



Title:

Research on Profile Geometric Feature Parameters Extraction of Complicated Thin-walled Ring Parts with Irregular Section

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Introduction:

The metallic W-ring is a typically complicated thin-walled ring part with irregular section, due to its multi-pass forming, closed ring structure, complex cross-sectional profile and small size, it is difficult to design CAD model of each forming pass in short cycle and low cost. The inverse modeling solution based on point cloud slicing is an effective way to reconstruct the ring parts. However, the lack of feature representation usually results in inaccurate and inconsistent topological CAD model. Consequently, it is difficult to represent the original design intention and to modify the final model parameters in an effective way [4]. On the other hand, the parametric representation of intermediate part geometric features is also the basis for the automatic process planning knowledge base.

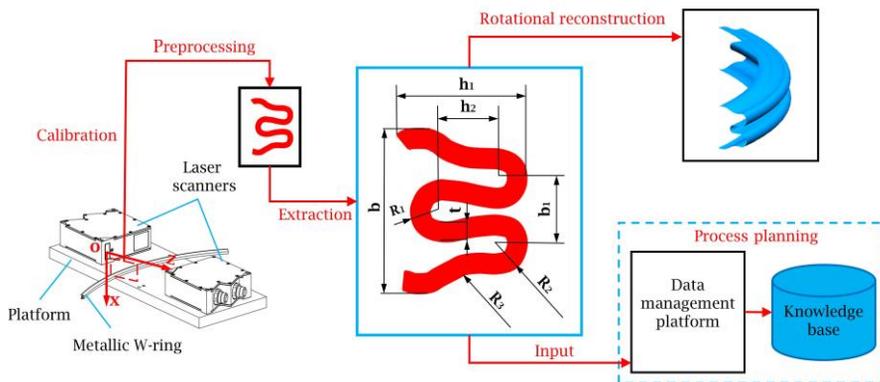


Fig. 1: Schematic diagram for the detection of profile geometric feature parameters extraction of metallic W-ring and their application.

As shown in Fig. 1, the geometric feature parameters of the metallic W-ring cross-section include width b , height h_1 , wave crest circle radius R_1 , wave valley circle radius R_2 , transition circle radius R_3 , wave valley center distance b_1 , wave height h_2 and thickness t . The profile geometric feature is the basic feature that characterizes the overall size, and is the basis for constraining and calculating other

geometric features, its parameters include width b and height h_1 . In the present work, we found that the profile geometrical feature parameters of each forming pass of metallic W-ring can be effectively characterized by the bounding box. Therefore, a profile feature parameters extraction method based on the bounding box is proposed. First, Andrew algorithm [1] is used to calculate the convex hull of the profile point cloud for each forming pass, then the minimum area bounding rectangle of the convex hull is built using the rotating calipers, and finally the profile feature parameters of the profile point cloud are obtained based on the minimum area bounding rectangle. The above work is an important part of the reconstruction of complicated thin-walled ring parts with irregular section and the establishment of an automated process planning knowledge base.

Calculate convex hull:

The minimum area bounding rectangle is a representation of the bounding box in two dimensions, the minimum area bounding rectangle of a point set is the same as the minimum area bounding rectangle of its corresponding convex hull, so this property is used to optimize the computation of the minimum area bounding rectangle. In real vector space, there is a point set $\{P_i \mid i = 1, \dots, n\}$, and the smallest convex set containing $\{P_i \mid i = 1, \dots, n\}$ is defined as the convex hull. The algorithms for building convex hull mainly include Graham scan algorithm [3] and Andrew algorithm [1].

The steps of Graham scan algorithm are as follows.

Step 1: The polar coordinate system is built by selecting the lower left point in the given point set $\{P_i \mid i = 1, \dots, n\}$ as the origin, and record the origin as P_0 .

Step2: Order the point set. The polar angles of the remaining points in the polar coordinate system are calculated, and the points are ordered in ascending order of polar angle. If there are multiple points with the same polar angle, only the distal point is retained. The set of points after sorting is denoted $\{P_1, P_2, \dots, P_m\}$.

