Journal of Computers Vol. 28, No. 6, 2017, pp. 277-287
doi:10.3966/199115992017122806025

Design of Color Mixing 3D Printing System Based on LabVIEW

Yupeng Guan[1], Bingxia Shen[1*], Yu Zhang[1] and Zi'ang Fu[2]

[1] School of Information and Communication Engineering, Beijing Information Science & Technology University, Beijng, 100101, China
shenbingxia@bistu.edu.cn

[2] School of Computer Science and Technology, Beijing Information Science & Technology University, Beijng, 100101, China

Received 24 July 2017; Revised 19 September 2017; Accepted 19 October 2017

Abstract. In this paper, we designed and implemented a complete set of color mixing 3D printing hardware and software system, including Delta structure three feed-single extrusion Fused Deposition Modeling (FDM) color mixing 3D printer, the LabVIEW upper computer software and LabVIEW monitoring & adjusting software. Through the software system, users can achieve custom color settings, view the color mixing and preview 3D print effects, remote adjusting of the printer, monitoring of the printing process in real-time, and receive the product photo by e-mail immediately when the printing task completed. Through the hardware system, a multi-color and gradient color 3D model can be achieved in once printing process without replacing the hotend and filaments or post-processing. The software system is full-featured and the interface is friendly. The hardware system is stable, products printing with color uniformity. The preview effect and the actual product is almost the same. The system greatly enhance the user experience, so that achieve the color mixing 3D printing more efficient.

Keywords: 3D printing preview, color mixing 3D printer, Fused Deposition Modeling (FDM), remote monitoring and adjusting

1 Introduction

3D printing first appeared in the 1990s. In recent years, with the development of technology, 3D printing technology has matured and there are dozens of different prototyping modes. The mainstream technologies [1] include Stereo Lithography Apparatus (SLA), Selective Laser Sintering (SLS), Selective Laser Melted (SLM), Three Dimensional Printing (3DP), Laminated Object Manufacturing (LOM), Fused Deposition Modeling (FDM), etc. FDM technology has become the most popular desktop 3D printing solution because of its low cost, small volume and simple operation [2]. But in daily life, many products, such as arts and crafts and so on, need to be printed in a variety of color at the same time. However, the level of the traditional desktop 3D printer which is restricted in the structure and control system [3] is mostly in the monochrome printing stage, not achieving this function. Therefore, color FDM 3D printing technology has wide application space and broad market prospect.

At present, there are some researches on color mixing 3D printing at home and abroad. Huang et al. [3] designed a three feed-single extrusion 3D printing hotend, and wrote the color slice plug-in based on ordinary slicing software, but the software operation was not easy to handle. Shi et al. [4] introduced the idea that Italy's Stick Filament company fitted a connection head at opposite ends of the wire rod, but the single hotend print and need to replace other color filaments halfway. Han et al. [5-6] designed a dual feed-single extrusion color mixing 3D printing hotend based on the TRIZ theory, but it can only realize the melting and mixing of two colors filaments. The Dutch Builder launched a color mixing 3D printing

* Corresponding Author

and designed a dual feed-single extrusion device, which can achieve the extrusion of two kinds of filaments/color through a nozzle, but it also limits the types of mixed color. Reiner et al. [7] introduced a method of using the two color heads to achieve continuous tone imagery. Cai and Zhu [8] improved the 3D printing hotend, but inside the hotend was a right Angle mixing, which would result in uneven mixing effect. Ali, Mir-Nasiri and Ko [9] provided a five-nozzle operation at the same time, in order to solve the long time consumption, color variety, less inaccurate printing problem, but it is also a technical problem for many filaments to be controlled and mixed at the same time. Liu [10] proposed the technology of multi-hotend linkage control, in order to realize the forming parts of different materials. Arikan et al. [11] detailed the entire 3D printing work process and then committed to measuring the colors of highly translucent printed materials.

