A Development of STL-Interfaced Constant-Speed Path Controller

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Abstract: SFFS(Solid Freeform Fabrication System) is commercializing to rapid prototyping concept in world-wide some corporations including the U.S.A, have much technological problems yet and need new mode for agile solid freeform fabrication as well as prototyping.

In this paper, we design an algorithm that the cutting path of laser beam, on the SFFS, is controlled with constant speed. The designed algorithm for constant-speed path control is implemented and experimented in the CAFL^{VM} (Computer Aided Fabrication of Lamination for Various Material) system, the new SFFS which is developed in this paper. Finally, the ceramic, new material developed in this paper, cut and fabricated. The dimensional accuracy and mechanical stability of the 3D object is confirmed through the experiment, also.

1. Introduction

In this paper, we design algorithm that the cutting path of laser beam, on the SFFS(Solid Freeform Fabrication Sys tem), is controlled with constant speed. The designed algorithm for constant-speed path control is implemented and experimented in the CAFL^{VM} (Computer Aided Fabrication of Lamination for Various Material) system, the new SFFS that was developed in this paper.

The CAFL^{VM} (Computer Aided Fabrication of Lamination for Various Material) system makes 3D solid model of various material using 2D cutting method of laser beam. So It is a new machine for rapid prototyping, tooling and manufacturing. Its process is an automated fabrication method in which a 3D object is constructed from STL(STereoLithography) 2D data, derived from CAD 3D image, by sequentially laminating the part cross-sections. The constant-speed path control is started from the STL data. After STL file is modified in data format to be available for control, The fabrication of the 2D part is, with constant speed, conducted from the 2D position data by laser beam. If the constant-speed control is not perfect, a good 2D solid model can not be made because of changeable stay-time in a point laminating the part cross-sections. In the shorter stay-time, the 2D part is not cut. In the longer stay-time, the material of the part cross-sections is burned. Therefore, we develop the constant-speed path control algorithm to stably solve the problem, and confirm its high-performance through experiment results from the application into CAFL^{VM} system. Finally, the ceramic, new material developed in this paper, cut and fabricated. The dimensional accuracy and mechanical stability of the 3D object is confirmed through the experiment.

2. CPC(Constant_speed Path Controller)

2.1 Configuration of CPC

The CAFL^{VM} system makes 3D solid model of various material using 2D cutting method of laser beam. So It is a new machine for rapid prototyping, tooling and manufacturing. Its process is an automated fabrication method in which a 3D object is constructed from STL(STereoLithography) 2D data, derived from CAD 3D image, by sequentially laminating the part cross-sections. It must be able to move to all desired position with the constant speed so that a 3D object can be automatically and precisely constructed from STL 2D data, derived from CAD 3D image, by sequentially laminating the part cross-sections. The precise 2D cut can be guaranteed only by constant-speed path control. To track the desired position with constant speed, STL 2D data are converted to 2D position data for control, by solving the crossing points of facet's subset and slicing plane. The control schematic diagram is shown in figure 1.

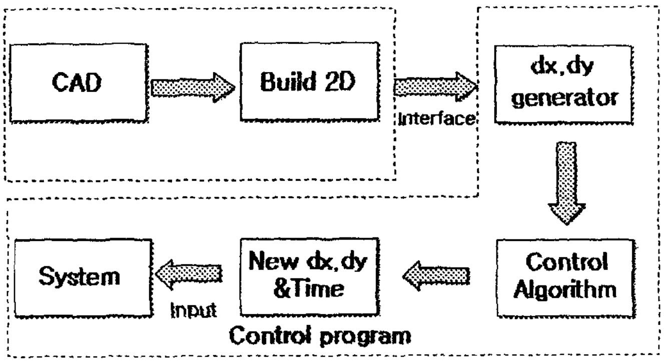

Figure 1. Control Block Diagram for 2D Fabrication

2.2 The Algorithm of CPC

A distance is decided by a time and a speed. So we firstly decide a speed and a time interval for a reference segment. Thereafter, every speed value in all the distance is changed in the constant speed. finally, The number of segment m and segment time interval T is derived. The detail algorithm is shown as below.

