

Experimental Research on On-line Monitoring and Compensation Algorithm of 3D Printing Based on Machine Vision

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Abstract—With the coming of the era of intelligence, machine vision and machine learning has become a research hotspot in recent years[1]. As an advanced manufacturing technology at present, 3D printing has been maturely applied in aerospace, bio-medicine and other fields[2]. However, a defect such as extruder head blockage, filament break, height error, warping and cracking occurred during the 3D printing process directly affects the printing quality and even the printing success rate. It is an inevitable trend to develop on-line monitoring on the health status of 3D printing devices to achieve unmanned operation of 3D printing. Therefore, this paper proposes a research on the on-line monitoring and compensation algorithm of 3D printing based on machine vision, which is significant to promote the development of 3D printing technology.

The printing process usually takes certain time so it couldn't be tracked and recognized by human eyes. Therefore, based on printing experiments and printing defect analysis, this paper comprehensively analyzes the monitoring mechanism, puts forward four monitoring elements and carries out certain theoretical analysis, aiming to realize real-time monitoring and improve printing success rate. Meanwhile, this paper analyzes the on-line monitoring by machine vision and compensation algorithm in theory, in order to guide the establishment of related experimental platform.

Keywords-3D Printing; Defect Analysis; On-Line Monitoring; Theoretical Analysis

I. PREFACE

The time required for 3D printing changes along with the workpiece size and modeling parameters, usually taking certain time, some even taking dozens of hours. However, the operator couldn't monitor the whole printing process by eyes on site [3]. If any abnormal conditions such as extruder head blockage, filament break, accumulation skew and height error occur during the printing process, existing 3D printers couldn't recognize them in time and will keep running, which will result in bad consequences such as printing failure, material waste and development cycle delay. Therefore, the author combines FDM experiments and carries out analysis on the 3D printing on-line monitoring method, aiming at realizing unmanned 3D printing.

II. MONITORING ELEMENTS

Based on the slicing and stacking principle, 3D printer slices the 3D model into a series of two-dimensional section outlines and stacks the outlines layer by layer from down to top. During the FDM process, the fused filament extruded from the extruder head deposits on the base plate according to the scanned single-layer section outlines and stacks in order to form the workpiece. Problems happened in any link may result in printing failure, as shown in Figure1. Considering the whole printing principle, the printing monitoring points should include the extruder head condition monitoring (filament feeding condition monitoring, motion error monitoring), the workpiece condition monitoring (single-layer two-dimensional section outline printing monitoring, stacking height error monitoring), the base plate condition monitoring (printing layer warping and delamination condition monitoring) and so on.

III. EXTRUDER HEAD CONDITION MONITORING

As an important component for FDM, the extruder head mainly fulfills heating, extruding, feeding and depositing functions, whose working condition greatly affects the printing process and quality. The extruder head blockage will directly cause printing failure, and the vibration produced when the extruder head changes direction will easily cause accumulation skew and height error. Based on this, the author puts forward a monitoring method on the extruder head motion state.

Extruder head blockage monitoring:

1) Measure the dynamic weight of the printed model by a pressure sensor. When the dynamic weight stops growing linearly, it indicates failure on the extruder head, for example, it is blocked.

2) Measure the feeding inlet of the extruder head by an infrared sensor. When the infrared sensor detects no obstacle, it indicates that the extruder head stops feeding materials.

Extruder head vibration monitoring:

Measure the motion state of the extruder head by a vibration sensor or a speed sensor. When the vibration intensifies or the speed increases, it indicates that the printer is printing the interior of the workpiece.