Aiming at the status quo of the above color mixing 3D printing, this paper has implemented a set of 3D printing system designed without midway replacing hotend, filaments, and late no artificial coloring processing, which can be molded multi-color and gradient uninterruptedly [12]. The hardware system has increased to three extruders and used the three feed-single extrusion design, which can mix three colors of filaments simultaneously. The LabVIEW software system mainly embodies friendly color mixing control, 3D print preview, remote adjusting, real-time monitoring and other functions, and the human-computer interaction experience is pretty good. Users can custom and modify the color parameter to meet own's demand, and can examine real-time mixed effect and 3D print preview effect in the process of setting colors. Moreover, users also can remote adjusting printer, and observe the feedback printer data and image information in the printing process to real-time monitor. Once having error the printer can be terminated immediately. The camera would recognition completed state intelligently at the end of the printing, and the current image would be sent to the designated mailbox where users can appreciate the print work immediately.

2 Theory Fundamental

2.1 Fused Deposition Modeling (FDM)

FDM technology refers to the filaments, such as PLA, ABS and nylon, would be heated by the hotend to high temperature about 200℃ to critical state, presented semiliquid and controlled to extrude to work platform by the program, fast cooling before forming a cross section. After the completion of the first layer, the hotend moves to the next level (layered thickness) to complete the next layer until the whole entity model is formed from the bottom up.

2.2 Cyan Magenta Yellow (CMY) Color Mixing

CMY color model is a subtractive color model, used in color printing. CMY refers to the three inks used in some color printing: cyan, magenta and yellow. Combinations of different amounts of the three can produce a wide range of colors with good saturation.

In this paper, three colors of the filaments are inks. The filaments are semiliquid state in the high temperature heating. When the filaments are mixed, the new color can be generated according to CMY principle.

3 System Architecture

The system architecture as shown in Fig. 1, consists mainly of two parts, including the hardware part and the software part.

The hardware part is made up of color mixing 3D printer and NI myRIO.

The printer is the FDM 3D printer based on the Delta structure, and the printer hotend uses the Diamond Hotend which is designed as three feed-single extrusion structure, which can mixed three colors of filaments at the same time.

NI myRIO communicates with the printer via serial port and communicates with the PC based on the TCP/IP protocol, which is mainly responsible for the communication between the printer and the PC.

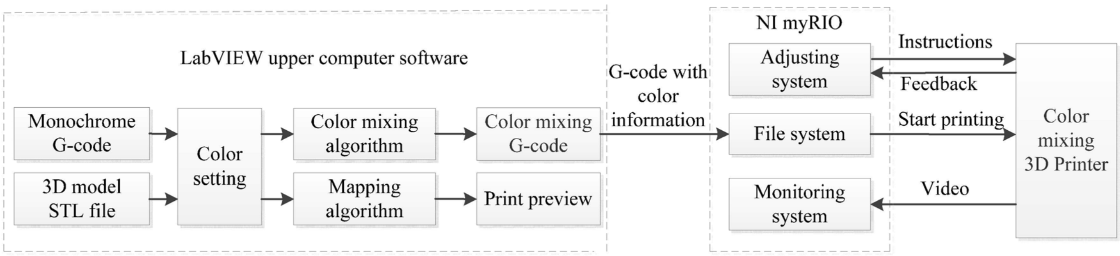

Fig. 1. Color Mixing 3D Print System Architecture

The software part consists of LabVIEW upper computer software and LabVIEW monitoring & adjusting software.

The main function of the upper computer software of LabVIEW is the color of model customizing and the effect of 3D print preview.

LabVIEW monitoring & adjusting software is mainly to adjust the printer and monitor the printer remotely.

Through the system, the complete color mixing 3D printing can be realized. A complete 3D printing process can be summarized as follows:

(1) design 3D models and export STL format files;

(2) process the STL model file by slicing, and generate the normal monochrome G-code ;

(3) import the STL model file and monochrome G-code into the upper computer software of LabVIEW to make the color configuration, and generate new G-code with the color information;

(4) use the LabVIEW monitoring & adjusting software to adjust the printer through myRIO, making the printer be ready to work;

(5) send the color mixing G-code to the 3D printer to make it start printing, and LabVIEW monitoring & adjusting software will monitor the printing process in real time.

