

# A Fit Metric for Footwear Customization

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## Abstract

Due to rapid advancements in technology and the globalization of companies, customized products are becoming key to a company's competitiveness, efficiency, profitability and market share. As a result, there is a trend toward extensive collection of individual customer data and the footwear industry is no exception. Even though the importance of footwear fit and comfort is well surveyed, the term, fit still remains somewhat subjective. A few studies have provided a methodology to quantify fit in 2-D. The 2-D fit metric has been worthwhile to show many footwear fitting problems. In this paper, the 2-D methodology has been extended to 3-D. First, the foot and the last outlines were aligned. Then, considering the heel height and toe-spring of the last, the height dimensions were included in the computation of the potential mismatch between foot and shoe. For ease of interpretation, the mismatch was color-coded. The proposed method enables footwear fit quantification so that fit-related comfort may be predicted. Furthermore, if a 3D foot scan is available, the proposed method will enable the manufacturer to choose the "best-fitting" last from a group of available lasts.

Keywords: Footwear, Fit, Comfort

## 1 INTRODUCTION

Research indicates that customer focus can influence today's business [1]. As a result, the business paradigm is moving from producer-centred productivity to consumer-centered customization [1]. Mass customization begins with understanding individual customer requirements and ends with the fulfilment process of satisfying the target customer with near mass production efficiency [2]. If product features can be broken down and offered to the consumer as choices, customizing the whole product or part of the product will be possible [3].

Historically, there has been an inclination towards product variety [1], partially, as a means of satisfying consumers' individual tastes and styles [4]. In order to attain a higher market share, in many situations, companies have flooded the market with products having numerous choices [1]. For example, there are more than 285 models of running shoes (167 men and 118 women) compared to just 5 unisex models in 1970 [1]. Thousands of new products are made annually in order to keep pace with ever changing customer tastes [1]. With each variation, manufacturers hope to bring products closer to what the customer wants.

Even though variety matters to consumers, each product may have a differing meaning to different consumers [3]. On one hand, variety means different options, and, in this case, product assortments are a clear benefit [3]. On the other hand, if the consumer prefers a single item that maximizes his or her needs, then a product assortment to find that single option is not necessarily a benefit [3]. Thus, "pleasing the customer is not just about producing more stuff, but it is about producing the right stuff" [1]. Allowing the customers to choose from the shelf can be wasteful and can also constrain a customer's ultimate satisfaction [5]. The difficulty of selecting the right pair of shoes in a large shoe store is a classic example.

Providing variety can be costly, as a manufacturer cannot take advantage of the economies of scale in production

and distribution [4]. Spencer [6] discusses the automation that is taking place in the footwear industry in order to produce high variety, low volume and low cost products. Mass customization can take place at different levels subject to the technological limitations and the product variations [4]. Thus, it is important to determine how much customization should be undertaken. For example, if the market place is very competitive, there may exist a greater need for a high level of customization [3].

Gilmore and Pine [7] have defined four different types of customization: adaptive, cosmetic, transparent, and collaborative. Adaptive and cosmetic approaches provide customization on top of standardized products, and there is no need to learn consumer's specific needs, while transparent and collaborative approaches offer differentiated products and require knowledge of customer preferences [3].

Adaptive customization is a standardized product that the consumer adapts to fit his or her needs [7]. Adaptive customization is appropriate for sophisticated customers who can learn how to adapt the product to fit their needs, while it is not appropriate for customers who are likely to be confused or frustrated [3]. For example, the consumer can use different lacing methods or off the shelf insoles to change or adapt a shoe based on his/her own personal needs. Companies such as Nike ([www.nike.com](http://www.nike.com)) allow customers to personalize the function of the model, Rival, so that it can alternate between a track shoe and a road shoe [8]. Thus, consumers can adapt "technology" to their own ways.

Cosmetic customization also uses a standardized product and customizes the aesthetic aspects [7]. Customatix® ([www.customatix.com](http://www.customatix.com)) and Nike®, for example, let consumers design their shoes based on a different array of styles, materials and colors [8]. The consumers can even build-in their own personalized logo on the shoe.

In transparent customization, customer needs are observed without actually involving the customer [7]. For example, the fashions and styles preferred by consumers can be observed. Similarly, worn shoes can be studied for wear patterns [9] in an effort to improve the outsole. Transparent customization is not possible when preferences are not well defined or observable [3].

