

## Research of G Code Interpreter for 5-axis 3D Printing

Qian Wang<sup>1, 2, a</sup>, Zhongmin Wang<sup>1</sup>, Haijun Wang<sup>2</sup>, Gang Wang<sup>3</sup>

<sup>1</sup>School of Mechanical Engineering, Tianjin University of Technology and Education, Tianjin, 300222, China

<sup>2</sup>Tianjin Bosheng RuiChuang Technology Co., Ltd, Tianjin, 300350, China

<sup>3</sup>School of Mechanical Engineering, Ningxia University, Yinchuan Ningxia, 750001, China

<sup>a</sup>1849075869@qq.com

### Abstract

Five-axis 3D printers can reduce the addition of supports, while five-axis 3D printers have no directly available motion command G code. Aiming at this situation, a design method of G code interpreter for 5-axis 3D printer is proposed to generate motion instructions for 5-axis 3D printer. According to the structural characteristics of G code, the structure type is analyzed to solve the problem that a large number of supports need to be added under different circumstances. Feature extraction, data extraction and motion instruction addition are developed based on Python regular expression. Through MATLAB simulation experiments, it is verified that there is no interference between print-head and print-head, and the visualize of G code is completed. The effectiveness of the interpreter is proved, and G code of motion instruction used by five-axis 3D printer can be generated.

### Keywords

Five-axis 3D printer; Regular expression; Feature extraction; Sports instruction.

## 1. INTRODUCTION

3D printing can realize the production of complex parts, greatly reduce the processing process, shorten the production time, release design thinking, and reduce the cost of small batch production [1]. Compared with traditional 3D printers, printers can reduce the waste of consumables and the "step effect". However, the G code used by five-axis 3D printers has no software to directly generate, which becomes a pain point [2].

Traditional 3D printing to generate G code has been very mature [3]. However, traditional 3D printers need to add supports to print complex parts, resulting in material waste, reduced printing efficiency and rough printing surfaces. Remove the surface damage of parts caused by too much support, and the surface residual support caused by too little support. Due to the limitations of traditional 3D printers, a growing number of colleges and universities to research more degrees of freedom 3D printers, DAI [4] use of 6DOF serial manipulator to without the support of the complicated surface printing, sedimentary sequence and direction by changing the resin, the resin is always deposited along the surface of the convex hull, can effectively solve the problem of adding support, but the print effect is not ideal. Wang [5] used the five-free parallel 3D printer for block printing and changed the printing direction to reduce the support needed in the printing process, but did not propose a G-code generation method suitable for all models. Fred [6] et al. invented a desktop 5-axis 3D printer and used Rhinoceros and Grasshopper to make a GUI interface that could be independently operated by users. After the model was segmented, it was regenerated into usable motion instructions. Although this

method can be used for some complex models, the operation process is complicated, which violates the original intention of simple operation of 3D printing.

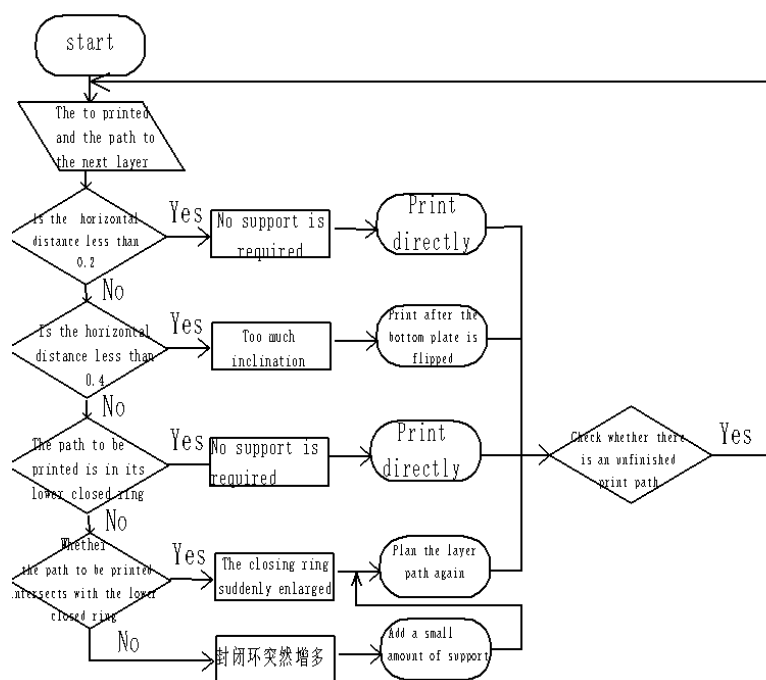
In order to complete 5-axis 3D printing, a g-code interpreter for 5-axis 3D printer is proposed in this paper. The interpreter uses the motion instructions used by traditional 3D printers to generate G codes suitable for 5-axis 3D printing, reducing material waste and improving printing efficiency by reducing support.