4 Hardware Design

In order to realize the color mixing 3D printing system, the project needs a regular 3D printer with high reliability and high accuracy as the experimental platform. Common desktop 3D printer structures include RepRap structure, MakerBot structure, Ulitimaker structure and Delta structure. The structure of Reprap is less stable and the forming area is smaller. The structure of MakerBot and Ulitimaker structure have good stability but poor scalability. However, the Delta structure is widely used in industry and the structure of the joint arm is high-precision, stable and reliable. In addition, it uses the remote extrusion structure and the extrusion head expansibility is greatly enhanced. So the Delta structure whose design diagram is shown in Fig. 2 is the optimal choice.

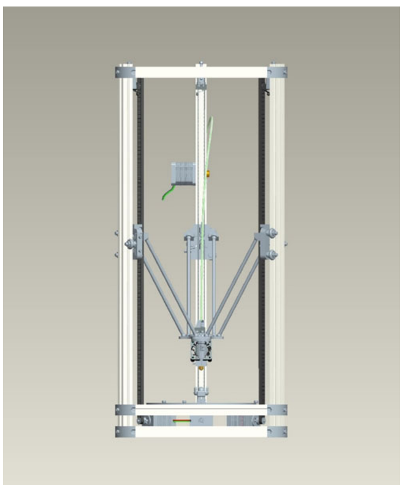

Fig. 2. Delta Structure 3D Printer Design Diagram

Based on the research of the open source Delta structure 3D printer, the overall 3D printer structure and the main parts are selected and optimized according to the experimental needs. This paper introduces the following six parts:

4.1 Extrusion Structure

The extrusion head adopts three feed-single extrusion structure design, in which mixed three kinds of color filaments at the same time. The extrusion head consists of cooling fan, heatsinks, heater cartridge, thermistor and nozzle. Three kinds of color filaments melt and mix in the extrusion head under 210 ℃ temperature; in order to prevent the plug, filaments in the throat is below 100 ℃ for 12 V DC cooling fan to ensure filaments to maintain solid on the heating module; according to the color mixing algorithm, the extruding quantity of each color filament was controlled; finally, 0.4mm diameter of the nozzle extrude the filaments. The extrusion head structure is shown as Fig. 3.

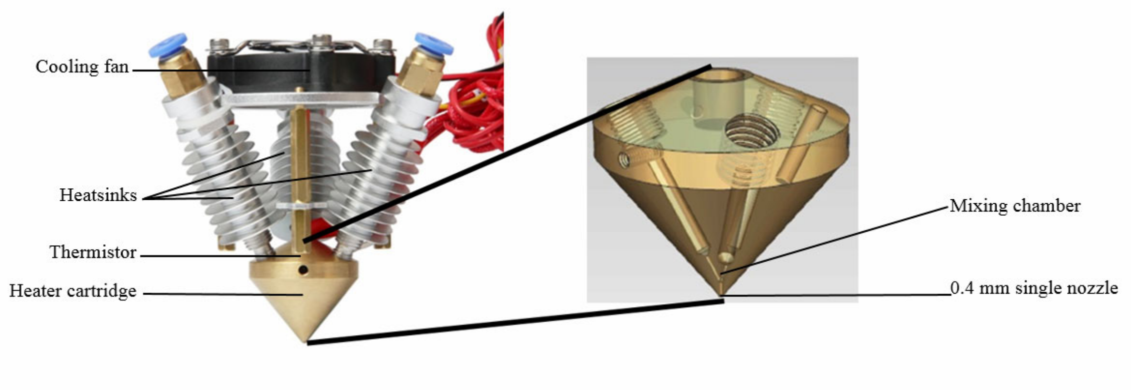

Fig. 3. The extrusion head structure

4.2 Feeding Structure

Adopting the remote extrusion design, the extruder is connected with the extrusion head through the feeding tube, which can effectively overcome the problem of the decline of the precision due to the excessive quality of the extrusion head in the process of printing at close range. The extrusion head adopts three feed-single extrusion structure design, so there are three the corresponding extruders. In terms of the extruder, a more mature MK8 extruder structure is selected, using 26 tooth brass wire feeding wheel to ensure the accuracy of wire feeding.

4.3 The Transmission Structure

Use the stable fish-eye rod joint arm to avoid the failure caused by loose arm in the printing process. The conventional pulley is replaced by the slide track, which reduces the error of printing accuracy caused by the pulley shaking in the fast printing process.

