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An analysis and evaluation of fitness for shoe lasts and human feet

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ABSTRACT

The main purpose of this research is to develop a process for identifying the most suitable shoe last for human feet. A fitness function was defined to determine the most suitable shoe last among several alternatives. Based on reverse engineering (RE) technology, this research included scanning the surface of human feet and shoe lasts in STL (Stereo Lithography) format. An STL slicing algorithm constructed the three most important measurements for human feet and shoe last, i.e., ball girth, waist girth, and instep girth. Fuzzy theory was used to analyze and build the membership functions of these three girths between the shoe last and human feet. The analytical hierarchy process (AHP) was applied to decide the weighting functions for each girth to determine the fitness function in all shoe last databases for the feet. Three case studies were implemented to find the ranking of 10 shoe lasts in the database. This research, which defined as the relationships between shoe last and human feet, can be used as a good reference for design in the shoe-making process.

1. Introduction

Shoe lasts are the basis for the design of industrial footwear. The properties of the shoe last design significantly influence the fitness of the shoes that are produced. The science of anthropometry is used to ensure that shoe lasts are designed and manufactured based on the features, characteristics, and functions of human feet. Anthropometric studies have shown that the shape and the fashion of the shoes directly affect the level of comfort that people experience when they wear shoes. However, people's feet are different, so the same type of shoe last cannot be used to make shoes to fit everyone. Like the three measurements of the human body, i.e., bust, waist, and hips, the most important features of human feet that influence the choice of shoe last are ball girth, waist girth, and instep girth. These three girths are related to the comfort and the fitness people experience in wearing shoes [1–4]. Conventionally, these features are measured and determined manually, so the accuracy is affected both by the tools used and the operator's skill. Because the appearances of shoe lasts and human feet are all in free-form and surface shapes, it is difficult to perform proper manual measurements. Therefore, reverse engineering (RE) scanning technology has replaced the manual measurements. The RE method decreases the errors caused by the manual operation, and it allows the use of the measuring data to promote the fitness of shoes within shoe last design [5,6].

The main purpose of this research is to design a process, based on the three main girths of shoe last, to analyze and evaluate the most suitable shoe last in the database of shoe lasts for the human feet. An STL feature-based, slicing algorithm was used to automatically construct the three most important feature-girth characteristics of human feet and shoe last. Fuzzy theory was used to build the membership functions for the three important features of shoe last and feet. The analytical hierarchy process (AHP) was applied to analyze the important indices from shoe experts to find the weighting factors for each girth to determine the fitness function among the shoe lasts and the feet. Three case studies were implemented to find the most suitable shoe last in the database of 10 shoe lasts to prove that this research provides an improved technique for choosing shoe last.

2. Literature survey

In the shoe last design and manufacturing process, grading and machining were the two key issues identified in previous research [22]. Traditionally, a shoe last is designed by using numerous measurements to acquire data about the foot. Cheng and Perng [18] provided the shoe-making industry with a more efficient and economical size-grading system to design shoe lasts. This grading system also promoted customer satisfaction by providing better fitting shoes based on foot size. A foot-size information system (FSIS) that provided shoe last-related information was established from the analysis results. Jimeno et al. [7,8] generated a tool-path algorithm from a "virtually digitized" model of the shoe last surface. The algorithm was analyzed in terms of computing cost

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and accuracy, and it was refined by applying a series of optimizations. The proposed algorithm was successfully implemented in a commercial CAD/CAM system specialized for making shoe lasts. This system can be used to produce shoe lasts with more precision and speed than other well-known classic approaches.

Lee and Cheng [9] proposed a multi-zone scaling method for a sample shoe sole. The grading process scaled the sample sole by different factors in different zones. This method divided the CAD geometrical model into several zones, and each zone was given a scaling dimension (value) to generate a new CAD geometrical model. Butdee [10] based his analysis on the hybrid features of surface and solid modeling to the primitive features in sport shoe sole design. Hu et al. [11] aimed at the special requirements of a high-speed machining process for shoe lasts and the large data set that could be obtained using the RE technique. Hu's study analyzed the conventional tool-offset methods and presented a B-spline, tool-offset model. Hwang et al. [12] and Kim et al. [13] proposed a technique for producing custom-tailored shoes from the template shoe lasts. Template shoe lasts can be derived by grouping all the various existing shoe lasts into a manageable number of groups and by combining all the shoe lasts in each group, such that each template shoe last for each group barely encloses all the shoe lasts in the group. A prototype system based on the proposed methodology has been implemented and applied to the grouping of the shoe lasts of various shapes and sizes and to the deriving template shoe lasts.