In collaborative customization, the needs and preferences of the consumer are identified by interacting with the consumer [7]. Digitoe® ([www.digitoe.com](http://www.digitoe.com)) follows the following steps in their mission to deliver custom footwear:

- Educate the consumer on the custom fitting process
- Consult customer service personnel for fitting needs and footwear selection
- Fitting appointment (1-2 hours)
- Incorporating fit information into the last
- Trial shoe fitting and customer approval
- Selection of material, colors and patterns and finalizing the order.

Similarly, orthotic companies such as Footmaxx® ([www.footmaxx.com](http://www.footmaxx.com)) use computerized gait and pressure technologies to generate custom orthotics [1]. Custom shoe inserts however, use a home impression kit ([www.customshoeinserts.com](http://www.customshoeinserts.com)) to make orthotics that are customized in terms of shape, size and differing foot needs. Such custom shoe inserts typically are in the range of USD125-200 per pair with a 1 or 2 week delivery time.

Although collaborative customisation may create the ideal customized product, it can be frustrating and may be very time consuming [3]. This type of customization aims to satisfy an individual's needs related to fit and comfort.

## 2 WHY QUANTIFY FIT?

The importance of product compatibility for comfort and satisfaction is well known [10]. Today, consumers select a shoe based on length and width measures even though studies have shown that these two measures are insufficient for proper fitting [10][11][12].

In order for a shoe to fit a person's foot, a good understanding of the 3D foot shape is necessary [10]. A good fitting shoe should be free of any high pressure points [13], and at the same time should have the right 'feel' and support. A meaningful way to evaluate footwear compatibility would be to determine the dimensional difference between the foot and shoe [10]. If guidelines or standards can be established for these dimensional differences, then footwear selection can be made much simpler. If a shoe is tight, the pressure or force will produce undue tissue compression making it uncomfortable for the wearer. When the shoe is loose, there will be slippage between foot and shoe resulting in damage or injury to soft tissue. Both these situations are undesirable as they may cause discomfort, pain or even injury to the wearer [10]. Thus, for the right fit, the desirable clearance between feet and shoes should be present in addition to having the foot supported in the most appropriate locations.

Since footwear fit is one of the most important considerations when purchasing footwear [14], it has to be understood when manufacturing footwear. A fit metric can be useful in the design and development of

good-fitting footwear. In addition, with the proliferation of e-commerce, a fit metric will allow people to purchase comfortable footwear with a fair degree of confidence. Thus, the aim of this paper is to illustrate a 3D methodology for quantifying footwear fit. Goonetilleke et al. [15] proposed a 2-D methodology to calculate the dimensional error between the foot and shoe and have discussed how that error can be used as an indicator of the quality of fit. An extension of that method to 3-D will allow a complete evaluation of the level of match or mismatch between foot and shoe. Since the last is a good representation of the interior shoe shape, surface differences between feet and lasts may provide useful information to determine the best match.

## 3 METHODOLOGY

### 3.1 3D Scanning and orientation

The Yeti® 3D foot laser scanner (<http://www.vorum.com>) from Vorum was used. The left foot of each participant was scanned when standing with half body weight on each foot. The last was scanned using the same scanner. After scanning the foot and last, the 3-D surface coordinates were extracted [16]. Then the coordinate system was established by "fixing" the plantar surface of the foot and last with the (x,z) plane and the "height" dimension along the y-axis.

### 3.2 Foot and Last Alignment

The 2-D foot outline was extracted from the 3-D scanned data (Figure 1). All points that lay on the (x, z) plane were used to determine the 2-D "shape" information. The points located on the circumference of this 2-D shape were used as the foot outline. The heel centerline of the foot and last outlines were then obtained using Matlab [15][16]. The linear transformation and rotation to obtain the heel centerline from foot outline were recorded. The combined transformation was then used on the whole foot and last surface points to generate the 3-D shape. Figure 2 shows the foot and last after alignment.