4.4 Printing Platform

Under the traditional high borosilicate glass add PCB hot bed, and heat the hot bed to 55 ℃ when printing to guarantee the PLA consumable will not shrink by quenching appear become warped edge deformation in the process of print.

4.5 Servo Control Part

The 42-step motor is as the motor mechanism and the drive of the 42-step motor is divided. The A4988 chip is used for 1/16 subdivision, and the motion precision of the 42-step motor is improved.

4.6 Master Control

The STM32 mainboard replaces the traditional Arduino Mega2560 and Reprap Ramps1.4 expansion board. The STM32 mainboard has a faster speed, more extensible options, and supports for multiple extruders.

After setting up a good experiment platform, the project needs to have the function of remote real-time monitoring and debugging printer, so using NI myRIO embedded development platform as a relay between the printer and the PC, which is responsible for collecting the image information and instructions. The NI myRIO embedded development platform includes analog input, analog output and USB interface, and supports a serial port transmission, WiFi function, and uses Xilinx FPGA and double nuclear ARM Cortex-A9 processor. In addition, myRIO can be programmed in LabVIEW or C programming language.

The PC and myRIO use the TCP/IP protocol over network connectivity to ensure reliable data transmission. myRIO connects with the printer through a serial port, and receives the information from the serial port in real time, and sends instructions to the printer via serial port from the PC. Meanwhile, connect the USB camera to myRIO, shoot the video of the working state of the printer, and transfer the video back to the PC in real time. This realizes the function of the remote real-time monitoring and debugging the printer.

5 Software Design

After the hardware has been mounted, a software to customize the color mixing, adjust and monitor the printer is required. Therefore, the paper introduce very detailed development of LabVIEW upper computer software and LabVIEW monitoring & adjusting software as below.

5.1 LabVIEW Upper Computer Software

The LabVIEW upper computer software includes two main functions: color mixing control and 3D print preview. The software interface is shown as Fig. 4.

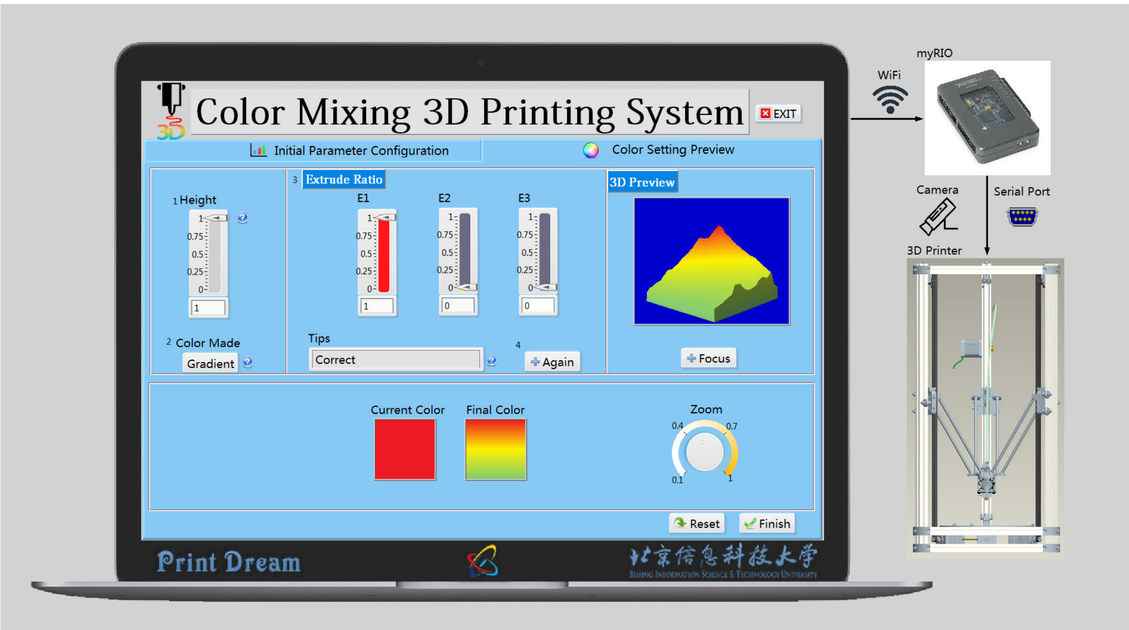

Fig. 4. Interface of LabVIEW Upper Computer Software

Color mixing control. The core of color mixing 3D printing system is the color mixing control software, which can be used to control the color of the model at different positions. Its principle is adding color information into the monochrome G-code, then generates the color mixing G-code. The input of

