Research on Algorithm of Optimized Sub-regional Scanning Path Generation for RPM

Jibin Zhao  Weijun Liu  Renbo Xia  Hongyou Bian

Key Lab of Advanced Manufacturing Technology, Shenyang Institute of Automation, Chinese Academy of Sciences,
Nanta Street 114#, Shenyang, 110016, China.

Email: jbzhao@sia.cn.

Abstract - Rapid prototyping is a technology of layered manufacturing; therefore, the scanning path of certain layer is quite important. An algorithm of sub-regional scanning path generation is presented in the paper. The algorithm divides complex sectional contours into some simple non-hole sub-region, the scanning path in every sub-region is continuous and the sub-regions are scanned in turn. At the same while, the scanning path is optimized in two ways. The first one is that the joining path between the regions is optimized, which is effective on decreasing the vacant path. The second one is that the scanning path out of place at extreme points in a sub-region is optimized. The experiment shows the proposed algorithm not only improve the machine equality but also advancing the machine efficiency.

Index Terms - Rapid Prototyping, Scanning path, Polygon, CAD, Intersect point

I. INTRODUCTION

Rapid prototyping techniques provide a capability for building three-dimensional objects or parts directly from computer aide design (CAD) models. It is also sometimes called solid freeform manufacturing of layered fabrication [1]. This capability introduces a significantly enhanced flexibility in current manufacturing processes. For example, manufacturing processes that involve a design, redesign, prototyping or production of three-dimensional models, models or patterns, may be efficiently realized in a matter of hours or days, not months, thereby obviating slower, more complex and expensive manual machining techniques. Various rapid prototyping (RP) processes have been developed and used in the past decade. The better known among these processes are stereo-lithography (SL), selective laser sintering (SLS), fusion deposition modeling (FDM) and laminated object manufacturing (LOM).

Rapid prototyping is a technology of layered manufacturing. In the process of part’s manufacturing, the most essential step is scanning to manufacture certain section of the part. Therefore, the scanning path of certain layer is quite important. In the light of the difference of scanning path, the scanning path includes the following three types.

1) Zigzag scanning path. All scanning line of this type of scanning path is parallel and the parallel line is scanned by to-and-fro (see Fig.1(a)). This scanning method is an approach widely used. Some improved scanning methods [2, 3, 4] are proposed for different machining purpose and for improving performance of parts. Some study [5] optimized the scanning direction of scanning vectors to advance machining efficiency.

2) Contour parallel scanning path. The scanning line of the scanning path is parallel to the boundary of contour and the scanning line generated by equidistant line of contour (see Fig. 1(b)). The algorithm of the scanning line generation involved lots of operation of polygon so as that the algorithm is complexity. But the scanning method has soundness efficiency [6, 7].

3) Fractal scanning path. This scanning path is composed of short fractal line (see Fig.1(c)). The scanning method rarely used in LOM or SLA, but it is found to be used in SLS [8, 9].

Scanning path generation is to hatch sectional contours in fact. The sectional contours obtained by slicing STL model are a set of closed polygon. These polygons are maybe concave or convex. The region surrounded by the polygons is maybe simply connected or complicated connected region. Therefore, the hatching problem of sectional contours is translated into the hatching problems of complex polygon. The problem is the basic operation of computer graphics.

II. SOME PROBLEMS OF RELATED WORK

In all type of rapid prototyping processes, including SL and SLS, Zigzag scanning path is an approach widely used. Some improved scanning methods are proposed for different machining purpose and for improving performance of parts [2]. Shi [3] complemented a zigzag scanning path for SLS. The direction of scanning line in a sub-regional could be selected to meet the quality demand of part. Zhao [10] presents a zigzag scanning method for SL. The method could effectively generate the sub-regional scanning path. In 2006, Bian and Liu[11] proposed a method of sub-regional scanning path for laser metal deposition shaping (LMDS). A optimal dividing sub-region is discussed in the paper. In these scanning method, some problems exits.

1) Some Error Exist
When the scanning line is generated to fill the plane region by set scanning line space, the error is appeared with the scanning line space in fact at extreme points. When the practical scanning line space is less than the set one, the area occupied by the adjacent scanning line overlapped excessive. Whereas, the area occupied by the adjacent scanning line overlapped fewer. The excessive scanning space is shown in fig.2. The scanning line of the case destroys severely the scanning quality of the sectional contours. For laser metal deposition shaping (LMDS), shaping precision and quality of boundary is badly affected, further more; the followed shaping machine is directly affected by above case. Fig.3 shows local hummock of over cladding by fewer scanning space and local ravine of lack of cladding by scanning line overlapping fewer. And that, the more error scanning line space become, the more the flaw become. So we must remove the flaw by optimizing the scanning line space [12, 13].