Step1. Let (x_1, y_1) (x_2, y_2) be position value of X and Y. Then the deferential distance is $dx_1 = x_2 - x_1$, $dy_1 = y_2 - y_1$, Distance is $P = \sqrt{dx_1^2 + dy_1^2}$

Step2. Then $P_{seg} = T_{seg} \times V_{seg}$

P_{seg} : Segment of P

T_{seg} : Time interval of segment

V_{seg}:Constant Speed

Step3. So, $P / P_{seg} = m$ (m:Segment number)

Step4. Now, Let's divide P into P_X and P_Y by m

$$\frac{P}{m} = \sqrt{(dx_1/m)^2 + (dy_1/m)^2}$$

Step5. Let T_{coord} be optimal time interval for constant speed

Given $T_{coord} = m \times T_{seg}$

$\therefore P = V_{seg} \times T_{coord}$

$(\because P = V_{seg} \times T_{coord} = V_{seg} \times m \times T_{seg})$

The composition of X and Y ocoordinates is a vector, because the driving distance is vector. So, the total distance P is divided a moving distance into m segments. Then, we can get the m segments which consist of the time T of the reference speed calculated by a reference distance.

we can know that the constant speed (distance/time) is guaranteed in all the distance, from the graph of fig. 2 calculating constant speed values for all the segments.

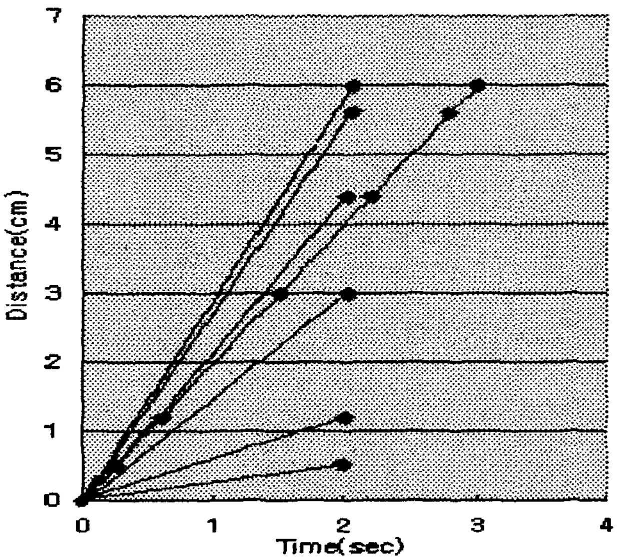

Figure 2. Constant Speed Values for all the Segments

2.3 The Experimental Set-up

The Windows NT and TMS32C44 DSP is used as the process for high accurucy of the control experiment environment. The IP(Industry pack) carrier board has four slots that uses a DSP-Link3 connection for communication with the host process. DSP Board has an input/output interface with CAFL^{VM} system. The control environment diagram of CAFL^{VM} system is shown in figure 3.

The CAFL^{VM} system is made up of the two AC motor(200W and 100W), laser system, limit sensor, home sensor and pneumatic system for the clearness of cutting face. The digital controller can automatically drive all the devices

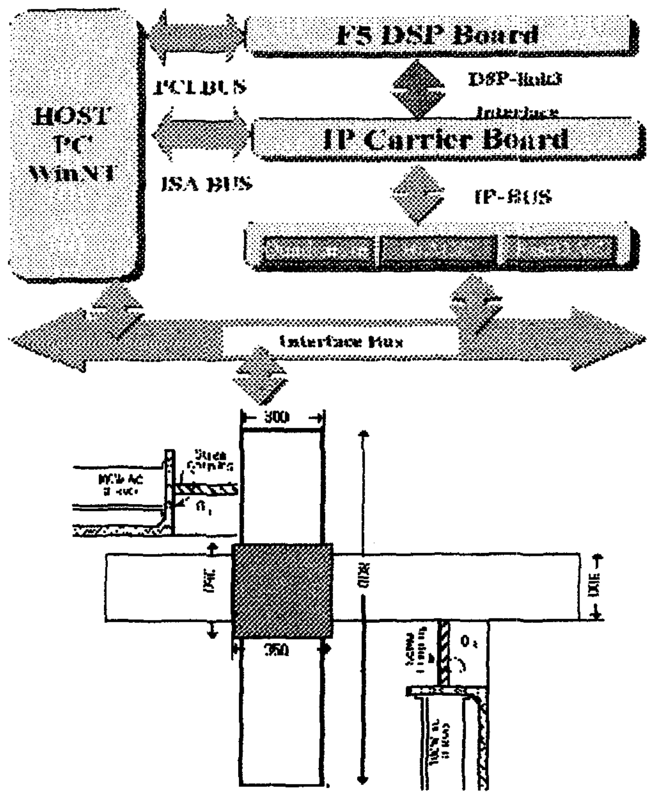

Figure 3. Experimental Set-up of CAFL^{VM}System

3. Experiment & Results

The experiment, that a 3D object is constructed from a solid CAD representation by sequentially laminating the part cross-sections on the CAFL^{VM} System, is shown in figure 4.