LabVIEW upper computer software includes user-defined color parameters, monochrome G-code, and the output is color mixing G-code. The software based on LabVIEW programming.

The color parameters can be set by LabVIEW upper computer software. The color parameters include model height (*H* for short), E1 Ratio (*E*1 for short), E2 Ratio (*E*2 for short) and color mode. Parameter *H* indicates the height position of the model. Parameter *E*1 indicates the ratio of extruder No.1 extrusion to total extrusion. The range of *E*1 is 0-1. Parameter *E*2 is similar as *E*1 which different is the ratio indicates No.2 extrusion. And *E*3 can be figured out by formula (1). The color mode indicates whether there is gradient change between the two colors.

$$E3=1-E1-E2. \quad \textbf{(1)}$$

Shown as below, there must use a fixed format to add the color information into the monochrome G-code:

M6050 S0.006734 P0.022447 D0.206734 C0.022447 Z0.000000

Related parameter explanation:

M6050: A specific G-code statement that enables the printer to recognize color mixing information.

S: E1 Ratio.

P: E1 Ratio change rate.

D: E2 Ratio.

C: E2 Ratio change rate.

Z: the height position of current color.

After the user customizing the color parameters, the values of above parameters will be calculated by the color mixing algorithm.

The parameters *S* and *D* correspond to *E*1 and *E*2 obtained by the user inputs. *S*=*E*1, *D*=*E*2.

The parameters *P* and *C* are computed by *H*, *S*, and *D*:

$$\Delta E1 = E1_n - E1_{n-1}, \quad \textbf{(2)}$$

$$\Delta E2 = E2_n - E2_{n-1}, \quad \textbf{(3)}$$

$$\Delta H = H_n - H_{n-1}. \quad \textbf{(4)}$$

(*n*=1,2,…,*N*. *N* is the number of user-defined color parameters)

If color mode is gradient change:

$$P = \frac{\Delta E1}{\Delta H}, \quad \textbf{(5)}$$

$$C = \frac{\Delta E2}{\Delta H}.. \quad \textbf{(6)}$$

If color mode is not gradient change:

$$P = 0, \quad \textbf{(7)}$$

$$C = 0. \quad \textbf{(8)}$$

Z is obtained by comparing *H* with Z_{all}:

Z_{all}: traverse the entire monochrome G-code to get all the values of *Z*, and generate Z_{all} array.

Compare every user-defined *H* value to all values in the Z_{all} array. When H_i is bigger than $Z_{\mathrm{all}j}$, $Z_i=Z_{\mathrm{all}j}$. Then compare H_{i+1}, get Z_{i+1}, and so on, get the *Z* array. (*i*=1,2,...,*N* *N* indicates to the number of user-defined color parameters. *j*=1,2,... *J*. *J* is the total number of layers of the model.)

After getting the M6050 statement, the software will insert it to the specified location in the monochrome G-code, which refers to traversing *Z* in Z_{all} array and inserting the corresponding M6050 statement in the upper line of the location which contains the *Z* value.

Through the color mixing control processing, the color mixing G-code will be generated from monochrome G-code. Then import the color mixing G-code into color mixing 3D Printer, and the colorful model will be printed.

3D print preview. After the realization of the basic functions of color control, when actual use of the process found that the product printed is often not the same with the imagination, the user is difficult to intuitively know that what effect is their own set of color parameters. Therefore, we developed the 3D print preview function. In the process of customizing color, the user can real-time preview print, and modify the settings at any time, until satisfied.

The problem is STL model does not contain any color information, it's not possible for directly color processing on the STL model. So the following steps describe color processing method by using LabVIEW to read STL model data and adding texture information.