2) Scanning Efficiency Problems

For advancing scanning efficiency, the sectional contour to be filled usually divided several sub-regions. Sometimes, the distance of the sub-regions to be filled in turn is far long. The path between sub-regions does nothing, so called “vacant path”, as shown in fig.2. The “vacant path” affects not only scanning efficiency but also scanning quality. Therefore, how to decrease the “vacant path” is an important problem.

A new algorithm of optimized sub-regional zigzag scanning path generation is proposed in the paper. The aim of the paper is removing above mentioned two defects. The complex sectional contours are divided into some simple non-hole sub-region, the scanning path in every sub-region is continuous and the sub-regions are scanned in turn. In this way, the vacant path to span the island region is avoided in simple parallel path and the machine efficiency is improved. The scanning lines interval in every sub-region is equality, as a result, the hummock and ravine disappeared. At the same while, the algorithm is simple and fast operation speed. Scanning path can be generated in the process of part’s machining.

III. DIVISION OF SECTIONAL CONTOURS

Division of region is concerned with direction of scanning line. The algorithm in the paper is discussed in case of horizontal scanning direction. If the angle is \( \alpha \) between optimized scanning direction and X-axis, scanning path is programmed according to the following step: rotating the current sectional contours by \( \alpha \) according to clockwise direction; programming the scanning path by term with horizontal direction; rotating the scanning path by \( \alpha \) according to anti-clockwise direction.

The purpose of dividing the sectional contours is transforming complicated connected region into simply connected region. The scanning path in every sub-region is continuous and the vacant path to span the island region is avoided. In this paper division of the sectional contours is translating the complicated contour polygon into monotone region surrounded by monotone polygon along perpendicular line L of scanning direction. To divide the region, extreme point of the contour polygon must be found along the direction L. The number of monotone polygons divided a complicated polygon depends on the number of extreme point. In common case, the number of monotone polygons divided a complicated polygon along direction L equal to the number of common minimum or maximum points. As shown in Fig.4, a sectional contour composes of outer contour 12345 and inner contour 6789. Therefore, the region is divided three monotone regions along direction L. The three monotone regions is I, II and III. Each monotone region lies between a maximum point and minimum point along direction L. In the case, continuous scanning can be carried out in a monotone region along scanning direction.
IV. Generation Algorithm of Sub-regional Scanning Line

A. Intersection Points of Scanning Line Width Contour Polygon

Scanning line is the segment of the horizontal line in contour polygon. Intersection points of scanning line and contour polygon are the intersection point of horizontal line and polygon. As shown in fig.5, A and B are the two vertex of polygon and their coordinates respective is \((x_a, y_a)\) and \((x_b, y_b)\). The horizontal line is \(y=y_0\). The type of intersection point includes two cases [14]. One is overlapping of scanning and edge segment, another is non-overlapping (see Fig.5). When the horizontal line overlays with the edge segment, there are sumless intersection points. In the case, the intersection point is regard as \((x_a, y_0)\). When the horizontal line does not overlaps with the edge segment, the intersection point is calculated by

\[
\begin{align*}
    x_p &= x_b - x_a (y_p - y_a) + x_a \\
    y_p &= y_0
\end{align*}
\]

(a) Overlapping

(b) Intersection

Fig. 5 The intersection points between scanning line and polygon

B. Construction of Data Structure

For convenience of planning the scanning path and recording the intersection points of scanning line and contour polygon, the paper designed a two-dimension table of intersection points to store the intersection points (see fig.6). Each chain store the coordinate value \(x\) of all intersection points of scanning line and contour polygon and the head node of the chain store sequence number of scanning line and the number of intersection point in the scanning line. All chains come into being a chain’s array.

C. Algorithm Presentation of Scanning Vector Sub-Region Generation

The followed is the detailed discussion of scanning path generation algorithm.

1. Searching of extreme points of sectional contour

Supposing the direction of scanning line is horizontal, searching all polygons of sectional contour for all the extreme points in \(y\) direction. When encountering non-common extreme points, only recording the non-common extreme points with greater \(x\) value. In the while, the number of maximum points equal to the number of minimum points, and then, ranking the maximum points and minimum points by rising order according to \(y\) coordinate value.

2. Searching the intersection points of scanning line with sectional polygon

There is no intersection point of scanning line and sectional polygon when scanning line lies between \(y=0\) and the least minimum points. Computing intersection points when scanning line lies at \(y=y_{min}+scandis\), where \(y_{min}\) is the least minimum points and \(scandis\) is scanning line space. Obtaining the intersection points and storing it in corresponding list of scanning line. At same while, adding 2 to number of intersection point in head node of scanning line list. When solving the intersection points, every encountering a minimum points, adding 2 to the number of intersection points; while every encountering a maximum points, subtracting 2 from the number of intersection points. When encountering the maximal maximum points, the number of intersection points between scanning line and sectional contour has subtracted to zero. At this time, searching is ended.

