Parametric Design of Grasshopper Based on Moulding Characteristics of Longitudinal Profile of Shoe Last

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Abstract. In order to achieve low-cost, high-efficiency customized footwear design and service to meet the individual needs of customers, quickly producing various types of shoe last based on different needs has become the key to customization. According to the moulding characteristics of the longitudinal profile of the shoe last, the key characteristic parameters and morphogenesis logic are found. Combined with the parameterized nonlinear thinking feature, the parameter logic is constructed. Rhino's parametric design plug-in Grasshopper is used to develop the shoe last design process. The automatic moulding process of the sectional view, combined with the parametric design of the shoe last and the cross-section of the shoe last, can form a quick custom shoe last method. A professional and rapid design method is formed to enhance the design and production efficiency of customized shoe lasts.

1. Introduction

Under the environment of market globalization, economic regionalization, information network and individualized demand of shoe industry, enterprises urgently need to explore an efficient and flexible design and processing method as a new competitive means to meet the needs of consumers[1]. Shoe last, as the matrix of a shoe, is also the soul of a shoe and the moulding of a shoe. It not only determines the shape and style of the shoe, but also determines the comfort and other special functions of the shoe. In the shoe last design process, quickly producing various types of shoe last based on different needs has become the key to customization.

As a nonlinear design method, parametric design can form a variety of constraint relations in the model through constraint equations, and generate different design forms quickly by using the change of parameters, so as to improve the speed of model generation and modification[2-3]. Although some scholars have proposed the use of CAD, Catia, UG and PRO-E to parametrically design shoe last by interpreting the distribution of plantar pressure and establishing the constraint of nonlinear sizes or other methods, designers lack direct visual experience in the design process. However, the parametric design of the Grasshopper plug-in can visualize the design process and record the entire modeling process at the same time. Designers can easily change the form of the model by adjusting the parameters[4-6].

According to the moulding characteristics of the shoe last profile, key feature parameters and morphological generation logic, and parameterized nonlinear thinking features, Rhino software's parametric design plug-in Grasshopper can build an automatic prototyping program for the
longitudinal profile of the shoe last as a feasible design method to enhance the design and production efficiency of customized shoe lasts.

2. Traditional shoe last longitudinal profile moulding process

Based on the foot shape, the shape of shoe last must follow the foot shape, so the design of the shoe last is closely related to the parameters of the foot[7]. This article gives an example of a standard female shoe last with the length of 240mm, the last toe allowance of 20mm and the heel-height of 40mm to briefly introduce the drawing process of shoe last longitudinal section, as follows:

2.1. Take the auxiliary points of the profile of the shoe last for moulding

Draw a horizontal line OA of 240mm length and divide it into 12 equal parts, 20mm each square; determine the point B of 135mm from the rear end point O as the tread point; heel height OC, 40mm; Toe spring AD, 9mm; Draw an arc with a radius of 135mm at tread point B, find the intersection E of the horizontal line of the heel height and the arc, as the back point of the last. Connect BE and divide it into 5 parts equally; connect BD and DE; find 2/5 of BE to make a perpendicular to DE, and find the midpoint F; over point E draw a vertical line of DE drawn up 60mm, and divide it into 3 segments, and get G, H and I; I is 4mm ahead of point I, G’ is 4.5mm behind point G, and GG’ is the back tolerance. Draw an arc with a radius of 90mm over I’; Draw an arc with a radius of 85mm over F, and find the intersection point J of two arcs; Move the rear straight line EI forward to 2/3 of the DE in parallel; move DE up to I and find the intersection K with the parallel line just drawn; the toe depth LD, 15mm; the toe width LM, 20mm; connect MI’, intersect with the vertical line of the 3/12 bottom line at N, as shown in Figure 1.

2.2. Generate profile auxiliary line of shoe last profile

As shown in Figure 2, E, G’, H, F, K, J, N, M, L, D, B, F, and E are connected with a polyline according to the direction of the arrows to generate an auxiliary polyline of the longitudinal profile of the shoe last. That is the basic frame of the longitudinal profile of the shoe last.

Figure 1. Take the auxiliary point of the profile of the shoe last for moulding.
2.3. Moulding shoe last longitudinal section
As shown in Figure 3, according to the curvature reference directions indicated by the arrows, the auxiliary polyline of the longitudinal profile of the shoe last is converted into a curve, and the profile of the standard female shoe with the length of 240 mm, the last toe allowance of 20 mm, and the heel height of 40 mm is shown.

