The Control of SFFS in the Office Environments and It’s Integration

Jung-Su Kim*, MinCheol Lee**, Won-Hee Lee***, Dong-Soo Kim***
* Department of Mechanical and Intelligent Systems Engineering, Pusan National University,
  Jangjeon 2-dong, Geumjeong-gu, Busan 609-735, Korea
  (hanuki0128@gmail.com)
** School of Mechanical Engineering, Pusan National University,
  Jangjeon 2-dong, Geumjeong-gu, Busan 609-735, Korea
  (ncllee@pusu.edu)
*** KIMM(Korea Institute Machinery & Materials), 171 Jang-dong,
  Yusaeong-gu, Daewon, 305-343, Korea
  (ellban@kimre.kr)

Abstract: SFFS(Solid Freeform Fabrication System) can quickly makes models and prototype parts from 3D computer-aided design (CAD) data. Three dimensional printing(3DP) is a kind of the solid freeform fabrication. The 3DP process slices the modeling data into the 50–200um along to z axis. And we pile the powder and make the manufactures. A manufacture is made by the SFFS has the precision of the 50um. Therefore the x-y table of SFFS to move a printhead must be the system that has a high speed and accuracy. So we proposed the SMCSPO algorithm for SFFS. The major contribution is the design of a robust observer for estimating the state and the perturbation of the timing belt system, which is combined with a robust controller. The control performance of the proposed algorithm is compared with PD control by the simulation and the experiment. The control algorithm of the SFFS is presented in the office environment. The system between control system and printhead for the SFFS is also integrated

Keywords: SFSS(solid freeform fabrication system), 3DP(3D printing), SMCSPO(Translating mode control with sliding perturbation observer)

1. INTRODUCTION

These days, development cycle of goods has been changed very fast. Therefore, the developers are suffering much difficulty. And very fast development cycle brings the increase of a cost and the waste of a time 1).

SFFS(solid freeform fabrication system) can shorten the product development cycle and improve the design process by providing rapid and effective feedback to the designer.

SFFS could quickly makes models and prototype parts from 3D computer-aided design (CAD) data. SFFS in the office environment is a tool that streamlines and expedites the product development process 2). In their efforts to reduce production time, improve quality, and reduce cost, companies of all sizes rely on SFFS in the office environment. As a visualization tool, SFFS helps for companies to reduce the likelihood of delivering the wrong product, or a poor quality product to the marketplace.

Methods, processes, and systems for rapid tooling(RT) are also developing. While early efforts were focused on faster delivery of tooling, new developments are underway to improve the performance of short-run and production tooling. Many of these new concepts involve the additive SFFS process to achieve results that are unthinkable in machined tooling 3).

In this paper, the high precision control algorithm applies the control of the SFFS in the office environments and it’s integration.

2. THE STRUTURE OF SFFS

Fig 1 expresses the concept of the 3D RODS (three-dimensional digital real object duplication system). 3D RODS is divided into the scanning part and freeform fabrication part. The part to make freeform fabrication is the SFFS.
In this study, we used 3DP process for SFFS. 3DP is a kind of the solid freeform fabrication. 3DP process slices the modeling data into the 100um. We pile the powder and make a manufactures. The advantage of this method is a high-speed manufacture. Also a manufacture cost is very low.

The SFFS should have the precision of the 50um. Therefore the x-y table of SFFS to move a printer head must be the system that has a high speed and accuracy. The timing belt system has high speed and proper accuracy to control the x-y table. So we selected the timing belt system for the x-y table. AC motor is used for actuating x-y table. And the stepping motor and DC motor are used DC motor is used for z-axis and for roller, respectively.

Fig. 3 expresses the concept of the equipment. And Fig. 4 shows the developed SFFS in the office environments. Z-axis supplies the powder to the building room. And the roller spreads a powder to be supplied. Printing head is moved by the x-y table.

The timing belt system of the SFFS needs the control algorithm of the high precision. Therefore a robust control algorithm is applied to the SFFS. And because a system performance is decided by the processing parameters, processing parameters need the optimization.

3. THE CONTROL OF THE SFFS

3.1 SMCSPO

The controller of each axis consists of MMC board. The MMC board supports the position control mode to the basis.
But position control mode has the limit in the precision. Position control is controlled by the PID control. So we proposed the SMCSPO algorithm. The SMCSPO (Sliding Mode Control with Sliding Perturbation Observer) algorithm is designed for high precision control and robust in the timing belt system. Fig. 5 shows a block diagram of the SMCSPO algorithm.

The major contribution is the design of a robust observer for estimating the state and the perturbation of the timing belt system, which is combined with a robust controller. The control performance of the proposed algorithm is compared with PD control by the simulation and the experiment.

### 3.2 Simulation of the dead-zone

MMC board supports the velocity control mode and the torque control mode. The torque of the motor is controlled in the torque control mode by the input voltage. But dead-zone severely exists in the torque control mode. So the effect of the dead-zone in control is evaluated by the simulations in the PD control and SMCSPO.

The position error according to the dead-zone is shown in the simulation. Fig. 6.1 shows the position error according to the motor’s dead-zone which exists to the 50% of an input torque.