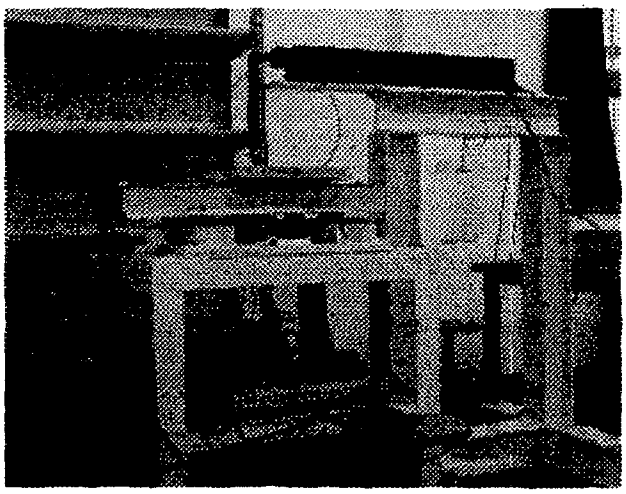

Figure 4. CAFL^{VM} System

The 2D slice which was cut by the control algorithm, is shown in figure 5. Its material is ceramic. Fig. 6 shows the 3D object made with the 2D slices. Becaluse the constant-speed control was perfect in this extperiment, a good 2D solid model and a 3D object were made without any changeable stay-time in a point laminating the part cross-sections. If the constant-speed control were not guaranteed, the 2D part could not be cut at the shorter stay-time or the material of the part cross-sections could be burned at the longer stay-time.

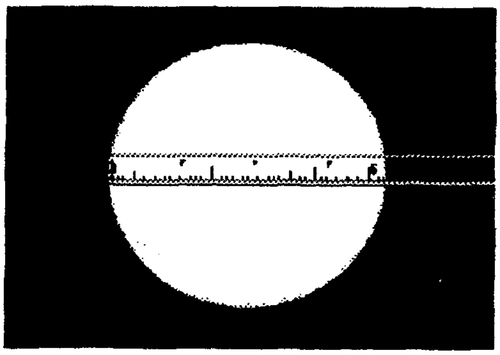

Figure 5. A 2D Cutting Slice

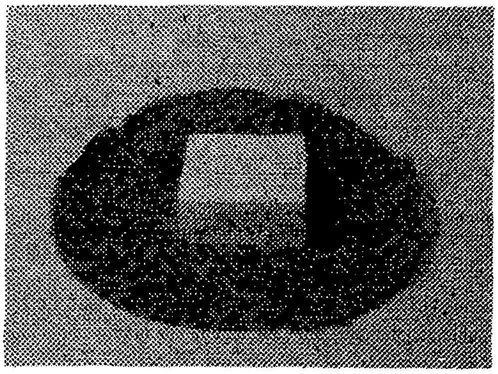

Figure 6. A 3D object fabricated by the CAFL^{VM} system

Good adhesion between the ceramic layers is essential to the dimensional accuracy and mechanical stability of the 3D object. As shown in Fig. 6, the cross section of the laminated ceramic layers after firing at 900°C for 1h demonstrates that layers are strongly bonded each other without delamination and cracking.

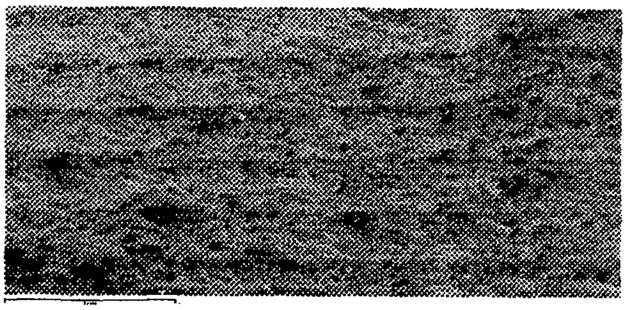

Figure 7. SEM micrographs of cross section of ceramic

The figure 8 and 9 compare the control performance between point-to-point control result and the experiment result of the constant-speed path controller automatically interfaced into STL data file. The 5th layer was cut in this experiment. The figure 8 is a tracking result from the 2D position data by point-to-point control. The figure 9 shows so much higher performance, without any position error, than the figure 8.