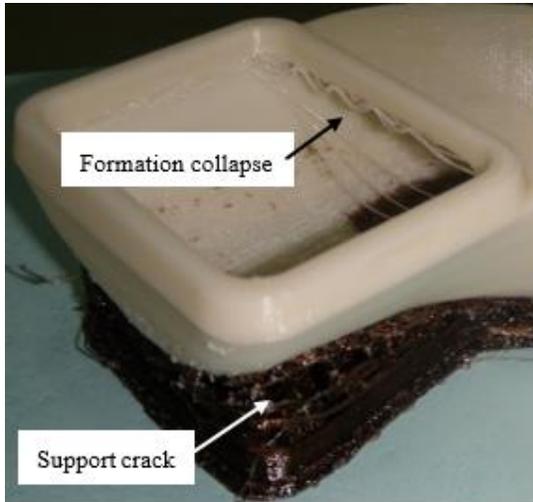


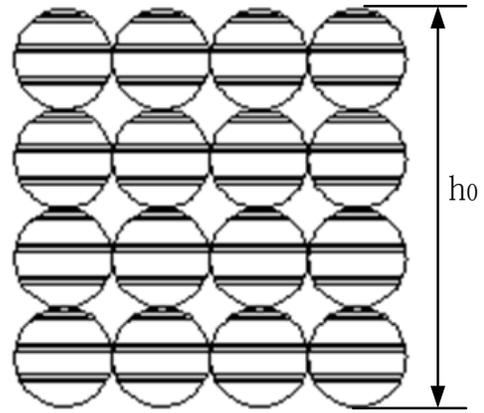
Figure 1. Printing defects

IV. WORKPIECE CONDITION MONITORING

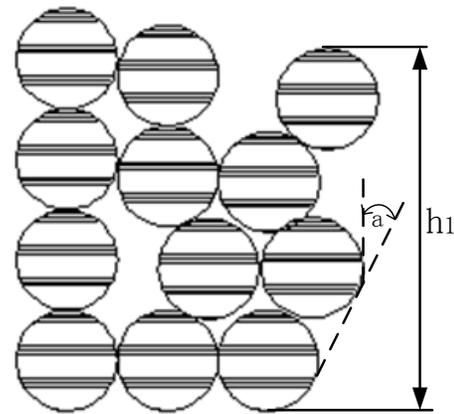
The workpiece condition monitoring is an important link to ensure the printing quality. Any error, defect or single-layer failure during the printing process will directly affect the printing success rate, which mainly includes the height error monitoring and the section outline integrity monitoring.

A. Height error monitoring

In theory, each layer stacks up orderly during the printing process, but in practice, the machine vibration and the material contraction will cause accumulation skew and produce height error ($h_1 < h_0$) and angle error (α), as shown in Figure2.



(a) Ideal stacking effect



(b) Actual stacking effect

Figure 2. Height error analysis

Therefore, it is in need to put forward a method to detect and compensate the height error by machine vision: install a camera and a light source on the left side of the modeling room, design the right side of the modeling room into a whiteboard, and observe the deviation between the projection line and the graduated lines on the whiteboard to monitor the height error, as shown in Figure.3. Set each layer thickness as t , the theoretical height of the layer n $h_0 = t * n$, and the actual height is h_1 . When $h_1 = h_0$, it means there is no height error; when $h_1 < h_0$, it means there is height error and need compensate layer number $k = \frac{h_1 - h_0}{t}$.

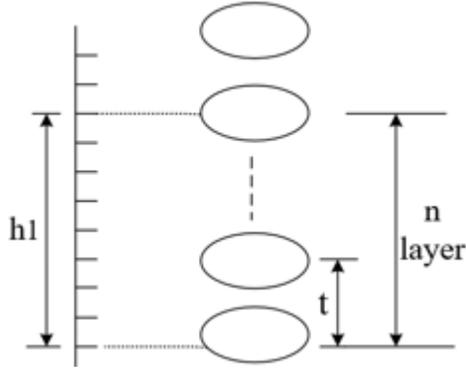


Figure 3. Height error monitoring principle

B. Section outline monitoring

The section outlines of 3D printing are decided by the workpiece shape. When the extruder head is blocked or the filament is broken, stuck or short, the section outlines will be printed incompletely and will produce waste. Existing printers without detecting device couldn't identify these abnormal conditions and will keep running.

Use a camera to track the extruder head motion and track the real-time section outline, then compare it with sliced ideal section outline to monitor printing condition of current layer. Usually the two-dimensional section outline consists of straight lines, equal radius curves and variable radius curves, as 1, 2, 3 in Figure4. Use the camera to track the extruder head motion and design circular tracking trajectory, as circle 4 in Figure4. The camera needs automatically adjust the focal length when the outline shape changes.

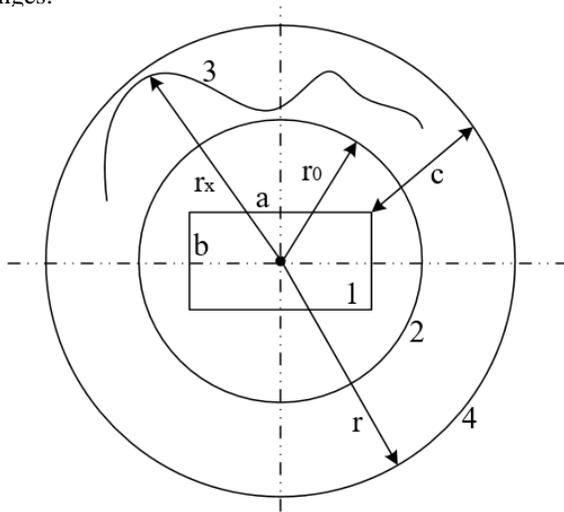


Figure 4. Section outline monitoring analysis

When the section outline is straight line 1, the focal length is c ,

$$c_{\min} = r - \sqrt{\left(\frac{a}{2}\right)^2 + \left(\frac{b}{2}\right)^2}$$

$$c_{\max} = \begin{cases} r - \frac{b}{2}, & a > b \\ r - \frac{a}{2}, & a < b \end{cases}$$

