TOOLPATH GENERATOR FOR MULTI MATERIAL FREEFORM FABRICATION (MMFF) PROCESS

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Abstract

Fabrication of Rapid Prototyping (RP) of a mechanical part using multi-material powder-deposition is carried out to improve the functional aspect as well as the life time. This RP allows the multi-material fabrication by modifying the material delivery subsystem.

This paper reports the fabrication of multi-material free-form parts, hereafter will be abbreviated as MMFF. This paper also presents a method of tool-path generation. The shape and the size of the part are the input of the RP-process; typically, this input is either a 3D-model from a CAD system or a set of coordinates from a CMM. In this report, the input is obtained from a CAD system. The model is sliced at a pre-determined thickness interval, and the results are a set of 2D sections. A section contains a single outer loop and may have inner loops. A tool path is generated for each section, and the path will later be traversed by a deposition nozzle. Scanning gaps between two parallel path is determined based on the geometry of the loops of the section. Tool path generator also facilitates the inputting setting data to appropriate the dimension machine capacity.

Key words: tool-path, product powder, supporting powder

INTRODUCTION

Research and development of RP processes are aimed at reducing the production cost, increasing product quality and producing multi material product.

Jepson *et al* state that the key to the development of a rapid prototyping of Multi-Material Selective Laser Sintering (M2SLS) process is the redesign of the current powder delivery subsystem [2]. They developed an SLS process that is capable to produce multi material part in vertical formation. The process was called *Functional Gradient Materials* (FGMs). In this process, the tungsten carbide provides the resistance of abrasion and erosion, and the cobalt provides ductility and fracture resistance. Erosion resistance near the sharp edges and corners is desirable, and is achieved by increasing the relative amount of tungsten carbide nearby the sharp area. Fracture resistance is important in the area distant from edges and corners.

One of powder depositor device uses a hopper nozzle construction. Kumar et all developed a method to flow the powder using assistance of vibration and pressure. Flow of powder in hopper construction was observed.

Khalil et al developed bio-polymer depositor device using hopper nozzle construction. Pneumatic valve was installed in the center of the hopper construction in order to control the flow of material**.**

Multi hopper nozzles are installed on plotter construction. For each layer, a hopper deposits one type material. Multi material powder deposition is made possible by repeat traverses, each of which deposits one type of material. To guarantee the product dimension accuracy, the compensation for position of each hopper must be accurately determined.

The next problem in the deposition process is to form the shape of deposited powder of each material on every layer. This paper investigates the method of forming the shape of deposited powder and the problems arose during the process of deposition.

OPERATION SYSTEM OF MMFF MACHINE

The multi-material free-form fabrication uses multi-hopper nozzles to deposit powder. The fabrication consists of two types of depositions i.e. that of the product and of the supporting body. These depositions are executed alternately. The powder deposition to fabricate the part, i.e. the first deposition, always precedes the second one. The motion of the nozzle during the first deposition traverses a generated 2D tool-path. Figure 1 shows the construction of the hopper and the nozzle. On the other hand, the second deposition is performed by a slot feeder counter-rolling cylinder in a single motion. The supporting powder fills the empty space between the previous depositions. Figure 2 shows the diagram of the slot feeder counter-rolling mechanism.

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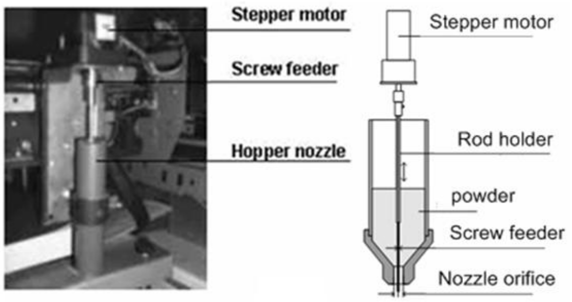