3. Extracted key characteristic parameters of profile of shoe last
By analysing the drawing process of the traditional shoe last longitudinal section drawing, 10 key characteristic parameters and characteristic points of the longitudinal profile of shoe last are extracted, which are shoe last length OA, heel height OC, back height EI, last toe allowance LM, toe depth DL, toe spring AD, back tolerance GG', back point of topline I', tread point B, and length of topline I'J, where the characteristic parameters 1-6 can be adjusted according to the measurement data of the foot type during customization. In this study, the given reference value is used as the known data. The characteristic parameters 7-9 are based on the proportional algorithm of the measured data of the foot type. The characteristic parameter 10 is the reference value of the known national standard data, which are label values used by last factories, as shown in Table 1.
Table 1. Summary table of moulding characteristic parameters and characteristic points of longitudinal profile of shoe last.

| No. | Parameter name              | Calculation method                                      | Length (unit: mm) | Marked in the figure |
|-----|-----------------------------|---------------------------------------------------------|-------------------|----------------------|
| 1   | Shoe last length            | Known data, can be adjusted according to the user's design requirements and the measurement data of the foot type during customization | 240               | OA                   |
| 2   | Heel height                 |                                          | 40               | OC                   |
| 3   | Back height                 |                                          | 60               | EI                   |
| 4   | Last toe allowance          |                                          | 20               | LM                   |
| 5   | Toe depth                   |                                          | 15               | DL                   |
| 6   | Toe spring                  |                                          | 9                | AD                   |
| 7   | Back tolerance              | Foot length *2%                                 | 4.5              | GG’                  |
| 8   | Back point of topline       | Foot length *2%                                 | 4.5              | II’                  |
| 9   | Tread point                 | Foot length *59%                                 | 135              | OB                   |
| 10  | Length of topline           | Known national standard data reference value      | 90               | I’J                  |

4. Parametric logic construction based on Grasshopper

4.1. Hierarchical logic combing of characteristic parameters

As shown in Table 2, according to the importance level of the shape control the parameters are divided into a primary parameter, secondary parameters, and tertiary parameters. The first-level parameter refers to the length of the foot, which is the basic parameter that should be determined firstly to draw the longitudinal section of the shoe last; the secondary parameters are the key characteristic parameters extracted through the drawing process of the standard shoe last section, but can also be modified by the target style through the process of customizing the shoe last; the third-level parameters are based on the secondary parameters, for the accuracy of the curve shape of the longitudinal profile, and the shape control points are added for the customization process in order to modify the shape details. The corresponding step is to connect the key feature points with the last curve in the shoe last drawing. The shape of the connecting curve is often determined by the personal experience of the drafter, so there is some uncertainty. The third-level parameters have no determined parameter values, and it is still necessary to adjust the location of each point through a certain experience to adjust the curves of each segment. The logical relationship is shown in Figure 4.

Table 2. Parametric variables required for longitudinal profile drawing of shoe last using Grasshopper.

| Parameter level | Parameter name              | Effect                                      |
|-----------------|-----------------------------|---------------------------------------------|
| Primary parameter | Foot length                | Control overall foot length for different users |
| Heel height (back point of the last) |
| Back height |
| Back tolerance (maximum point of heel curve) |
| Secondary parameter | Back point of topline       | Key characteristic parameters of longitudinal profile of shoe last |
| Length of topline(front point of topline) |
| Last toe allowance |
| Toe depth |
| Toe spring(front point of the bottom) |
| Tread point |
Figure 4. Logical relationship diagram of primary, secondary and tertiary parameters.

4.2. *Edit input logic relationship through Grasshopper*

The above characteristic parameters are logically connected in combination with the conventional moulding process of the longitudinal profile of shoe last. It includes the length calculation method and shape connection mode of each feature part. The longitudinal profile of the shoe last is obtained according to the personal data of the customized measurement and individual requirements, and the basic operation method is used for logic construction in the parametric plug-in Grasshopper of the three-dimensional modeling software Rhino. The result can be seen instantly on the Rhino interface during the construction process. The final program interface of the logical relationship and the longitudinal profile of the shoe last is shown in Figure 5.
4.3. Operation and inspection of drawing effect
After modifying the shape of the curve by three levels of parameters to make the last profile accurate, the final last curve will be baked separately to the Rhino interface, as shown in Figure 6. In the Rhino interface, you can open the edit point to verify again. In order to facilitate the next 3D design and production of the last, the corresponding formats can be derived based on different moulding software.