When the section outline is equal radius curve 2, the section outline and the tracking orbit are concentric circles with unequal radius, so the focal length c is constant, $c = r - r_0$.

When the section outline is variable radius curve 3, the focal length c changes with the shape, $c_x = r - r_x$.

V. BASE PLATE CONDITION MONITORING

Base plate is an important component of 3D printing, whose cleanliness level before printing, levelling level and heat deformation during printing process may cause workpiece weak bonding, delamination and warping, and affect printing success rate. Therefore, the base plate condition monitoring mainly includes levelling monitoring and temperature monitoring.

VI. CONCLUSION

By carrying out 3D printing (FDM) experiments and combining defects occurred during the printing process, this paper analyzes reasons for on-line monitoring and puts forward on-line monitoring elements on 3D printing, which include the extruder head condition monitoring, the workpiece condition monitoring and the base plate condition monitoring. It also carries on some theoretical analysis on the on-line monitoring method, aiming to improve 3D printing quality and success rate.

This paper puts forward on-line compensation algorithm by analyzing the cause of the error, and studies the visual monitoring algorithm for different section outlines, in order to guide the establishment of experimental platform.

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REFERENCES

- [1] Kun He, Zhijun Yang, "Intelligent Fault Diagnosis of Delta 3D Printers Using Attitude Sensors Based on Support Vector Machines", *Sensors* 18, pp:19-28, 2018
- [2] Yedige Tlegenov, Geok Soon Hong, Wen Feng Lu, "Nozzle condition monitoring in 3D printing", *Robotics and Computer Integrated Manufacturing* 54, pp:45-55, 2018
- [3] D. Cabrera, F. Sancho, C. Li, M. Cerrada, R. V. Sánchez, F. Pacheco, J. Valente de Oliveira, "Automatic feature extraction of time-series applied to fault severity assessment of helical gearbox in stationary and nonstationary speed operation," *Applied Soft Computing*, Vol. 58, pp. 53-64, 2017.

- [4] J. W. Guo, J. P. Wu, Z. Z. Sun, J. Y. Long, S. H. Zhang, "Fault diagnosis of delta 3D printers using transfer support vector machine with attitude signals," vol. 7, pp. 40359-40368, 2019.
- [5] Y. Li, B. S. Linke, H. Voet, B. Falk, R. Schmitt, M. Lam, "Cost, sustainability and surface roughness quality - A comprehensive analysis of products made with personal 3D printers," *CIRP Journal of Manufacturing Science and Technology*, vol. 16, pp. 1-11, 2017.
- [6] Barry Berman, "3-D printing: The new industrial revolution. *Business*", *Horizons*. 55, pp: 155-162, 2012.
- [7] Hongle Wang, Jiayu Wang, Qinghua Zhou, QingchunXiong, Ziqi Wei, "Comprehensive Error Compensation Method of Numerical Control Machine Based on BP Neural Network", *Journal of Xi'an Jiaotong University*, 6, pp:138~145, 2017.
- [8] WenzhenKuang, Feng Chang, Li Xu, Jiying Li. Rai, "Profile Recognition Based on Optimized Ant Colony Algorithm", *China Railway Science*. 7, pp:8-13, 2017.
- [9] Yu Yao, Haiou Zhang, Gulan Zhang "Counter Recognition and Defect Analysis on Metal Parts Direct Forming Deposition Layer". *Mechatronics*.3, pp:16~20,2014.
- [10] HanqingZheng, An Gu, Mingyi Li, Xiangdong Cheng , "Applied Research on Object Contour Recognition Algorithm Instrumentation and testing technology", *Instrumentation and testing technology*.35, pp:106~110, 2016.
- [11] Hongmei Shi, Hua Chai, Yao Wang , "Algorithm Research on Embedded Railway Identification Based on Target Recognition and Tracking", *Journal of Railway*.7, pp:58-65, 2015.