28 Footwear Fit Categorization

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There is a growing trend to sell many types of consumer products through the web in order to maintain or enhance a company's competitiveness, and sometimes to establish a niche market. For products such as footwear however, manufacturers are facing quite a challenge to provide consumers with good fitting shoes. Footwear fitting is generally performed using the two variables of foot length and foot width (or girth), even though feet and shoes are three-dimensional objects. As a result, the matching between feet and footwear are quite variable and can be quite unacceptable even with the same brand of shoes. Footwear fitters speak of "perfect fit" and more commonly a "proper" or "correct" shoe fit even though the term "fit" appears to be nebulous. This chapter is an attempt to quantify and categorize footwear fit. Using digital manipulations, the foot shape was "adjusted" to the required heel height. The last and foot were then mapped to each other to determine the level of match and mismatch. The magnitude of the match or mismatch was color-coded and overlaid on the foot surface so that such color maps can be used to determine subjective preferences. The proposed footwear fit quantification can be used to predict potential discomfort and even fit-related comfort, if the material properties of the shoe are known. The method can also be used to rank different footwear lasts for any given individual.

28.1 (Mass) customization of footwear

Research indicates that customer focus can influence today's business [1]. As a result, manufacturers attempt to meet the differing customer preferences through product variety [2]. With growing product variety and opportunities in e-commerce, the old paradigm of mass production becomes sluggish [3], especially, when there is a change of the business paradigm from producer-centered productivity to consumer-centered customization commonly known as mass customization [4]. Mass customization is an attempt to satisfy individual customer needs with near mass production efficiency [5]. By breaking down the product features into components and offering those components to the consumer as choices, customization of the whole or part-product is possible [6].

Historically, there has been a trend to introduce product variety to cater to varying consumer tastes and styles [1], [7]. For example, from 1970 to 1988, the number of running shoe models increased from 5 to over 285 (167 men and 118 women) [1]. In order to keep pace with ever changing customer tastes, thousands of new products are made annually and with each variation, manufacturers attempt to bring products closer to what the customer needs. Even though variety matters to consumers, each product variety may have a differing meaning to different consumers [7]. Product assortments can be beneficial, if variety means different options rather than different products, as finding the required item among a large assortment can be quite frustrating for any consumer. Hence, allowing a customer to choose one product from a "shelf" can be wasteful and can also constrain a customer’s ultimate satisfaction even though a store shelf may have great marketing appeal [8]. The difficulty of selecting the right pair of shoes in a shoe store is a classic example. In this case, product variety can be a hindrance rather than a benefit. Hence, the need satisfaction process should be attained not purely through more variety but by manufacturing the "right" products. Mass customization means to generate these “right” products in order to fulfill customers’ needs at different levels [6], [9], [10]. The footwear industry can adopt this methodology for the next generation of footwear manufacturing and product design.

Gilmore and Pine [11] 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 for the company to learn consumer’s specific needs, while transparent and collaborative approaches offer differentiated products and require information on customer preferences [7]. Adaptive customization, is appropriate for sophisticated customers while it is not appropriate for customers who are likely to be confused or frustrated [7]. Consumers need to learn how to adapt the standardized product to fit their needs [7], [11]. Examples include the use different lacing methods in shoes, off the shelf insoles to change or adapt a shoe based on his/her own personal needs, ability to configure a shoe for different applications or activities such as the Nike "Rival", which can alternate between a track shoe and a road shoe [12]. Cosmetic customization refers to customizing the aesthetic aspects of standardized products [11]. For example, Cmax (www.cmax.com) and Nike allow consumers to design their shoes based on a different array of styles, materials and colors [12]. In transparent customization, customer needs are observed without actually involving the customer [11]. For example, shoe wear patterns can be studied and used to improve the outsole [13]. Transparent customization becomes difficult, if not impossible, when preferences are not well defined or observable [7]. In collaborative customization, there is a need to interact with the consumer to identify their needs and preferences [11]. As a result, collaborative customization can create the ideal customized product even though it can be a lengthy process. For example, Digitoe (www.digitoe.com) in their mission to deliver custom footwear uses the following steps:

- Educate the consumer on the custom fitting process.
- Consult customer service personnel for fitting needs and footwear selection.

