Research on Error Analysis and Online Recognition Method of Contour in 3D Printing

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Abstract. The accuracy of 3D printing is related to the software and hardware structure, such as modeling software, slicing software and the kinematic characteristics of nozzle components. In order to explore methods to improve printing accuracy, this paper conducts research based on fused deposition modeling (FDM). On the basis of the experiments, the constituent elements of the cross-sectional profile and the mechanism of its error are analyzed, and the insight software is used to verify. Finally, based on the idea of digital twins, this paper initially explores the online recognition method of contour.

1. Introduction
3D printing technology has been successfully applied in aerospace, biomedical and many other fields [1]. However, printing accuracy is still an important factor restricting the industrial application of 3D printing technology. 3D printing technology is based on the principle of layered stacking, and then scans and prints according to the cross-sectional contour of the part. The modeling accuracy, conversion accuracy, scanning accuracy of the cross-sectional contour and kinematic accuracy of the printer will directly affect the accuracy of the printed parts.

Fused deposition modeling (FDM) as one of the most common 3D printing technologies, has the advantages of relatively simple structure and low cost. It has been widely popularized. Therefore, the paper chooses FDM to carry out the research on printing accuracy. The accuracy analysis is mainly carried out around the whole process from model conversion to the part being printed. At the same time, the corresponding printing experiment is carried out, and the insight software is used to compare and analyze information of the cross-sectional contour. The importance of online recognition and feasible online recognition method of contour are proposed.

2. Experimental Research
A bottle is printed in the experiment by using FDM200mc. The model material is ABS with white color, and the support material is water-soluble support with brown color. Double nozzle structure is adopted, the printing temperature is 270 ° and the ambient temperature is set to 75 °. In order to explain the relationship between the virtual contour and the actual printed contour, a certain layer of cross-sectional contour of the bottle is taken out, as shown in Figure 1. (a) is the virtual contour of a certain layer of the bottle, (b) is the actual printed contour of a certain layer of the bottle.
From the printing process, the actual printed contour may be affected by factors such as conversion accuracy of the model, printing parameter settings, structure of the printer, etc. And there is an error between the actual printed contour and the virtual contour. The influence of this error is a combination of multiple factors. Through experiments, it is found that different cross-sectional contours, different placement methods, different scanning path planning, different moving structures and different printing materials all have an influence on this error. In order to explore the influence of errors, the paper analyzes the constituent element and generation process of contours, and aims to propose an online recognition method of contour to improve printing accuracy.

3. Constituent Elements of Contour

3D printing is to convert a three-dimensional model into several two-dimensional sections by slicing, and then the two-dimensional sections are printed layer by layer. Each two-dimensional section is a plane figure, and its constituent elements include points, straight lines, and curves. Depending on the shape of the part and the placement mode during printing, the straight lines on the two-dimensional cross-section have different orientations, and the curves have the types of concave curve, convex curve, equal curvature curve and variable curvature curve. The schematic diagram of the constituent elements of the two-dimensional section is shown in Figure 2. Depending on the constituent elements, the two-dimensional section has a variety of situations, which can be composed of a single element or two elements.
4. Error Analysis of Contour

The error of contour refers to the difference between the designed cross-sectional contour and the actual contour of the printed part. The error of contour mainly includes the conversion error of the model format, the scanning error of the nozzle, etc., which is related to the setting accuracy of the model, placement mode of the model, nozzle scanning method, etc.

After the 3D modeling of the part, it is usually necessary to convert the PRT format to the STL format. The STL format uses triangular elements to approximate the contour [1]. The size and orientation of the triangular elements will greatly affect the approximation accuracy. Even singular points may appear in curved contours. In order to study the conversion errors of different cross-sectional contours, the models of PRT format and STL format are compared through the insight software. Draw the (a), (b) and (c) models in Figure 2 into a 20mm solid, select the horizontal placement mode (the height in the Z direction is 20mm), and use the insight software for slicing. The tool of curve information under the view menu can display two-dimensional cross-sectional contour information, including the number of nodes, length, and area. By comparing the length and area information of the two format files, the conversion error information of the model is obtained, as shown in Table 1.
Table 1. Conversion error

| Constituent Element                  | Length error value (mm) | Area error value (mm²) | Length error ratio | Area error ratio |
|-------------------------------------|------------------------|-----------------------|-------------------|-----------------|
| straight line                       | 0.527                  | 10.511                | 0.329%            | 0.657%          |
| constant curvature curve            | 0.709                  | 21.839                | 0.564%            | 1.739%          |
| straight line and constant          | 0.772                  | 24.467                | 0.375%            | 0.857%          |
| curvature curve                     |                        |                       |                   |                 |