Figure 1. Nozzle and The Screw Feeder

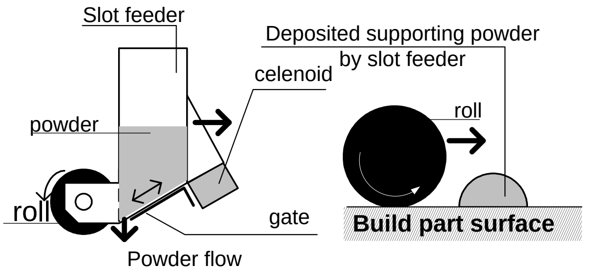

Figure 2. Slot Feeder Counter Rolling Cylinder

Currently, operation system of MMFF machine is based on G/M code format like the common CNC operation system in order to simplify the positioning of the hopper. The shaping operation is similar to that of milling operation, i.e. the hopper traverses a tool-path that will result in a desired shape. The shape is obtained by extracting a planar section at a certain position and orientation. A complete 3D part is constructed by creating a set of parallel planar sections, each of which is constructed by the previous tool path motion. The tool-path is specified using the G/M code format. Prior to fabrication, the tool path is previewed for verification purposes.

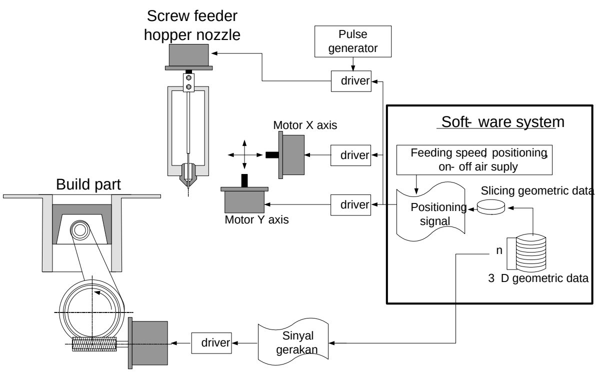

Figure 3. Control Configuration of MMFF Machine

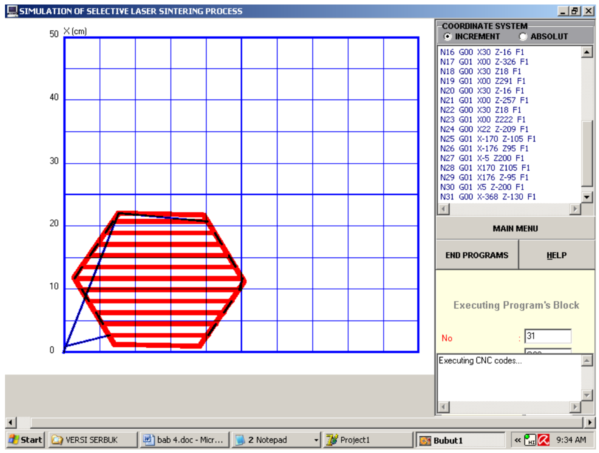

Figure 4. Simulation and Verification of Nozzle Path

DEVELOPING TOOL-PATH GENERATOR

Tool path generating method

Four well-known methods to generate tool path are the Raster Scan, the Contour, the Spiral, and the Vernoi. The Raster Scan, a.k.a. the zig-zag, method defines a shape by a set of parallel lines of uniform distances. Each of the line has its own length, depending on the shape. The path can be traversed using two methods: one-directional and two-directional traversal. Figure 5 shows these methods of traversal. The one-directional has two mode of tool path: the depositing and the idle modes. These modes are executed alternately. The two-directional has the advantage of shorter overall length of traversal. The Raster Scan method requires a final traversal of the outer loop to improve the quality of the section/part. This method is also relatively simple to program.

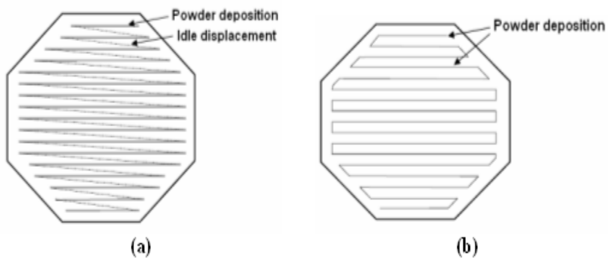

Figure 5. (a) Zig Method, and (b) Zig-zag method

In the Contour method, the tool traverses the contour of the shape, starting from the outer contour and proceeding to the inner contour. The Contour method requires a thorough and complicated analysis of the tool path in order to anticipate possible cusps and disjoint contours, and thus this method will complicate the programming works. The Spiral method is a variation of the Contour method in which a pair of subsequent contour is smoothly connected. The resulting path is topologically similar to a spiral, and hence the name of this method. The Vernoi method is commonly used in the determination of robot trajectories. This method can be adopted for tool path generation. This method is considered the best among the other methods. Pamali[6] reports a possible occurrence of numerical instability in the Vernoi method.