## 2. PROPERTIES

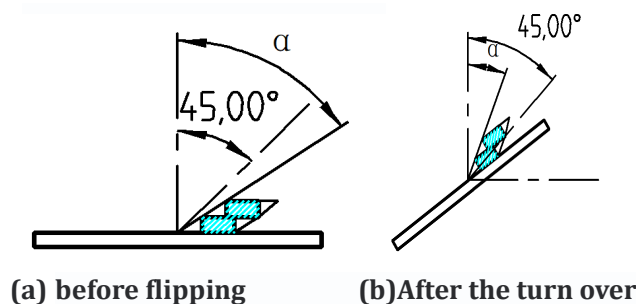
### 2.1. Basic Methods of Reducing Support

The successful printing of 3D printing must two conditions to satisfied. The printing path must be connected with the completed part. The nozzle cannot collide with the printed part [7].

Is calculated under the most peripheral path with a layer of recent distance and position of the relationship between path, get support type, the analysis process is shown in figure 1, the following for each of these three conditions (Tilt Angle is too large, closed ring suddenly increased, closed ring suddenly increased) were analyzed, and solve the problem of can't need to add a lot of support, the most common printer, for example, The diameter of its nozzle is 0.4mm and the height is 0.2mm.



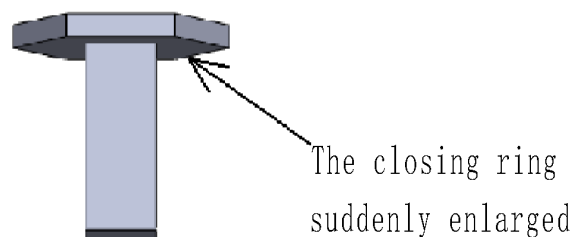
**Figure 1.** Type analysis of different added supports



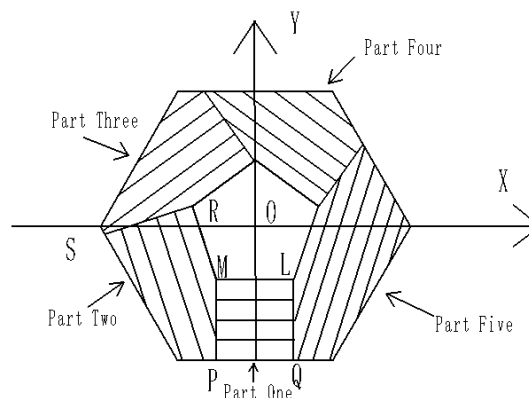
**Figure 2.** Schematic diagram of support reduction when inclination Angle is too large

(1) When the inclination Angle is too large, the printing path exceeds the forming range by  $45^\circ$ , as shown in Figure.2 (a). When the shortest horizontal distance between the outermost path and its lower path exceeds 0.2mm, it cannot be directly formed, and the bottom plate needs to be deflated by a certain Angle, as shown in Figure.2 (b). The specific solution is given in Section 2 to make the printing path within the allowable inclination range.

(2) When the closed ring suddenly increases, as shown in Figure 3, the printing path is suspended below and cannot be directly formed. Therefore, the layer path needs to be re-planned to realize unsupported printing. As shown in Figure 4, when printing the path of the first part, rotate the base-plate of the printer at a certain Angle along the axis parallel to ML through the center O of the base-plate circle, so that each path can realize unsupported printing on the basis of its completed inner path. Each part of the path is parallel to each other, closely adjacent. Complete the path plan in turn until the entire section is filled.