Step 3: Scan the set of ordered points and find the vertices of the convex hull. Initialize a stack S to hold the convex hull vertices and let P_0 and P_1 in the stack, Let $S(0) = P_0$, $S(1) = P_1$, and note that the top element of the stack is $S(k)$. If the path formed by the points $S(k-1)$, $S(k)$ and P_i is a left turn, then P_i is in the stack, $k=k+1$, and $S(k)=P_i$, as shown in Fig. 2(a). If the path formed by the points $S(k-1)$, $S(k)$ and P_i is a right turn, then $S(k)$ is out of the stack and $k=k-1$. At this time, if the number of elements in the stack is less than 2, then P_i is in the stack, $k=k+1$, $S(k)=P_i$, otherwise, the path formed by the three points $S(k-1)$, $S(k)$, P_i needs to be re-judged to turn, as shown in Fig. 2(b). And so on, until all points are traversed, the scan result is shown in Fig. 2(c).

Step 4: Output in order all the points saved in the stack, which are the vertices of the convex hull.

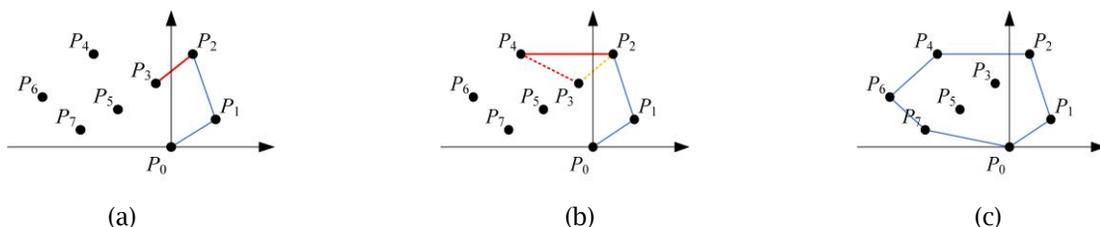


Fig. 2: Calculate convex hull based on the Graham scan algorithm: (a) P_1, P_2, P_3 left, P_3 in the stack, (b) P_2, P_3, P_4 turn right, P_3 out of stack, P_1, P_2, P_4 left turn, P_4 in the stack, and (c) Complete convex hull.

The Graham scan algorithm requires calculating the polar angles and ordering them by polar size, whereas the Andrew algorithm sorts by coordinate size only during the ordering process, and is therefore faster and more numerically stable than the Graham scan algorithm. The steps of Andrew algorithm are as follows.

Step 1: Order all the points in the point set from smallest to largest in terms of horizontal coordinates, and for points with the same horizontal coordinates, order them from smallest to largest in terms of vertical coordinates. The ordering result is $\{P_1, P_2, \dots, P_n\}$. At this point P_1 and P_n must be the vertices of the convex hull.

Step 2: Start from P_1 and search to the right to find the lower half of the convex hull, as shown in Fig. 3(a). The algorithm for determining the convex hull vertices in this step is the same as step 3 of the Graham scan algorithm.

Step 3: Start from P_n and search to the left to find the upper half of the convex hull, as shown in Fig. 3(b).

Step 4: Combine the results of step 2 with step 3 to obtain the complete convex hull.



Fig. 3: Compute convex hull based on Andrew algorithm: (a) The lower half of the convex hull, (b) The upper half of the convex hull.

Build the minimum area bounding rectangle:

After obtaining the convex hull corresponding to the metallic W-ring, the rotating calipers [5] are used to build the minimum area bounding rectangle of the convex hull. The principle of this method is to clamp the convex hull with a pair of parallel lines, calculate all the bounding rectangles of the convex hull by rotating the parallel lines, and finally determine the minimum area bounding rectangle from them. Freeman et al. [2] proved that at least one edge of the minimum area bounding rectangle of a convex polygon coincides with an edge of that convex polygon, which makes the computational effort of solving the convex hull minimum area bounding rectangle much simpler. The steps for solving the convex hull minimum area bounding rectangle using the rotating calipers are as follows:

Step 1: Extract the maximum and minimum vertices of the convex hull vertices in the orientation of the horizontal and vertical coordinates, denoted as $P_{x_{max}}, P_{x_{min}}, P_{y_{max}}, P_{y_{min}}$.

Step 2: Through the four vertices, two sets of parallel lines are identified to build the bounding rectangle of the convex hull, as shown in Fig. 4(a).

Step 3: Determine whether there is an edge in the bounding rectangle that coincides with an edge in the convex polygon. If so, calculate the area of the rectangle, save it as the rectangle area minimum, and record the coordinates of the four vertices of the rectangle. Otherwise, set the minimum value of the area of the rectangle to infinity.

Step 4: Reconstruct the external rectangle by rotating the two sets of parallel lines clockwise until one of the lines coincides with an edge in the convex polygon, as shown in Fig. 4(b). Calculate the area of the rectangle, compare it with the current minimum value of the rectangle area, and if it is less than the current minimum, update the area of the rectangle with the coordinates of the rectangle vertices.