(1) According to user-defined color, generate two-dimensional color map. According to the user-defined color ratio, corresponding to each height calculate the new color which formation from three color, and generates a two-dimensional color map with a unit size of 100×100 pixels that reflects the print effect. As shown in the *Final Color* in Fig. 4.

(2) Normalize the STL model. Because the STL model size is variable, and the map is fixed to 100×100 pixel square image, in order to accurately map, need to make the model normalization. The LabVIEW block diagram is shown in Fig. 5. It should be noted that the normalization of the model should maintain the original XYZ ratio, otherwise it will look distorted.

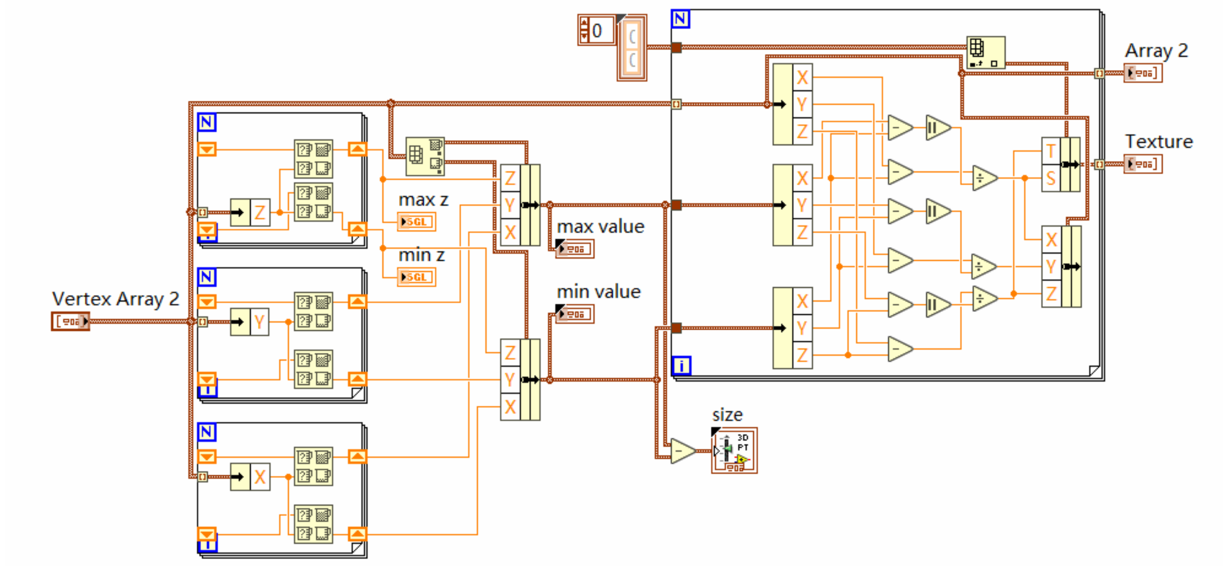

Fig. 5. STL Model Normalize Block

(3) Transform the STL model into points and correspond to the texture. Import the STL file and transform the STL model into points, then add it to the SceneMesh. After normalization, the Vertex Array and Normal Array data are redefined, and the Texture Array is added. At this time, the texture could be applied to the model surface by Apply Texture.vi. A 3D model with color information is available for user preview. The LabVIEW block diagram is shown in Fig. 6. Note that this operation does not change the original STL model information.