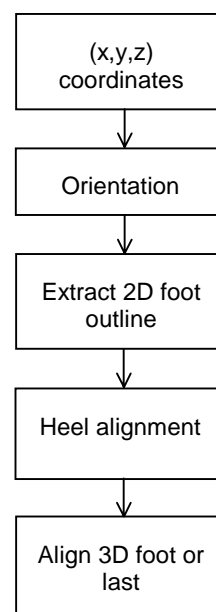


Figure 1. Flow chart for aligning foot and last

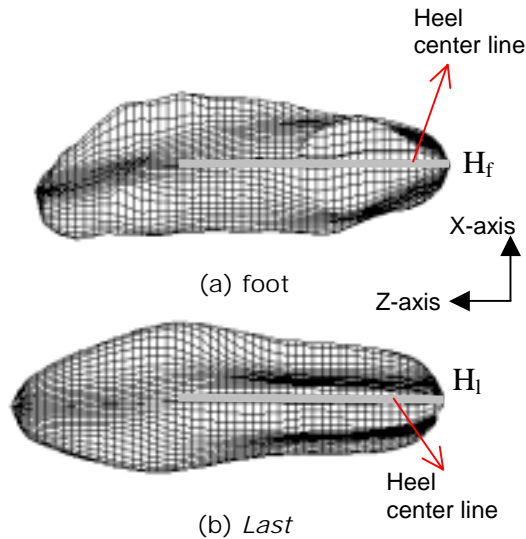


Figure 2. Heel center line of foot and *last*.  $H_l$  and  $H_f$  are the heel points of the *last* and foot respectively.

### 3.3 Matching of *last* and foot

After the foot and *last* were matched along the heel centerline, the foot shape was "adjusted" along the y-direction (Figure 3a, b) to account for the toe-spring and heel height of the *last* (Figure 3c). The foot and *last* after matching are shown in Figure 3d.

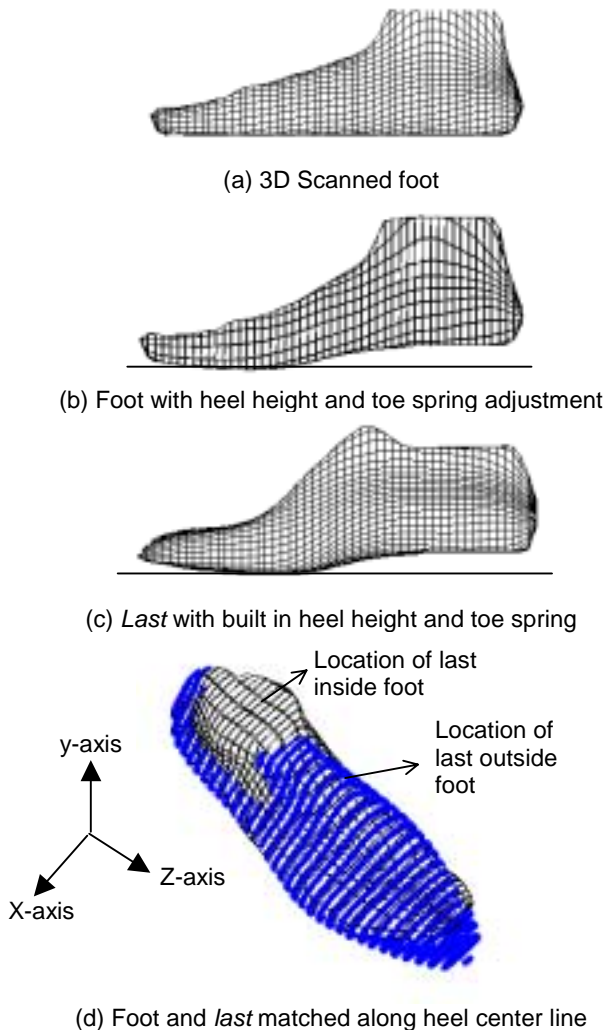


Figure 3. Foot and *last* matching

### 3.4 Computation of dimensional match

In order to compute the dimensional differences, sections spaced at 1mm intervals (along the z –axis) were used. The dimensional differences were then color-coded for easy interpretation (figure 4). It is important to differentiate the positive and negative differences (Figure 3d). A positive "error" exists if the *last* surface is outside the boundary of the foot surface, while a zero or negative "error" is present otherwise. The concept of sign difference is very important in footwear fitting as a positive error will result in a loose fit, while the presence of a negative error can be categorized as a tight fit.

### 3.5 Selection of *lasts*

When the complete foot shape is available, different *lasts* can be selected based on cost, fitting needs and the time available to produce a pair of shoes (figure 5). The most expensive and time-consuming procedure would be to produce a custom *last* for each individual consumer. For aesthetic customisation, the *last* can be selected using the current sizing method by using foot length and possibly foot width. This method is relatively cheaper and less time-consuming since there is no need to make new *lasts*. However, the degree of fit cannot be guaranteed as foot length and foot width alone are insufficient to generate the complete 3-D foot shape [11][12]. A different set of measures [16] may allow a closer match between last and feet if it is possible to obtain critical foot parameters.

