A Machine Learning Approach to the Design of Customized Shoe Lasts

Brian G. Booth[a*], Jan Sijbers[a] and Toon Huysmans[a,b]

[a]imec-Vision Lab, Department of Physics, University of Antwerp, Antwerp, BE
[b]Section on Applied Ergonomics & Design, Department of Industrial Design Engineering, Delft University of Technology, Delft, NL

Introduction

Footwear manufacturing begins with the design of a shoe last, and this last design has a large impact on the comfort and fit of the resulting shoe. Yet, the design of shoe lasts remains something that is done by hand, with experts manually shaping the last based on a small set of foot measurements (Ma and Luximon, 2013). Computer-aided design techniques have been proposed to reduce the effort and time in the design of shoe lasts, with some techniques even making their way into commercial software (e.g. Shoemaster). Yet these systems continue to rely on significant fine tuning of the last design prior to manufacturing (Wang et al., 2011). Meanwhile, advancements in machine learning have made inroads into the manufacturing sector with multiple examples of success (Wuest et al., 2016). The idea behind machine learning is to present a computer with various examples of correct solutions to design problems. The computer then mathematically defines a relationship between the problem and the correct solution (Zhang & Zhou, 2014). These machine learning techniques have yet to be applied to shoe last design.

Purpose of the study

The purpose of this pilot study was to evaluate whether machine learning algorithms can be used to design shoe lasts in an accurate fashion (i.e. sub-millimeter error).

Methods

Seventy individuals gave their informed consent for this study. Their feet were scanned with an Elinvision FootIn3D laser 3D foot scanner (rs scan, Paal, BE) to create 3D meshes of their foot shapes. The individuals hand-made shoe lasts were also scanned by the same scanner and used to evaluate the designs of the machine learning system.

An automated shoe last design system was then defined using three machine learning techniques. First, the 3D foot scans, and the 3D shoe last scans, were each reduced to 10 dimensions using principal component analysis (Stanković et al., 2018). Second, a non-linear regression was performed between the 10 dimensions of the foot scan and the 11 common shoe last measurements listed in Figure 1 (Ma and Luximon, 2013). This non-linear regression was performed using a chained neural network (Zhang & Zhou, 2014). Third, a multivariate linear regression was then performed between the 11 shoe last measurements and the 10 dimensions of the shoe last scan.

The machine learning system was evaluated using leave-one-out cross validation: For each individual, the regressions were computed with the remaining 69 individuals, then those regression functions were used to predict the shoe last designs for the remaining individual.

Results

Figure 1 shows the shoe last measurements predicted by the machine learning system. On average, the prediction error was roughly 10% of the measurements range.

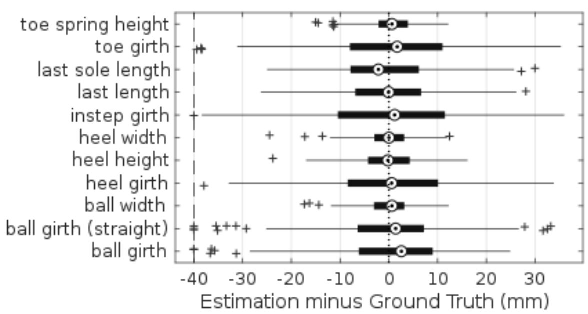

Figure 1. Shoe last measurement errors.

Figure 2 shows the average geometric error between the shoe lasts designed by the machine learning system and the individual's hand-made shoe lasts. The median geometric error was 3.02 mm.

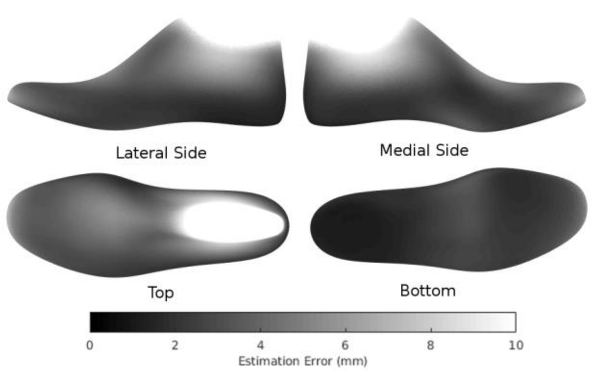

Figure 2. Shoe last geometric errors.

Discussion and conclusion

Overall, the results are encouraging and show that the machine learning system is providing reasonable designs most of the time. Still, large errors in last design were seen above the ankle and near the toe. These were due to difference in shoe styles that were not considered in the study (e.g. boots vs. sneakers, toe box differences). Also, the presence of outliers in Figure 1 indicates that more examples are required to compute accurate regression functions. We expect that addressing these two limitations will provide us with an accurate automated shoe last design system.

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