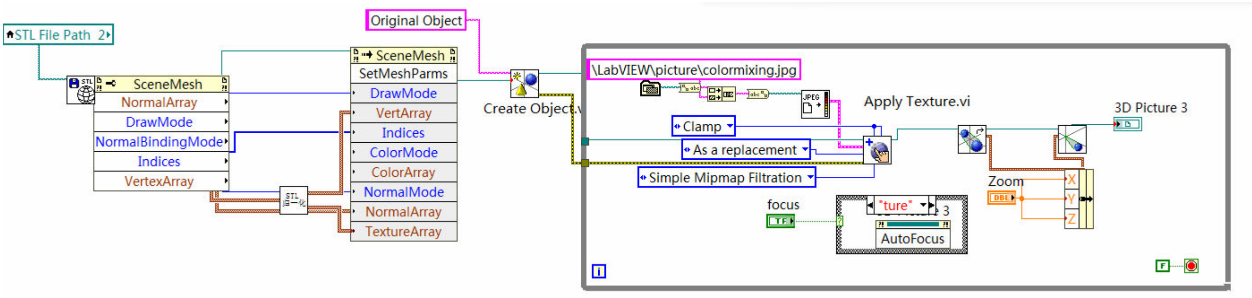

Fig. 6. STL Image Mapping Block

Fig. 7 shows the contrast of print preview with the actual product. to achieve the WYSIWYG(What You See Is What You Get) effect. The system greatly enhance the user experience, and make the color effect settings more efficient.

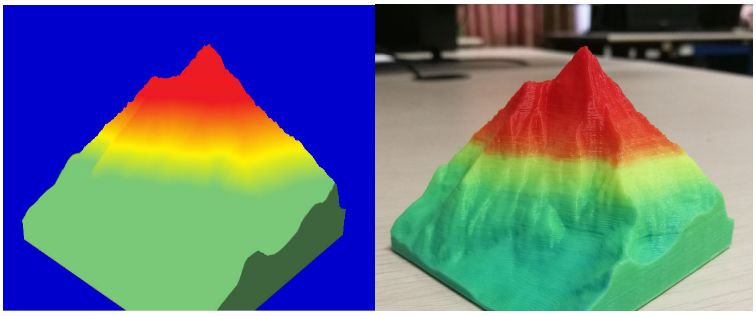

Fig. 7. Print Preview vs Actual Product

5.2 LabVIEW Monitoring & Adjusting Software

Finally, in order to coordinate with myRIO achieving the function of remote monitoring and adjusting, we also develop the monitoring and adjusting software. Fig. 8 shows the LabVIEW monitoring & adjusting system schematic diagram.

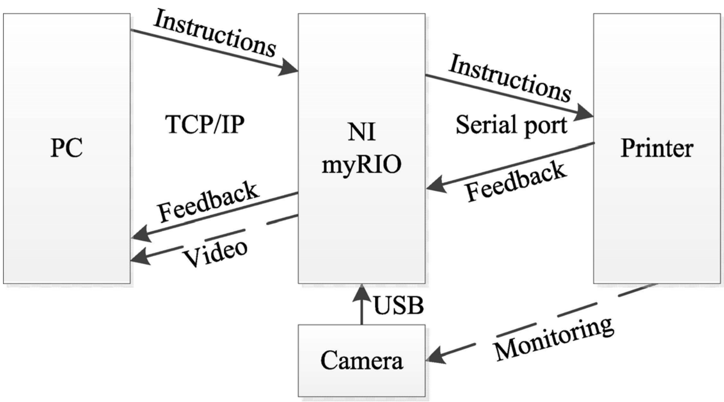

Fig. 8. LabVIEW monitoring & adjusting system schematic diagram

The software is divided into PC end and myRIO end. The program working on PC end interacts information with myRIO end by shared variables based on TCP/IP protocol.

The PC program is in charge of sending instructions and receiving feedback information. The myRIO program is mainly responsible between the printer and PC communication, myRIO communicates with the printer through serial port, and send the USB camera video to PC though WiFi network. The functions of LabVIEW monitoring & adjusting software list as following:

Command sending. As shown in the area 1 of Fig. 9, by sending specific instructions to printer, user can easily control the movement of hotend, preheating the hotbed and hotend, selecting files to print and sending advanced adjusting instructions.

Information display. As shown in the area 2 of Fig. 9, by receiving and displaying the feedback information from printer, user can immediately acquire current printer working status and file information. The feedback information includes hotend position, current temperature of hotbed and hotend, current printing progress, the remaining printing time, file name, file size and so on.

Video monitoring. As shown in the area 3 of Fig. 9, through receiving the video information (20 frames per second) capturing by USB camera, user can remote monitor current printer working status. Besides, the program can intelligently recognize when the printing job complete, and take a finished 3D product photo and send it to the appointed user email automatically, by this way user can see their 3D work at the first time. Email interface is shown in Fig. 10. The 3D work is shown in Fig. 11.