- Fitting appointment (1-2 hours).
- Incorporate fit information into the *last.*
- Shoe fitting trial and customer approval.
- Selection of material, colors and patterns and finalizing the order.

It seems obvious that the interaction between customer and manufacturer is high in order to achieve collaborative customization. Similarly, orthopedic companies such as Footmaxx (www.footmaxx.com) use computerized gait and pressure technologies to fabricate custom orthotics [1]. Such custom shoe inserts typically cost around US$ 125-200 and take about 1 to 2 weeks to be delivered to one's home. Companies such as Custom Shoe Inserts (www.customshoe-inserts.com), on the other hand, make custom orthotics by using an impression kit to determine the shape, size, and differing foot needs. Collaborative customization aims to satisfy an individual's needs related to fit and comfort and may create the ideal customized product even though it can be time consuming and sometimes frustrating for the consumer [7]. Overall, whatever the chosen level of customization, the existence of a suitable fit-metric for footwear fitting can help, if not enhance customer-fitting needs in relation to footwear.

28.2 Why quantify fit?

The importance of product compatibility for comfort and satisfaction is well known [14], [15]. Today, most consumers select footwear based on length and width measures, even though many studies have shown that these two measures are insufficient for proper fitting [15], [16], [17]. In order for a shoe to fit a person's foot, a good understanding of the foot shape is necessary [15]. A good-fitting shoe should be free of any high pressure points [18], but 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 [15]. If guidelines or standards can be established for these dimensional differences, then footwear fitting can be made much simpler. If a shoe is tight, the pressure or force will produce undue tissue compression making the shoe uncomfortable. When the shoe is loose, there can be foot slippage relative to the shoe resulting in damage or injury to soft tissue. Both these situations are undesirable as they may cause discomfort, pain, or even injury [15]. In order to achieve the right fit, the desired clearance between feet and shoes should be known in addition to supporting the foot at the most appropriate locations.

Since footwear-fit is one of the most important considerations when purchasing footwear [18], it has to be understood when manufacturing footwear. The availability of a fit-metric can be useful for the design and development of the right fitting footwear. With the proliferation of e-commerce, a fit metric will allow people to purchase comfortable footwear with some degree of confidence. Thus, the aim of this chapter is to illustrate a 3D methodology to quantify footwear fit.

Goonetilleke et al [19] proposed a 2-D methodology to calculate the dimensional difference between a foot and shoe last and have discussed how that error can be used as an indicator of the quality of fit. An extension of that method to three dimensions as given here, will allow a complete evaluation of the level of match or mismatch between feet and shoes.

28.3 Methodology to quantify footwear fit

The proposed methodology consists of four steps: (1) 3D scanning and orientation, (2) foot and last alignment, (3) computation of dimensional match or mismatch, and finally (4) the selection of lasts.

(1) 3D Scanning and orientation: The Yeti 3D foot laser scanner (www.vorum.com) from Vorum was used. The left foot of each participant was scanned when standing with equal 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 [20]. The coordinate system was established by "fixing" the plantar surface of the foot and *last* on the (x,z) plane and the “height” dimension along the y-axis.

