with a 120-degree ultra-wide angle lens. The image sensor adopts the OV2640 sensor, which is controlled by the SCCB bus and can output 8/10-bit image data in various resolutions by rectification, sub-sampling, scaling, and windowing. With high sensitivity and low operating voltage, it is suitable for embedded applications. Image acquisition using the OV2640 image sensor output SXGA (1280 * 1024) format pictures, with 120 degrees ultra-wide angle lens, can meet in close distance to the meter display area image information acquisition.

5.2 Image transmission

With the help of Bafa Yuntu Cloud, apply to publish/subscribe mode, connect to the cloud server via Socket interface based on TCP/IP protocol, and use HTTP protocol for data transfer. ESP32-CAM connects to the WiFi network, connects to the cloud server via TCP/IP protocol, writes the upload address, user private key and uploads the subject name into the HTTP message header, and sends POST to request to upload image information, gets the status code returned from the cloud after the upload is finished, and judge whether the upload is successful according to the status code, and resend the request and upload if the upload fails[11].

5.3 Image Download

Image downloading uses Socket communication technology to establish a connection, Socket type is Streaming Socket. should Threading multi-threading technology sends a heartbeat regularly and keeps the connection. First, create sockets and bind sockets to the local network to achieve network connectivity. Then, the remote connection to the cloud server is made based on the defined TCP server address IP with the server port. After the connection is established, the data sent by the cloud server is received cyclically in binary format, which is decoded to UTF-8 format and intercepted URL address, and the heartbeat Keep Live command is defined to turn on the timing and send a heartbeat to the cloud server every 30 seconds to prevent the connection from being interrupted. Finally, the lossless compressed image (PNG format) is downloaded from the intercepted URL address and saved to a local folder for image processing operations. As shown in Figure 5.

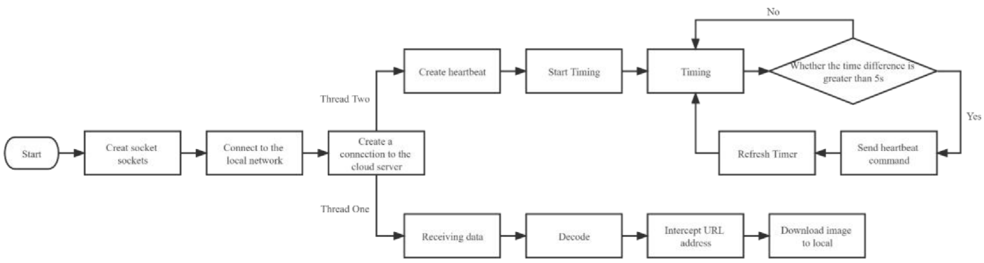

Figure 5. Socket programming flow chart

5.4 Mobile design

Each device comes with an independent WLAN signal as well as a device ID. The user can control the machine by scanning the code, connecting to the LAN, or connecting to Bluetooth. The user's host computer can be connected to the Bluetooth signal of ESP32 to achieve two-way communication between the user and the dosing machine.

6 CONCLUSION

The process-oriented multi-dimensional printer designed based on IJP technology is composed of an automatic material feeding module, high-energy grinding module, printing drive module, nozzle fixture module, printing nozzle module, and finished product lifting module, which has the functions of intelligent proportioning, high-energy grinding, fine discharging and detailed printing. This equipment improves product forming accuracy, shortens product forming time, and broadens the complexity of product forming compared to existing equipment. The process of multi-dimensional printing equipment will solve the problem of traditional experiments or production limitations in time and space, making manufacturing more efficient, intelligent, and refined. At present, China is implementing the development of the emerging manufacturing class industry, and unmanned, intelligent, and remote equipment and instruments will become the mainstream wave. In this context, the designed process-oriented multi-dimensional printing equipment has a broad market prospect.

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