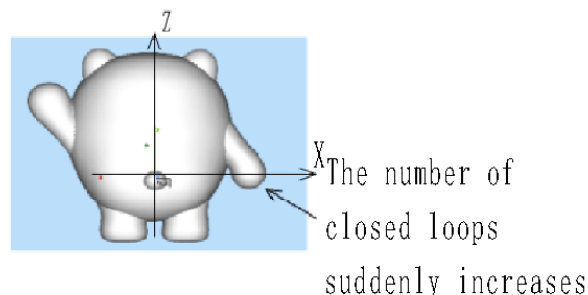


**Figure 3.** Sudden enlargement of the closed ring



**Figure 4.** Filling the dangling path diagram

(3) When the number of closed rings suddenly increases, as shown in Figure. 5. In this case, direct printing cannot be realized. It is necessary to add tree-like support below it and then convert it to the first or second case to complete printing.



**Figure 5.** Sudden increase of closed loop number

## 2.2. Axis G code Generation

G code interpreter can realize preconditioning, data extraction, model feature extraction, motion instruction generation and other functions.

1) preconditioning: Blank lines and comments in G code are matched with regular expressions to remove unnecessary characters and avoid affecting the normal execution of the interpreter.

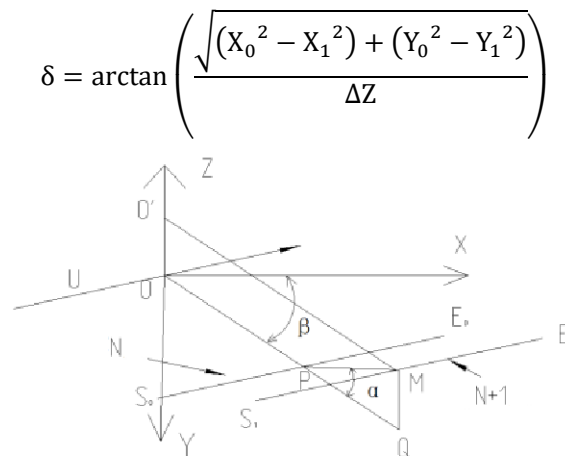
2) data extraction: Uses regular expression to extract effective path coordinates and save them in an array, which is convenient for subsequent calculation.

3) Model feature extraction: Extracts the included Angle relative to the horizontal plane after the midpoint of the peripheral path is connected with the midpoint of the path closest to it in the next layer, and the specific process is as follows.

As shown in FIG. 6, point P(X<sub>0</sub>Y<sub>0</sub>) is the S<sub>0</sub>E<sub>0</sub> midpoint, and the midpoint M of is projected into the plane XOY.

When PQ < 0.2, the path is in the forming range.

When 0.2 ≤ PQ < 0.4, the path tilt Angle is too large. Calculate the included Angle  $\delta$  between PM and PQ.



**Figure 6.** Print path analysis

According to s, the Angle  $\theta$  needed to rotate the bottom plate can be obtained:

$$\theta = \begin{cases} 45^\circ - \delta & \delta < 45^\circ \\ 0 & \delta > 45^\circ \end{cases}$$

When PQ > 0.4, if the path is contained in the lower sealing ring, it can be directly printed, otherwise it can judge whether the upper and lower sealing faults intersect. If the intersection is closed rings suddenly increase in size, otherwise, it is closed rings suddenly increase in size. Due to space constraints, the judgment process is not described here.

(4) Motion command generation 3D printer does not have "follow function" [8]. When the base plate is turned over, the nozzle moves with the base plate and moves along the path at the same time, which can improve printing efficiency and avoid wire drawing [9]. The motion of the nozzle is through the center of the circle O of the bottom plate, and the axis U parallel to S<sub>1</sub>E<sub>1</sub> makes the spiral motion of rotation Angle  $\theta$  moving distance d. The line segment is used to fit the spiral trajectory, and  $\theta$  is decomposed into m equal parts. The Angle of the ith rotation is:

$$\theta_i = \theta \times i / m (i = 1, 2, \dots, m)$$

The line vector L of axis U is expressed as:

$$L = \{r + \lambda\omega\}$$

Is a point on axis U,  $\omega$  is the unit vector along axis U,  $\lambda \in \mathbb{R}$ .