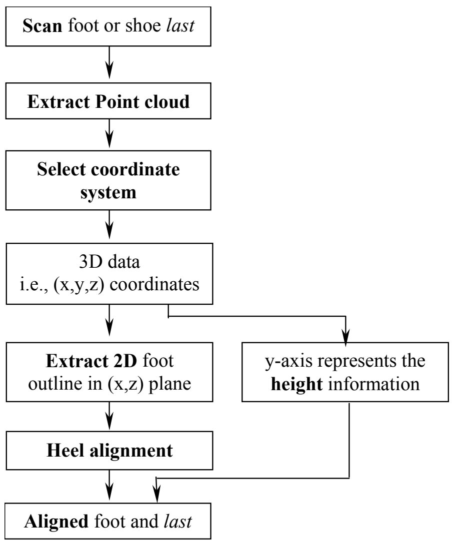

Figure 1: Flow chart for aligning foot and shoe last

(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 [19], [20]. The transformations required to orient the heel centerline along z-axis were first determined, after which the combinatorial linear and rotational transformations were applied to the whole foot and Last surface points to generate the 3-D shapes. Figure 2 shows the foot and *last* after alignment. After the foot and Last were matched along the heel centerline, the foot shape was digitally "adjusted" to account for the toe-spring and heel height of the *last* (Figures 3a - 3c). The foot and *last* after matching are shown in Figure 3d.

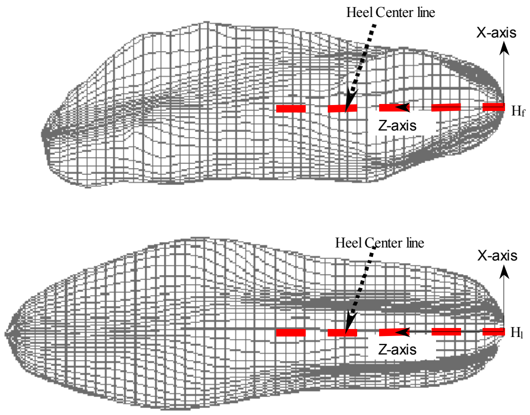

Figure 2: Heel centerline of foot and shoe last (H_f and H_l are the heel points of foot and shoe last respectively)

(3) Computation of dimensional match or mismatch: In order to compute the dimensional differences between foot and shoe last, sections along the z –axis, each spaced at 1mm intervals were used. The dimensional differences at each point were then color-coded for easy interpretation (Figure 4). Positive and negative differences should be distinguished as they have very different implications (Figure 3d). A positive "error" is one where the last surface is outside the boundary of the foot surface, whereas a zero or negative "error" is present otherwise. The concept of sign difference is very important in footwear fitting as a positive error is a loose fit, while a negative error can be categorized as a tight fit.

(4) 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 4). The most expensive and time-consuming procedure would be to produce a custom *last* for each individual consumer. For aesthetic customization, the *last* can be selected using foot length and possibly foot width sizing. This method is relatively cheap and less time-consuming since there will be no necessity to make new *lasts*. However, the degree of fit may not be satisfactory as foot length and foot width may be insufficient to generate the 3-D shape of foot [16], [17]. A different set of measures [20] may allow a closer match between *last* and feet if it is possible to obtain the characterizing parameters for each of the two three-dimensional shapes.