Ranking the intersection points of scanning line by rising order according to \(x\) coordinate value. In this way, two neighboring \(x\) coordinate value in one scanning line add the \(y\) coordinate value of the scanning line forming a scanning vector, and then the scanning vector is made up of the intersection interval of scanning line in sectional contour. Every intersection interval corresponds to a hatching segment in scanning line.

3. Generation of sub-region scanning vector

Extracting the two front elements from the list of scanning line with intersection points, adding the \(y\) coordinate value forming a scanning vector and storing it into the file of scanning vector. Then, extracting the two front elements from the next list of scanning line forming another new scanning vector. If the number of intersection points of this scanning vector comes into being a chain’s array.
line isn’t equal to that of last scanning line, the new scanning vector need to be judged whether or not belonging to same region with last scanning vector. The judging method to be adopted is what is presented in reference [10]. Namely, verifying the projection in X-axis of the two vectors if the overlapping segment exists. At the same while, once forming a scanning vector, the two front elements should be deleted from the corresponding list and t subtracting 2 from he number of intersection points in head node. When disposing the even number of scanning vector, interchanging start point and end point of the vector and inverting direction of the vector. In the case, all the scanning vectors formed zigzag scanning.

Extracting scanning vector one by one from the same region, until there is no scanning vector in the next scanning line belonging to the same region or the number of intersection points of the scanning line has become zero. At this time, extraction of scanning vectors in the region is over.

When extraction of the scanning vector in a region is finished, searching the extreme point whose y coordinates is near to that of the last scanning vector of the region. If the extreme point is minimum point, extracting the scanning vector from scanning line by terms of descending order of y coordinate. If the extreme point is maximum point, extracting the scanning vector from scanning line by terms of rising order of y coordinate. If the number of intersection points of the scanning line is zero, searching the next extreme point whose y coordinates is near to that of the last scanning vector of the region. Until the number of intersection points of all scanning line is zero, the extraction of scanning vector in the sectional contour finished. In this way, once one region hatching is finished, through the shortest vacant path the hatching can be transferred to another region. This way decreased the vacant path and advanced the machine efficiency.

As shown in Fig.7, the sectional contour is hatched. Firstly, Extracting the first scanning vector, hatching the region by terms of rising order of y coordinate. After the region is finished hatching, searching for the maximum point and hatching the region II by terms of descending order of y coordinate. Subsequently, hatching the region III by terms of descending order of y coordinate. Lastly, hatching the region IV by terms of rising order of y coordinate.

(4) Optimization of sub-region scanning vector

For every sub-region, computing the distance between the last vector and the first vector in a sub-region and the extreme points of the sub-region. If the distance is not equal to scandis that is the scanning line space set, computing the scanning line space again. The new scandis maybe is not equal to the old scandis, but the difference is very little. Thereafter, computing the intersection points between the new scanning line and the contour line segment again. As a result, the scanning line space in a sub-region all is equal.

D. Analysis of the Algorithm

When the scanning vector is extracted in same region, we do not judge the scanning vector whether or not belonging to the region, until the number of intersection points of scanning line is changed. If the number of intersection points of next scanning line is not changed, that means that extreme points is not occur. The scanning vector obtained from the list of scanning line is belonging to the same region with that of last scanning line. In this way, the judging time is highly reduced and the running efficiency is advanced in effect.

In reference [10], the scanning vector in every region is extract by terms of rising order of y coordinate. In this way, the scanning vector of hatching every region begins from the bottommost of y coordinate. After hatching a region is finished, “vacant path” could be quit long to be span (see Fig.7). In the paper, the hatching sequence of all regions is optimized according to the distance between the end point of the last vector of last region and the start point of the first vector. The hatching in every region is not merely entered in the bottommost of y coordinate. Consequently, the “vacant path” is decreased effectively.
then, for testifying the optimized scanning path, we experimented by laser metal deposition shaping. The material of cladding is nickel based metal powder. The condition is that 0.6mm layer thickness, 1.3mm scanning line space, 5mm/s scanning speed, 900W laser power, 4g/min powder feeding. As shown in fig.9, Contrast cladding experiment in a layer is conducted. Fig.6 (a) shows the photo of cladding experiment by original scanning path and fig.6 (b) shows the one by optimized scanning path. We found that the cladding surface in fig.6 (a) is rough, but the cladding surface in fig.6 (b) is smooth.

VI. CONCLUSION

In the paper the hatching problem of intricate sectional contour is studied and an algorithm of sub-regional scanning path generation is presented. The algorithm divides complex sectional contours into some simple non-hole sub-region. At the same while, the scanning path is optimized in two ways. The first one is that the joining path between the regions is optimized, which is effective on decreasing the vacant path and advancing the machine efficiency. The second one is that the scanning path out of place at extreme points in a sub-region is optimized. The experiment shows that optimized scanning path could improve the machine equality of parts.

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REFERENCE