The point q on the rigid body rotates  $\theta$  around axis N and moves the position after  $d = s \cdot \theta$  at the same time  $q(\theta)$ :

$$q(\theta) = T(\theta)q(0)$$

$q(0)$  is the initial position, and the spiral motion transformation matrix  $T(\theta)$  is:

$$T(\theta) = \begin{bmatrix} e^{[\omega]\theta} & (I - e^{[\omega]\theta})r + \omega s\theta \\ 0 & 1 \end{bmatrix}$$

3D printing requires not only the movement instruction G code of each moving axis, but also the movement state of the extrusion head during the movement of each axis, and the extrusion head is regarded as the E axis. In the generation process of G code of axis E, the length of printing path is J, and the length of material extrusion is S. Volume of extrusion material  $V_c$  is equal to volume  $V_g$  of feed material[10], as shown in Figure. 7. Volume of feed material:

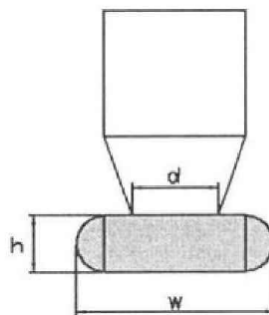
$$V_c = \left(\frac{d}{2}\right)^2 \times \pi \times S$$

Extrusion material volume:

$$V_g = [(W - h) \times h + (h/2)^2 \times \pi] \times J$$

Extrusion length:

$$S = \frac{[(W - h) \times h + \left(\frac{h}{2}\right)^2 \times \pi] \times J}{\left(\frac{d}{2}\right)^2}$$

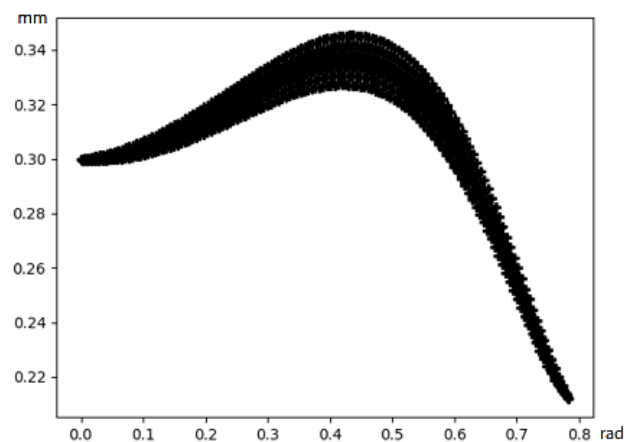


**Figure 7.** Relationship between print cross section and nozzle

### 3. TESTS

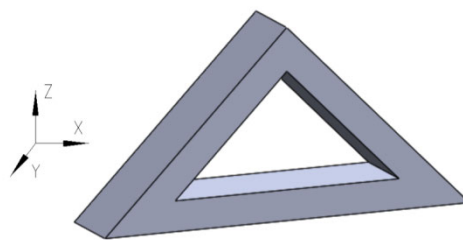
In order to verify that the print head does not collide with the printed part in the printing process, the shortest distance between the print head and the printed part is calculated to prove that the print head does not collide with the printed part in the flipping process of the bottom plate. In the flipping process, the printed piece moves in an arc around the axis U, and the sprinkler head moves in a spiral motion of linear fitting, and the deflection Angle is  $\omega = \theta_i - \theta_{i-1}$ . Take  $\omega$  as  $0.7^\circ$ . Taking the spatial coordinate R (100,0,100) of the nozzle in the printing process as an example, the coordinate point of the position to be printed is  $R'(100,0,99.7)$ , and the maximum Angle of reversal is  $\pi/4$ . The printing process is still layer by layer. The nearest distance between the nozzle and the printing point varies with the Angle as shown in Figure 8.

It can be seen that the minimum distance is greater than 0.2mm and the maximum distance is less than 0.34mm, and there will be no collision in the flipping process.

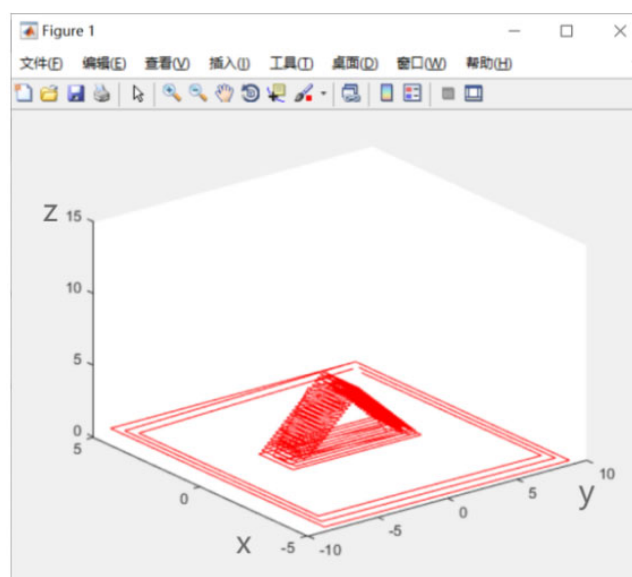


**Figure 8.** Distance between the nozzle and the printed piece when turning over

In order to verify the effectiveness of track generated by interpreter, 3D model Figure 9 was sliced and put into interpreter, and the generated G code track was visualized by MATLAB, as shown in Figure 10.