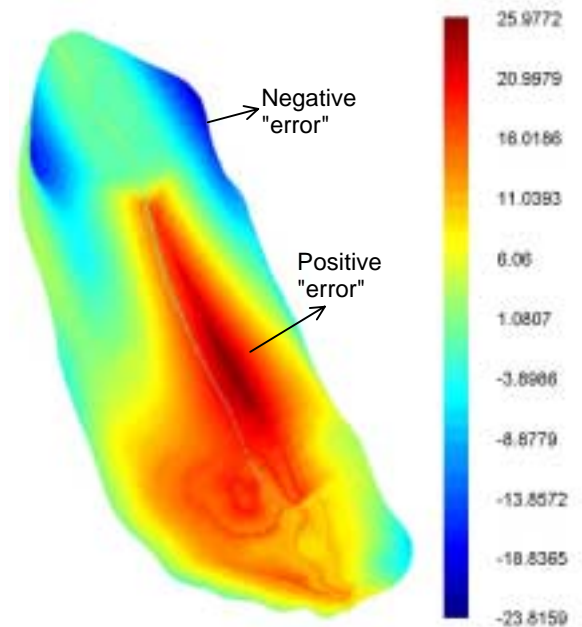


Figure 4. Dimensional differences between foot and *last*

## 4 DISCUSSION AND CONCLUSIONS

Currently, most of the mass customisation in the footwear industry is in the aesthetic domain, and shoe sizing based on only foot length and width are used. This method may require several fitting trials before the preferred fit for foot and shoe can be achieved. For groups that are unable to give their subjective opinions

(for example, subjects who have no sensation in their feet and children who cannot express the degree of fit), a fitting trial is somewhat meaningless. With the proliferation of e-commerce, footwear purchase through internet can be greatly enhanced if a fit metric is present. Thus it is vital that the proper “clearance” between the foot and shoe be present for the foot to function as needed.

In this paper, a method based on dimensional differences is proposed to quantify footwear fit. Important elements of the method involve the orientation and alignment of foot and shoe, and shape adjustment to take care of

shoe characteristics such as toe-spring and heel height. The method allows the designer or developer to understand areas that may cause fit problems for users so that design modifications may be performed even without fitting trials. The method can be further enhanced through perception and sensation studies [10]. Since the discomfort and pressure tolerance level on the surface of the foot may be different, there may exist a need to scale the allowable dimensional differences to account for “similar” sensations. Further study is needed to generate guidelines for the clearances between feet and shoes.