PD control had the position error of 3.8mm. But SMCSPO only had the position error of 300um. The result of SMCSPO algorithm showed more accuracy and better performance than PD control. But if dead-zone exists more over the 50% of an input torque, SMCSPO algorithm has the limit in the performance. Fig. 6.2 shows the position error of the SMCSPO algorithm at the 62.5% of an input torque. SMCSPO had the position error of 3.4mm.

### 3.3 Experiments

We knew that the results of the simulation is not good for a system with too severe dead-zone and the torque control mode is not to be suited for the SFFS because the system has more severe dead-zone. So we selected the velocity control mode. The velocity control mode is the method which the velocity changes according to an input voltage of the motor. Dead-zone does not exist in the velocity control mode. Because the velocity control mode uses the maximum torque.

We applied the torque control mode and the velocity control mode to the SFFS. The two kind of modes are used in the experiments.

Fig. 7.1 shows the position error of a PD control in the torque control mode. PD control has the position error of 900um and the overshoot of 17mm. Fig. 7.2 shows the position error of a SMCSPO algorithm. SMCSPO algorithm has the error of 100um and the overshoot of 7mm. Overshoot is very high because high P gain is given to overcome the dead-zone in the torque control mode. So we experimented the velocity control mode that has not a dead-zone.

Fig. 8.1 and Fig. 8.2 show the position error of a PD control and the error of a SMCSPO algorithm in the velocity control mode, respectively. PD control had the position error of 200um. Also the PD control existed a phase-delay. But SMCSPO algorithm had the error of 20um. And the phase is not delayed.

The results of SMCSPO algorithm showed more accuracy and better performance than PD control. And velocity control mode showed better performance than torque control mode.
4. SYSTEM INTEGRATION FOR THE SFFS

4.1 A bitmap of the tooth model conversion

3D print head uses the transmission of the bitmap file. So the 3D CAD model have to be converted to the bitmap file in the slicing data by the transformation algorithm. The bitmap transformation algorithm uses XOR method on the overlapping region of contour. If the region is overlapped, XOR method changes the color into black in white or white in black. We used the rapidform at the slicing data extraction. The method of the XOR algorithm to apply is as follows.

a. The case which other contour comes into being at a contour outside. Fig. 9(a) shows a bitmap to be produced. XOR algorithm is not applied to this case.
b. The case which other contour comes into being at a contour inside. Fig. 9(b) shows a bitmap to be produced. In this case the color of second’s contour is reversed into the white. 
c. The case which many contours comes into being at the overlap region.

Fig. 11 Surface quality of the powder

(a) a case of 50um layer thickness
(b) a case of 300um layer thickness
(c) a case of 100um layer thickness

Fig. 12 A manufactured sample made by the SFFS according to a layer thickness
4.2 Optimization of the processing parameter

The performance of the system is changed as the processing parameter. So we measured the best suitable processing parameters. The quality of the products in each layer and the resolution of the encoder in the Y-axis are evaluated. Also we measured the quality of the spreading powder according to the moving speed of the X-axis and a layer thickness.

The spreading speed of the powder has greatly affected the quality of a manufacture. Fig. 11 shows the quality according to the moving speed of the X-axis and a layer thickness. The roller revolves at the speed of 180rpm.

Spreading speed of the powder was decided by the crack of the powder’s surface and the undersupply of the powder. In the result of measurement, spreading speed of 0.3m/s showed most good result.

The precision of a manufacture is decided by the layer thickness. Fig. 12(a) shows a manufacture in the layer thickness of 50um. In the layer thickness of 50um, a manufacture is broken by the roller. Fig. 12(b) shows the manufacture in the layer thickness of a 300um. In this case, a manufacture is not broken. But layers are not bound. Fig. 12(c) shows a manufacture in the layer thickness of 100um. The situation of a manufacture was very good. And layers were bound very well. So the SFFS selects the spreading speed of 0.3m/s and the layer thickness of 100um.

4.3 A manufacture of a tooth model

The slicing data is extracted by the rapidform. And creating the bitmap is performed by the XOR algorithm. An experiment condition is as follows:

- Layer thickness: 100 µm
- Powder spread speed: 0.3 m/s
- Jetting volume: Droplet dia. = 100 µm
- Layer count: 340 layers
- Part size: 70 X 55 X 34 mm
- Printing resolution: 635 dpi
- Encoder resolution: 635 dpi

Fig. 13 shows a manufactured prototype of a tooth model. The tooth model was made very well.

5. CONCLUSION

We proposed the SMCSPO algorithm in the x-y table of the SFFS. In the simulation and experiment, SMCSPO algorithm showed more accuracy and better performance than PD control. But if dead-zone exists more severely than the 50% of an input torque, SMCSPO algorithm had the limit in the performance. It is shown that the control result of the velocity control mode is better than torque control mode. PD control had the position error of 200um. And the PD control existed a phase-delay. But SMCSPO algorithm only had the error of 20um. And the phase is not delayed. In the system integration, best suited processing parameters are found. The powder spreading speed of 0.3m/s showed most good result and the situation of a manufacture was very good in the layer thickness of 100um. Bitmap’s creating used the XOR algorithm. Finally, we used the optimal parameters and made a tooth model.

ACKNOWLEDGMENTS

This study was sponsored by “Three-Dimensional Digital Real Object Duplication System (RODS)” Development Project from the ministry of commerce, industry and energy. We appreciate and thanks to everyone who has supported and participated this study.

REFERENCES