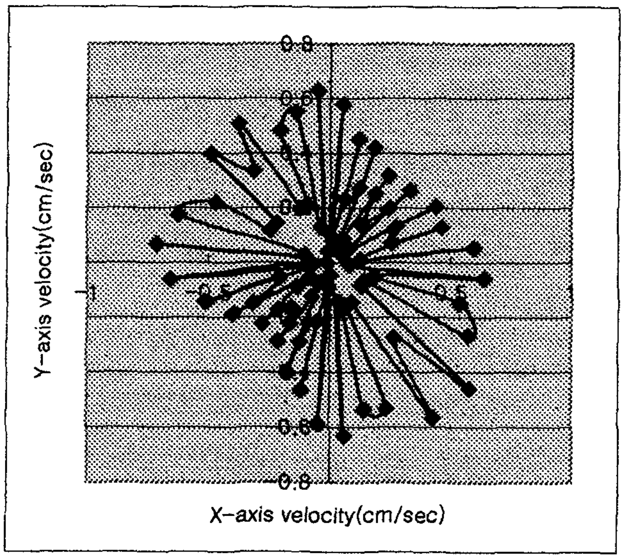

Figure 8. The result of speed vector by point-to-point position control

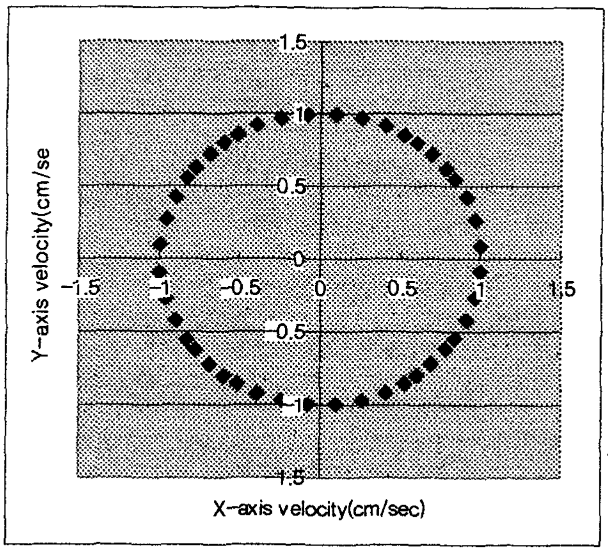

Figure 9. The result of speed vector by constant-speed position control

4. Conclusion

We designed the new control algorithm that guarantee the constant speed and precise positioning. We developed the position-tracking algorithm to be controlled with constant speed and successfully implemented in the CAFL^{VM} system developed in this paper.

In this paper, the fabrication of the 2D part was, with constant speed, conducted from the 2D position data by laser beam. If the constant-speed control were not perfect, a good 2D solid model could not be made because of changeable stay-time in a point laminating the part cross-sections. In the shorter stay-time, the 2D part could not be cut. In the longer stay-time, the material of the part cross-sections could be burned.

Therefore, we developed the constant-speed path control algorithm to stably solve the problem, and confirmed its high-performance through the experimental results from the application into CAFL^{VM} system. Finally, the ceramic, new material developed in this paper, cut and fabricated. The dimensional accuracy and mechanical stability of the 3D object was confirmed through the same experiment.

References

[1] R. H. Crawford and J. J. Beaman, "Solid Freeform Fabrication: A New Manufacturing Paradigm," IEEE Spectrum Magazine, Feb. 1999.

[2] Lee, C. H., T. M. Gaffney, and C. L. Thomas, "Soft Tooling for Low Production Manufacturing of Large Structures," *in Solid Freeform Symposium Proceedings.* University of Texas at Austin, Austin. Texas, pp. 207-214, Aug. 1996.

[3] Chua chee kai, Leong kah Fai, Nanyang Technological University "Rapid Prototyping: Principles& Applications in Manufacturing" John Wiley & Sons, Inc. June. 1996.

[4] Wesley E. Snyder "Industrial Robots: Computer Interfacing and Control" in differential motions and the jacobian pp.151-175, in Path control pp.178-200, Prentice-Hall, 1985.

[5] Brady, M. "Basics of robot motion planning and Control." in Robot motion, pp.1-50, M.I.T.Press, 1983.

[6] Weiss, L., Prinz, F., Neplotnik, G., Padmanabhan, K Schultz, L. And Merz. R., "Shape Deposition Ma nufacturing of Wearable Computers," in Solid Freeform Symposium Proceedings, University of Texas at Austin Austin, Texas, pp. 31-38, Aug. 1996.

[7] P.Bonaldi and C.Barlier, "Examination of Various Stochastic Algorithms Research on Placement Methods Dedicated to the Rapid Prototyping Process: Strato-conception "Proceedings of the 6th European Conference on Rapid Prototyping and Manufacturing, Nottingham, UK July 1997.

[8] Y. Zheng and W. S. Newman, "Software Design Challenges for Computer-Aided Manufacturing System Nottingham, UK, July 1997.

[9] E. A. Griffin, J Daufenbach, and S. McMillin, "Desktop Manufacturing: LOM vs Pressing," *Am. Ceram. Soc. Bull* 1994.

Acknowledgements

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