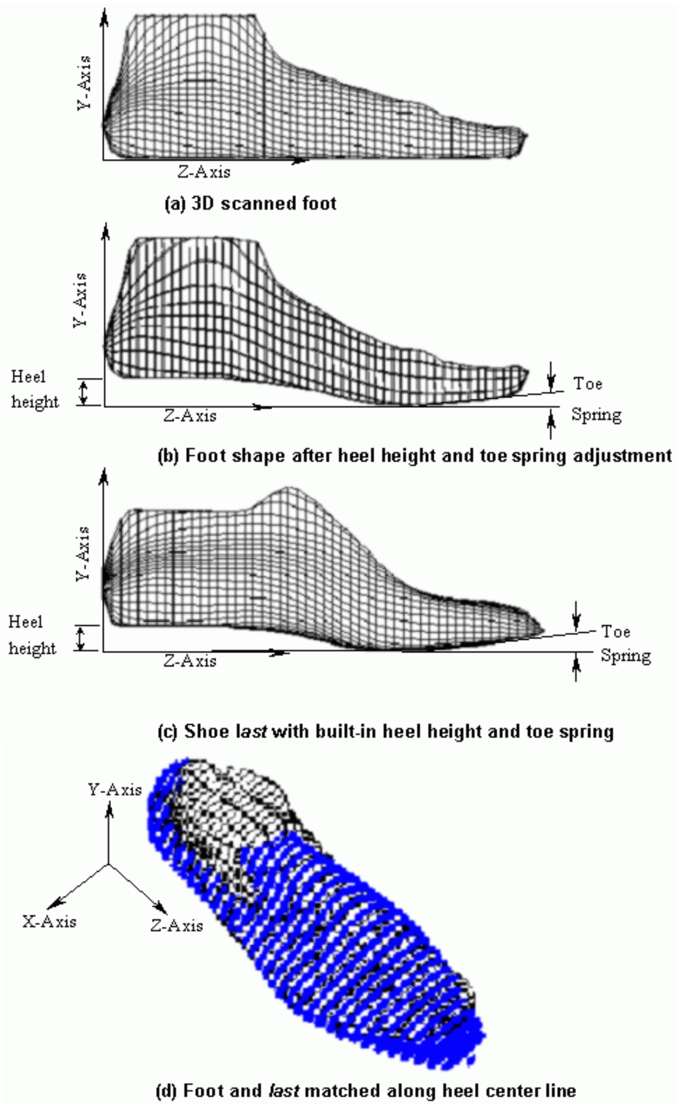

Figure 3: Foot and shoe last matching

28.4 Discussion and conclusions

Currently, most of the mass customization in the footwear industry is in the aesthetic domain, with some sizing customization. This method may require several fitting trials before the preferred fit for footwear can be attained. For groups that are unable to give their subjective opinions (example, subjects who have no sensation in their feet and children who cannot express the degree of fit), a fitting trial will be 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.

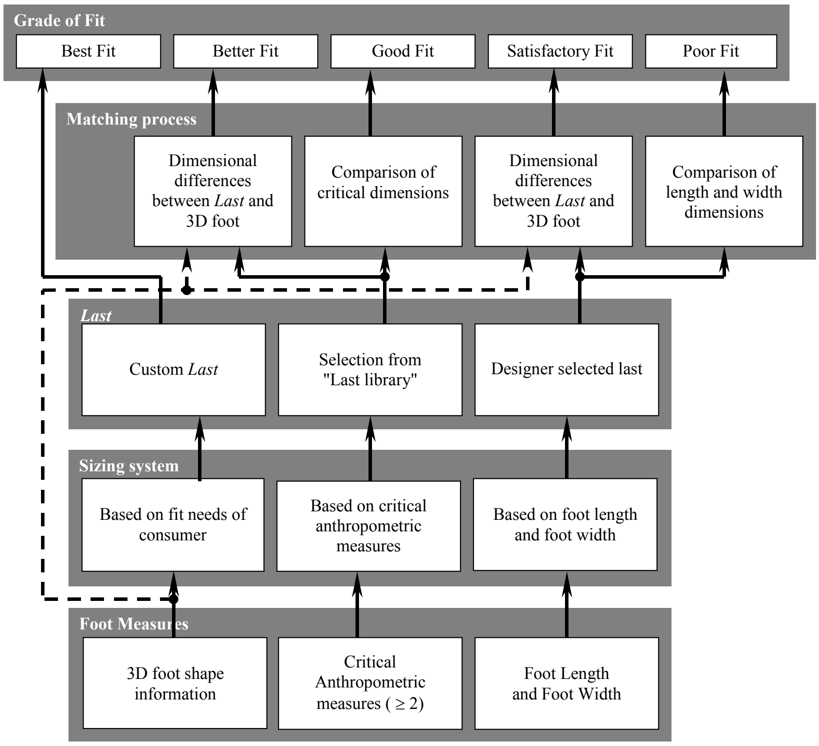

Figure 4: Last selection to achieve different degrees of fit

In this chapter, we proposed a method based on dimensional differences to quantify footwear fit. Important elements of this approach 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. One weakness of this method is neglecting the shape change with bending at the metatarsophalangeal joint. However, the method allows the designer or developer to have some understanding of 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 biomechanics, perception, and sensation studies [15]. 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 desired guidelines for the clearances between feet and shoes.

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