5. Comparative analyses of the traditional longitudinal section drawing method and the parametric drawing method
5.1. Step comparison
According to the traditional custom process of personal shoe last, the steps of drawing the traditional shoe last profile are as follows:
(a) Measure the target user's foot length, and according to the individual and the style needed determine the length of the foot, heel height (back point of the last), back height, the maximum point
of the heel curve, back point of the last, back point of topline, front point of topline, last toe allowance, toe depth, toe spring (front point of the last), tread point.
(b) Measure and obtain the position of each feature point.
(c) Connect each feature point with a polyline.
(d) Connect each feature point with a smooth curve.
(e) Adjust the curve shape, curvature, etc. according to personal experience to make the shape smoother and more accurate.
(f) Scan the draft and import into the computer, and then trace the curve for further 3D production.

Using the parameterized shoe last profile procedure that has been already written in Grasshopper, the steps to customize the personal last profile are as follows:
(a) Measure and determine characteristic parameters, as in the traditional method.
(b) Input the measurement data directly into the primary and secondary parameters in the program, and the initial shoe last longitudinal profile curve is automatically generated.
(c) Adjust the third-level parameters to make the curve shape more accurate.
(d) Export curves directly for further 3D production.

After comparison, the parametric drawing process has less process of measure each feature points, polyline and smooth curve connection, computer scanning and curve tracing compared to traditional drawing.

5.2. Efficiency comparison
The parametric drawing process is only two steps less than the traditional drawing process, but the efficiency is completely different. In order to avoid the influence of the painter's experience, this article invites a shoe learner who understands the shoe lasting process, but the experience is not familiar. The primary students use the above two methods for time-consuming comparison experiments, and finally found that in the process of customizing the shoe last moulding measurements and determining the various characteristic parameters required by the target user to generating an electronic version of the longitudinal profile of the shoe last that can be further used, the cumulative time of the conventional method is about 37 minutes; and the parametric method takes two fewer steps and takes about 9 minutes and 30 seconds, greatly reducing the time it takes to customize a brand new shoe last profile, as shown in Table 3.

Table 3. Time-consuming comparison of traditional and parametric methods for drawing longitudinal profile of shoe last.

| Step Description                                                                 | Time Consuming | Traditional Drawing Method | Parametric Drawing Method |
|-------------------------------------------------------------------------------|----------------|-----------------------------|----------------------------|
| Measure and determine the various characteristic parameters required by the target user | 5 mins         | √                           | √                          |
| Measure and obtain the position of each feature point                          | 10 mins        | √                           | ×                          |
| Connect each feature point with a polyline                                    | 2 mins         | √                           | ×                          |
| Input the measurement data directly into the primary parameter and the secondary parameters in the program, and the preliminary shoe last longitudinal profile curve is automatically generated | 2 mins         | ×                           | √                          |
| Connect various feature points with smooth curves                             | 5 mins         | √                           | ×                          |
| Adjust the curve shape, curvature, etc. according to personal experience to make the shape smoother and more accurate | 5 mins         | √                           | ×                          |
| Adjust the third-level parameters to make the curve shape more accurate        | 2 mins         | ×                           | √                          |
| Scan the draft and import into the computer, and then trace the curve for further 3D production | 10 mins        | √                           | ×                          |
5.3. Result comparison
In order to compare the differences between results realized by two methods, this article compares the results of shoe last longitudinal profile drawn by primary trainees with two different methods mentioned above in 5.2. It is found that the effect of parametric drawing is smoother, while the effect of drawing by traditional method still has much sketch mark. It can be seen that it is much easier for a normal primary person to achieve more precise and more beautiful shoe last longitudinal profile as shown in Figure 7.

![Figure 7. Comparison of results realized by two methods.](image)

6. Summary
The aesthetic and comfort of the customized shoes depend on the shoe last. In order to ensure the accuracy of the shape, it is a useful method to follow the moulding characteristics of the longitudinal section of the shoe last and combine with the parametric design plug-in Grasshopper to construct the automatic moulding program of the last profile. The efficiency of the shoe last design is greatly improved, and it is also a technological innovation with commercial value, which will bring more possibilities for the personalized design of shoes in the future.

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