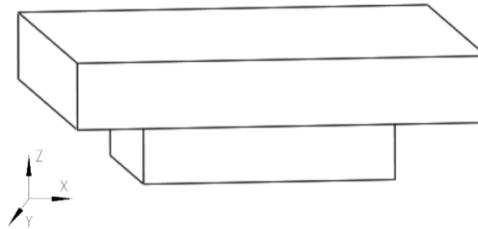


**Figure 9.** Model to be printed

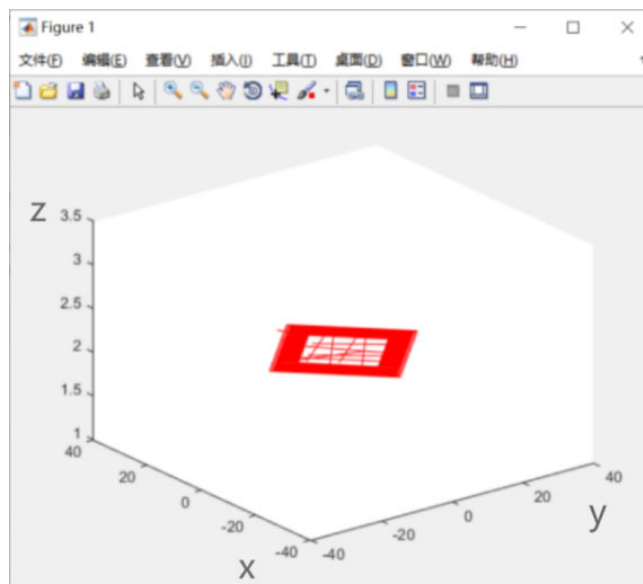


**Figure 10.** G code trajectory generation diagram

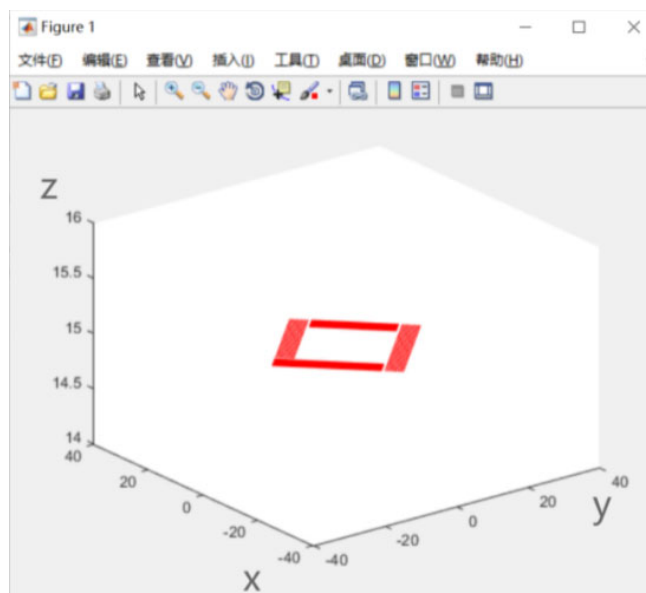
The model is shown in Figure 11, the layer is suddenly increased as shown in Figure 12, and its path is re-profiling as shown in Figure 13. The generated trajectory is similar to Figure 4 in section 1. The generation sequence is from inside to outside, and the outer path depends on the inner printing path to achieve the expected effect.



**Figure 11.** Sudden increase of large model



**Figure 12.** Enlarging the layer path display



**Figure 13.** Planned path

## ACKNOWLEDGMENTS

In this paper, the traditional 3D printer G code is read line by line based on regular expression, and irrelevant symbols and comments are removed. The coordinate of motion track was extracted, the distance and position relationship between the current path and the nearest path were calculated, and the support was divided into three cases and treated differently. Generate G code to follow the movement instruction, so that the nozzle is flipped to do synchronous movement. Finally, G code image description is used in MATLAB to prove that there will be no collision between the turning nozzle and the print. The interpreter is designed to provide G code for five-axis 3D printing, which provides the basis for five-axis 3D printing.

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