Step 5: Repeat step 4 until the overall rotation angle exceeds 90° .

Step 6: Output the coordinates of the vertices of the bounding rectangle.



Fig. 4: Build the minimum area bounding rectangle of a convex hull based on the rotating calipers: (a) Build the bounding rectangle, (b) Update the bounding rectangle.

The minimum area bounding rectangle corresponding to the convex hull of the fourth forming pass profile point cloud of the metallic W-ring is built using the rotary calipers, as shown in Fig. 5. After determining the minimum area boundary rectangle, the width and height of the minimum area boundary rectangle are used to represent the width and height of the metallic W-ring, thus enabling the extraction of geometric features of the metallic W-ring profile.

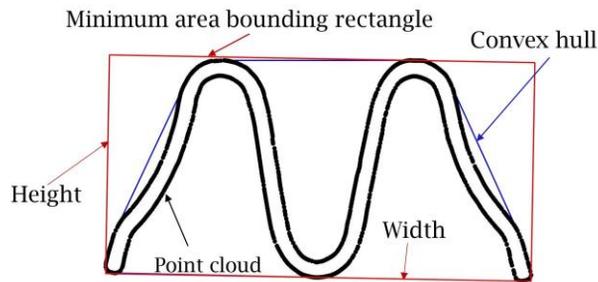


Fig. 5: The extraction results.

Results:

For metallic W-ring samples, the profile point cloud is obtained directly by optical scanning equipment, and after pre-processing such as denoising, the profile geometric feature parameters are extracted using the method in this work. Fig. 6 shows the results of extracting the geometric feature parameters for six forming passes of the metallic W-ring samples, Tab. 1 shows the results of extracting the feature parameters and standard, and the relative error is given.

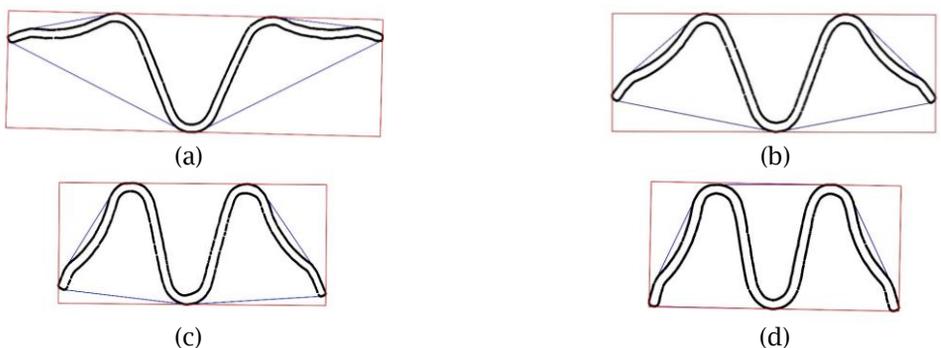




Fig. 6: Multi-pass profile geometric feature parameters extraction: (a) First pass, (b) Second pass, (c) Third pass, (d) Fourth pass, (e) Fifth pass, and (f) Sixth pass.

	<i>Forming pass</i>	<i>Standard</i>	<i>Results</i>	<i>Relative</i>
<i>Section width (mm)</i>	First pass	13.915	13.891	0.002
	Second pass	11.939	11.871	0.006
	Third pass	9.697	9.682	0.002
	Fourth pass	8.222	8.268	0.006
	Fifth pass	6.552	6.577	0.001
	Sixth pass	5.780	5.720	0.010
<i>section height (mm)</i>	First pass	4.218	4.244	0.006
	Second pass	4.099	4.120	0.005
	Third pass	4.132	4.148	0.004
	Fourth pass	4.274	4.180	0.022
	Fifth pass	4.726	4.465	0.055
	Sixth pass	4.836	4.624	0.044

Tab. 1: Multi-pass profile geometric feature parameters extraction results.

Conclusions:

A profile geometric feature parameters extraction method based on the bounding box is proposed, first, Andrew algorithm is used to calculate the convex hull of the profile point cloud, then the minimum area bounding rectangle of the convex hull is built using the rotating calipers, and finally the profile geometric feature parameters of the profile point cloud are obtained based on the minimum area bounding rectangle. namely section width and section height. The experimental results verified the universality and effectiveness of the method, which laid the foundation for the subsequent rotary reconstruction of the entity and the creation of an automated planning knowledge base.

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