Procedures

Based on the Raster Scan method, the procedure to generate the tool path is listed in the followings:

1. create a set of planar sections of the part by slicing at a predetermined thickness and a predetermined direction of the plane
2. for each section: (a) create a set of parallel line segments each of which is inside the section, and the distance of adjacent lines are previously predetermined, (b) generate a G/M code of the parallel lines that will be traversed by the hopper, and (c) generate a G/M code of the outer loop of the section

Contour definition

Whenever a part has one or more holes, the resulting sections will have inner loops. A method to differentiate between the area on the section that is "filled" with material, and the area that is not filled must be established. In this work, the ability of DXF format to differentiate those areas are used. The ability is based on the ANSI-31 hatching.

Transforming arc to line (arc to line)

All arcs along the section are approximated by a series of lines of uniform length. The number of lines is adequately created in order to maintain a predefined tolerance of ε. Figure 6 shows an approximation of an arc by a line.

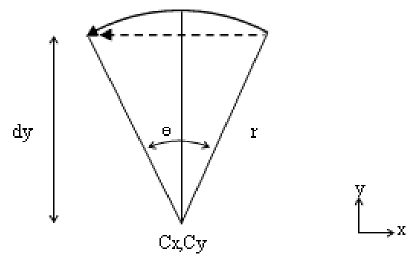

Figure 6. Geometry and Approximation of Arcs

The center of the arc is (Cx, Cy), and the radius is r, and the angle is θ. The angle can be derived as the followings:

$$Cos(\frac{\theta}{2}) = \frac{dy}{r}$$

$$\frac{\theta}{2} = ArcCos(\frac{dy}{r})$$

$$\theta = 2ArcCos(\frac{dy}{r})$$

The gap between the arc and the line segment is

$$\varepsilon = r - dy$$

If the gap is predefined, then the angle can be computed as the followings:

$$\theta = 2ArcCos(\frac{dy}{r})$$

$$\theta = 2ArcCos(\frac{r-\varepsilon}{r})$$

$$\theta = 2ArcCos(1-\frac{\varepsilon}{r}) \quad \text{..................} \quad (1)$$

For an arc starting from angle α and ending at β, the number of line approximating the arc can be expressed as:

$$n = \frac{\beta - \alpha}{\theta} \quad \text{.................... ....} \quad (2)$$

The starting coordinates of the first line segment is:

$$x1 = Cx + r\,Cos\,\alpha \quad \text{......................} \quad (3)$$

$$y1 = Cy + r\,Sin\,\alpha \quad \text{..................} \quad (4)$$

The coordinates of the subsequent vertex that form the remaining line segments are:

$$x2 = Cx + r\,Cos(\alpha + \theta) \quad \text{............} \quad (5)$$

$$y2 = Cy + r\,Sin(\alpha + \theta) \quad \text{..............} \quad (6)$$

Generation of G/M code and its verification

A relatively complex part is used as the test case for the algorithm; Figure 7 shows the part. The solid model was constructed in a CAD software. Then, a set of planar sections were constructed using the software's functionality; this task is straightforward. The results are parallel sections. The parameter of the task of construction is either the number of sections to be constructed or the distance between a pair of adjacent section. For the part at hand, the numbers of generated sections are 10.

Figure 7. Sample Part and Its Sections

The next task is to generate tool path for each section. This task is performed using the hatching functionality of the CAD software; again, this functionality is always provided by any CAD software. A section at hand is hatched using ANSI-31 hatching. Figure 8 shows a hatched section. The lines are divided into two types: parallel lines and the closure polygon. These lines and polygons serve as the core information to generate the tool path in G/M format. Figure 9 shows a list of G/M code that is generated based on the lines and polygons. For the part at hand, the fabrication of a section requires 70 – 130 lines of G/M code in average.