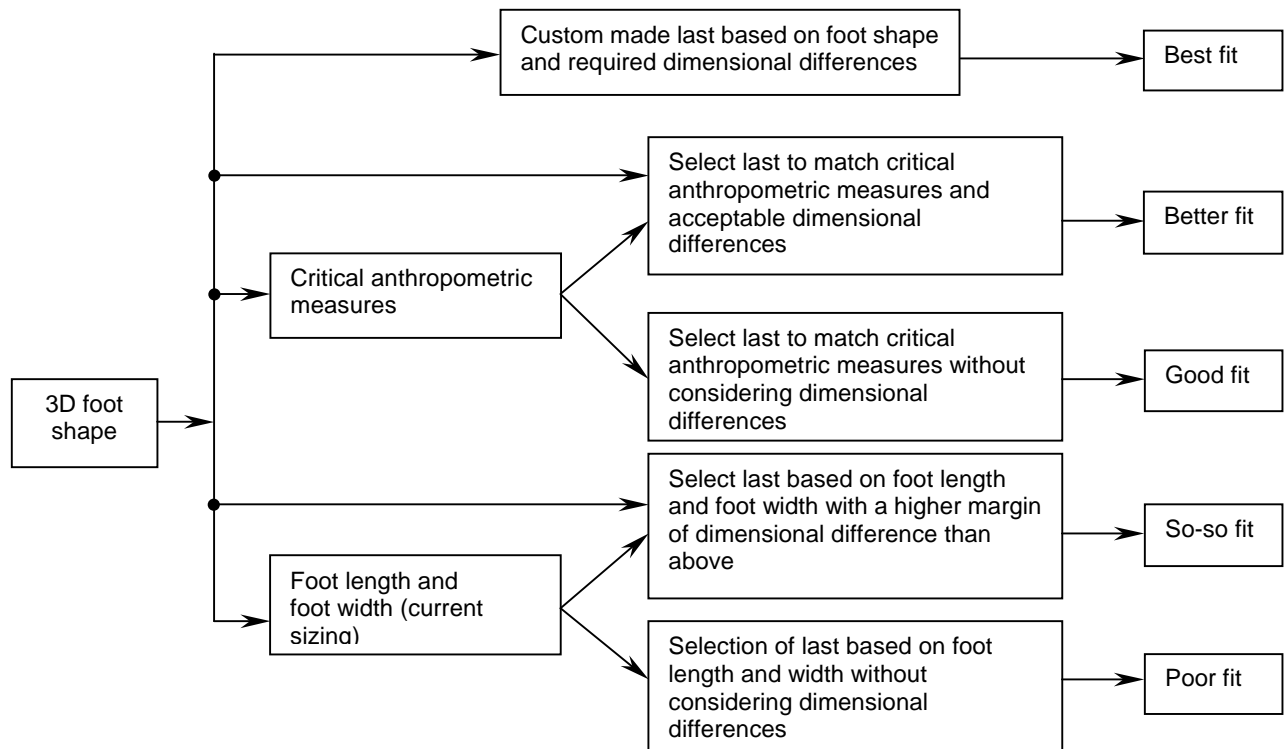


Figure 5. Last selection to achieve different degrees of fit

## REFERENCES

- [1] Cox, M. W. and Alm, R., 1998, The Right Stuff-America's Move to Mass Customization, Annual Report, Federal Reserve Bank of Dallas.
- [2] Jiao, J. and Tseng, M., 1999, An Information Modelling Framework for Product Families to Support Mass Customization Manufacturing, Annals of the CIRP, 48/1:93-98.
- [3] Kahn, B., 1998, Variety: From the Consumer's Perspective, Product Variety Management Research Advances (Eds. Ho T.-H. and Tang C. S.), 19-38.
- [4] Lancaster, K. 1998, Markets and Product Variety Management, Product Variety Management Research Advances (Eds. Ho T.-H. and Tang C. S.), 1-18.
- [5] Du, X., 2000, Architecture of Product Family for Mass Customization, PhD Thesis, Department of Industrial Engineering and Engineering Management, Hong Kong University of Science and Technology.
- [6] Spencer, J. E., 1996, Robotics Technology and Advent of Agile Manufacturing Systems in the Footwear Industry, Assembly Automation, 16/3:10-15.
- [7] Gilmore, J. H. and Pine, J. B., 1997, The Four Faces of Mass Customization, Harvard Business Review Jan-Feb: 91-101.
- [8] Friedman, W., 2000, Nike Picks up the Pace in Race to Harness Web, Advertising Age, 71/10:S4.
- [9] Cavanagh, P. R., 1980, The Running Shoe Book. Mountain View, CA: Anderson World.
- [10] Goonetilleke, R. S. and Luximon, A., 2001, Designing for Comfort: A Footwear Application, Proceedings of the Computer-Aided Ergonomics and Safety Conference '01, Maui, Hawaii. Plenary session paper.
- [11] Goonetilleke, R. S., Ho, C.-F., and So, R. H. Y., 1997, Foot Anthropometry in Hong Kong, Proceedings of the ASEAN '97 Conference, 81-88.
- [12] Goonetilleke, R. S. and Luximon, A., 1999, Foot Flare and Foot Axis, Human Factors, 41: 596-606.

- [13] Quimby, H. R., 1944, The Story of Lasts, New York: National Shoe Manufacturers Association.
- [14] Cheskin, M. P., 1987, The Complete Handbook of Athletic Footwear, New York: Fairchild Publications.
- [15] Goonetilleke, R. S., Luximon, A., and Tsui, K.-L., 2000, The Quality of Footwear Fit: What We Know, Don't Know and Should Know, Proceedings of the Human Factors and Ergonomics Society Conference, 515-518.
- [16] Luximon, A., 2001, Foot Shape Evaluation for Footwear Fitting, PhD Thesis, Department of Industrial Engineering and Engineering Management, Hong Kong University of Science and Technology.

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