In the above-mentioned research efforts, the relationships between human feet and shoe last features were seldom addressed, which may have resulted from the deference to shoe-making industrial secrets. So, the determination of the feasible connections between human feet and shoe lasts is the main objective of the current research.

3. Methodology

3.1. The three main girths and their characteristic points

Various foot girths and shoe last girths have been defined by the shoe-making industry [4]. For the purposes of this paper, the three important girths, shown in Fig. 1, and the characteristic points for shoe last and human feet are defined as follows:

(1) *Ball girth:* the circumference of the foot, measured with the inner and outer ball points, as shown in Fig. 2. These two points are defined individually as the maximum and the minimum coordinates of the *X*-axis, which is a measure of the width of the foot. So, if the coordinates of the two points are (x_1, y_1, z_1) and (x_2, y_2, z_2), a plane that passes through these two points and parallels the *Z*-axis provides this ball girth section plane. In shoe last, sometimes, the third characteristic point (vamp point) can be defined by the longest perpendicular line to the line segment between the shoe last tip point and the highest point of the shoe last, as shown in Fig. 3.

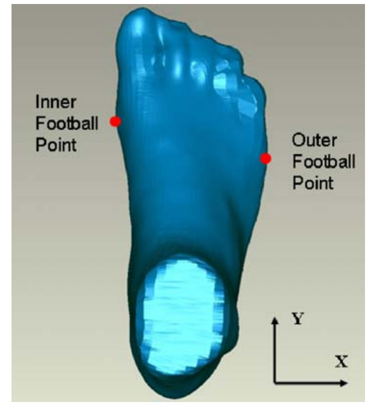

Fig. 2. Characteristic points of foot ball girth.

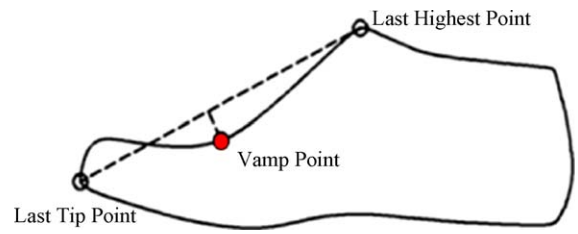

Fig. 3. Vamp point for shoe last ball girth.

(2) *Instep girth:* smallest girth over middle cuneiform prominence. The characteristic points for foot instep girth can be defined as the distance between the highest point in the arch region and the instep point, which is the shortest distance from the highest arch point to the dorsal side of the foot, as shown in Fig. 4. The foot instep girth sectional plane can be obtained by passing a line through the instep point and the highest point in the arch and is parallel to the *X*-axis. However, for shoe last, it is unclear to define the arch highest point and the instep point, so we defined the shoe last instep point as being half of the length of the foot on the dorsal side. A tangent vector $\vec{C}$ can be obtained by passing a line through the instep point, as shown in Fig. 5. Using the instep point and $\vec{C}$ as the normal vector, the instep plane and the instep girth can be obtained.

(3) *Waist girth:* the circumference at the approximate center of the metatarsal, which is between the ball girth and instep girth, with the shortest perimeter in the arch region, measured in a vertical plane that is perpendicular to the Brannock axis (a centerline segment through the heel point).

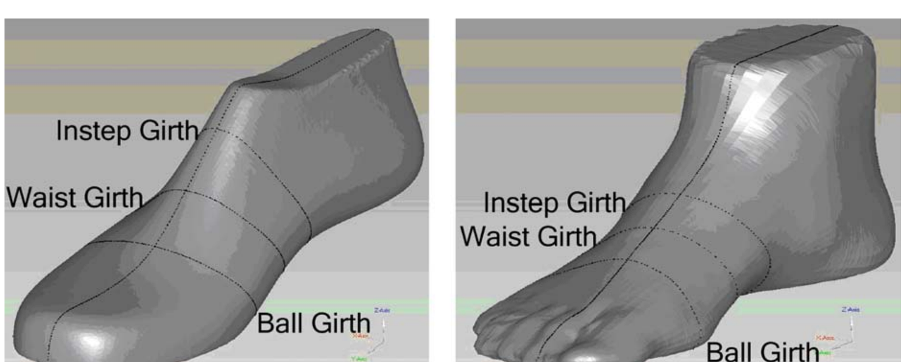

Fig. 1. The three girths in shoe last and foot.