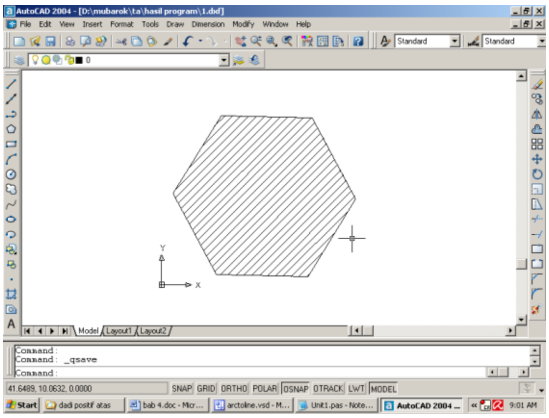

Figure 8. An Illustration of a Section and ANSI-31 Hatching

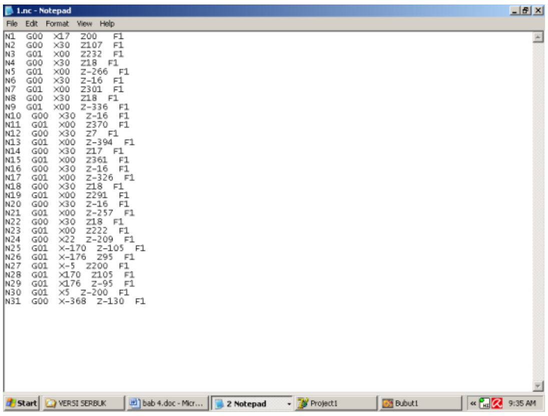

Figure 9. The Generated G/M Code

Then, the G/M code was verified using software that is developed in-house. Figure 10 shows the GUI of the software. The blue lines represent a rapid traverse where no deposition occurs. The red lines, on the other hand, represent a depositing stroke.

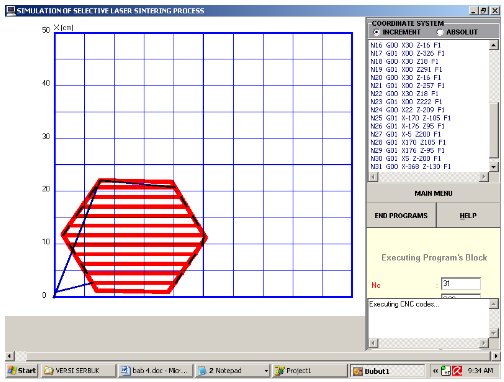

Figure 10. GUI of Software For Preview and Verification Of G/M Code.

FABRICATION OF THE PART

After the verification of the G/M code was completed, the fabrication of the MMFF part is performed. The machine was built in-house from scratch, as shown in Figure 11. It provides a translational planar motion. The *XY*-plane contains the motion of the hopper, and the *Z*-axis provides motion to proceed from a section to the next one. An in-house built hopper is attached to the machine, and thus the hopper is capable of performing 2D deposition on a particular planar section. For the part at hand, the average speed of G01 is 120 mm/min; and the average time of fabrication is 90 min. Figure 7 and 12 shows the fabricated MMFF part.

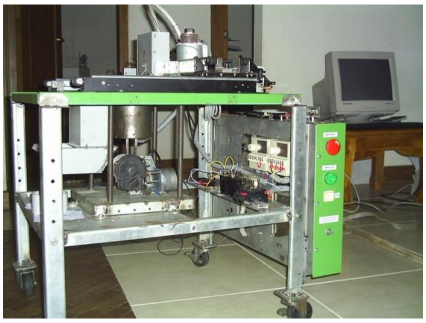

Figure 11. Our MMFF-Machine

RESULT AND CONCLUSION

Several parts were fabricated using the machine, and they were shown in Figure 12. Various features are introduced to the part to observe the behavior and the limit of our MMFF RP process and the machine. The performance was relatively stable, and is independent of the complexity of the fabricated parts. The raw material was the waste from plastic products. An attempt to use polyethylene powder of size 150 microns. failed to produce the part, and we observed that the plastic powder was melt instead of flowing through the nozzle; it indicated a false setting of heat and temperature. Because of the limitation of the nozzle, the size of powder to flow must be 150 microns or bigger; this is the size that was used for all of fabricated parts reported in this article. Therefore, the surface roughness is limited by the size of powder. The parts were infiltrated with cyanoacrylate glue to fill into the pore between particle of powder and to give strength to the parts.

Figure 12. MMFF Parts

For future research, we aim at investigating the failure of using new plastic powder that we encountered during previous research. The influence of thermal setting during the fabrication is also an interesting topic to be investigated in our future research. The behavior of the flow of the powder is also an important subject that is critical to the MMFF fabrication.

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