As can be seen from Table 1,
1) Conversion error values (length error and area error) are significantly different because the different cross-sectional contours have different constituent elements. The difference in length reaches 0.245mm, and the difference in area reaches 13.956mm².
2) The error of the cross-sectional contour composed of a single element is small, and the error of the cross-sectional contour composed of two elements is large.
3) Among all the cross-sectional contours composed of a single element, the error of the cross-sectional contour composed of straight lines is the smallest.
4) For different cross-sectional contours, the error values of length and area show the same change rule.

In summary, if the structure and shape of the part allow, the cross-sectional contour composed of a single element should be used as much as possible when designing a part. A single straight line is the best, and the highest conversion accuracy can be obtained.

In order to further study the approximation accuracy of the model, the insight software is used to view the node information of various cross-sectional contours. Through the tool of filter-points under the edit menu, the node information on the cross-sectional contour can be displayed. Taking the constant curvature curve as an example, its node information is shown in Figure 3.

Figure 3. Node information of constant curvature curve
Using this function of the insight software, the node information of the four constituent elements shown in Figure 2 can be obtained, as shown in Table 2.

| Constituent Element | Node number |
|---------------------|-------------|
| straight line       | 4           |
| constant curvature curve | 24       |
| straight line and constant curvature curve | 39 |
| straight line and variable curvature curve | 42 |

As can be seen from Table 2,

1) The node number is obviously different because the different cross-sectional contours have different constituent elements.
2) The more constituent elements are, the bigger node number is. The node number of straight line is the smallest.
3) The more complex the constituent elements are, the bigger the node number is. The node number is 42 when the cross-sectional contours are composed of straight lines and variable curvature curves.
4) The straight line is the simplest and the node is the end point of the straight line. The curve is more complicated, and more nodes are used to approximate the cross-sectional contour.
5) The bigger the node number is, the higher the accuracy of contour is. But the number of commutation times is bigger during scanning and the vibration caused will be greater.

Therefore, a reasonable node number should be used for the different accuracy requirements of the parts when rationally designing the cross-sectional contour.

5. Online Recognition of Contour
The model can be printed online after slicing, setting support, setting tool path and other processes. If there is an error or defect in the cross-sectional contour of a certain layer when printing, it will directly lead to the error accumulation or the printing failure [2]. Therefore, real-time monitoring is required when printing in order to find errors or defects in time.

Digital twins refer to the construction of an identical entity in the digital world by means of digitization, thereby realizing the understanding, analysis and optimization of physical entities. Digital twins are to make full use of data such as physical models, sensor updates, operating history, and integrates multi-disciplinary, multi-physics, multi-scale and multi-probability simulation processes to complete the mapping in the virtual space, thereby reflecting the corresponding life cycle of the corresponding physical equipment [6].

Based on the idea of digital twins, the size error of the cross-sectional contour is detected by using sensors, machine vision and other technologies to track the movement of the nozzle. The printing defects of each layer section is monitored by installing a vertically downward camera to collect real-time printing outline pictures and compare them with the virtual model. The theoretical value can be obtained by installing a height measuring instrument and using the product of the layer thickness and the number of printed layers. The height error of the printed part can be obtained by comparing the measured height with the theoretical value.
6. Conclusion
Error analysis of contour and online recognition method of FDM 3D printing are studied in this paper. The importance of online recognition of contour is analyzed based on the experiment. Through the analysis of the constituent elements of contour and the use of insight software to carry out error analysis of contour, a method of designing and printing based on accuracy assurance is proposed. Finally, a specific method of online recognition of contour is proposed based on the idea of digital twins.

Acknowledgments
Guangdong Ordinary Universities Youth Innovative Talents Project (3D Printing Quality Real-time Detection and Quality Prediction Key Technology Research:2018KQNCX343); Key Disciplines of Guangdong Province:Mechanical Engineering

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