Fig. 9. Interface of monitoring & adjusting software

Fig. 10. Interface of email

Fig. 11. The 3D work

6 Conclusion

In this paper, the color mixing 3D printing system we designed has increased the extruder to three, and implemented a three feed-single extrusion structure 3D printer with precise, stable and fast hardware characteristics. The thickness of the printed layer is adjustable and the minimum thickness is 100 micron. The printer uses 42 step motor, and the Angle 1.8 degree Angle. It also uses the structure of the Delta joint arm, and it has been implemented for more than 8 hours continuous printing without fault. The filaments are back to stably and extrude smoothly. The printer adopts the remote extrusion design, and the hotend has light quality and small inertia. The average printing speed of the printer is 60mm/s. We also have designed the color mixing 3D printing algorithm and generated color mixing G-code which could be recognized by 3D printer successfully, solved the problem of color processing on STL model and realized real-time 3D preview, also developed remote monitoring and adjusting system, real-time network video transmission rate can reach 20 frames per second. The program interface is generous and beautiful, and the software operation is simple. The interface contains the operation step and the prompt, and it is easy for the user to get to the hand. Test results show that the system is stable, and colorful print products are beautiful, the system can be widely used in the family, education, product design and other fields. However, the system's shortcomings is that in the current, the color can only vary with the height, it still can not achieve the same layer of different color design. Hope this article can be used as a basic research, and in the near future to achieve any color definition in colorful 3D printing system.

Acknowledgments

This work is supported by the Science Foundation of Beijing Information Science & Technology University (No. 1725005) and 2017 Talent Training Quality Improvement Foundation of Beijing Information Science & Technology University (No. 5111724101, No. 5111724104)

References

[1] H. Lipson, M. Kurman, The New World of 3D Printing, John Wiley & Sons, Indianapolis, Indiana, 2013.

[2] Z. Yang, Research mechanical structure design and control system for the 3D printer based on FDM technology, [dissertation] Changchun, China: Changchun University of Technology, 2017.

[3] Z.F. Hua, Y.L. Ma, J.M. Li et al., Research of colorful 3D printer fused deposition modeling, Machine Tool & Hydraulics 45(2017) 21-25.

[4] Y.S. Shi, L.C. Zhang, Y. Bai, et al., The development of 3D printing technology and software implementation, Science China Information Science 45(2015) 197-203.

[5] S.L. Han, Z.Y. Li, Y. Xiao, et al., Research of fused deposition modeling 3D printer for color mixture, Machinery Design & Manufacture 2015(11)(2005) 116-118.

[6] S. Han, Y. Xiao, T. Qi, Z. Li, Q. Zeng, Design and analysis of fused deposition modeling 3D printer nozzle for color mixing, Advances in Materials Science and Engineering 2017(2)(2017) 1-12.

[7] T. Reiner, N. Carr, R. Měch, O. Šťava, C. Dachsbacher, G. Miller, Dual-color mixing for fused deposition modeling printers, Computer Graphics Forum 33(2)(2014) 479-486.

[8] Z.H. Cai, G.H. Zhu, Research on FDM-type 3D printing based on the improved nozzle. <http://en.cnki.com.cn/Article_en/CJFDTOTAL-HELJ201622007.htm>, 2016.

[9] M.H. Ali, N. Mir-Nasiri, W.L. Ko, Multi-nozzle extrusion system for 3D printer and its control mechanism, International Journal of Advanced Manufacturing Technology 86(1-4)(2016) 999-1010.

[10] C. Jiang, G.F. Zhao, A preliminary study of 3D printing on tock mechanics, Rock Mechanics & Rock Engineering

48(3)(2015) 1041-1050.

[11] C.A. Arikan, A. Brunton, T.M. Tanksale, P. Urban, Color-managed 3D printing with highly translucent printing materials, in: Proc. SPIE/IS&T Electronic Imaging. International Society for Optics and Photonics, 2015.

[12] B. Shen, Y. Guan, A design of color mixing fused deposition modeling 3D printer. <http://en.cnki.com.cn/Article_en/CJFDTOTAL-BJGY201605013.htm>, 2016.