Creating shoe lasts through 3D feet scans clusterizaion and building middle foot for each population

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***Abstract* — This article describes a software tool for optimizing lasts design. The proposed solution is based on a statistical analysis of feet 3D-models. This approach consists of several stages. At the beginning, feet are measured and the dimensions are determined. On the next step, the cross-vertical/cross-horizontal sections are built at a given interval, parameters for each individual section are calculated. The obtained data is statistically processed, one-dimensional and two-dimensional histograms of feet parameters are constructed. Furthermore, feet are grouped by sex, age, and size. For each group, overlapping sections of the same type are drawn for a possible visual creation of the average section for a given sample.**

Keywords— data analysis, anthropometry, data processing

I. Introduction

Individual shoe companies, guided mainly by the direction of fashion, produce shoes without taking into consideration the anthropometric characteristics of various groups of the population. Non-compliance with the features of the shape and size of the feet, operating conditions and many other factors creates a number of problems associated with the unsatisfied demand for the shoes of quite large groups of the population. When designing a shoe, data from mass anthropometric measurements of the feet is usually not used; information about target audience, such as: age, unique regional features is left unused. Anthropometric studies provide the information needed to develop the internal shape of shoes. It is pretty evident that for mass production it is necessary to know not only the structure, but also feet size of target consumers [1]. At the same time, it is inefficient to use lasts that were modeled manually. Obviously, when working manually, the shape and size of templates depend entirely on the skill of the worker. Therefore, in these conditions, to create a shoe last of the correct form requires a lot of experience and intuition of the performer. Lack of sufficient geometric information about shoe last surface and its frame, complexity and duration of manufacturing processes, errors in shape and size forced industry experts to look for modern methods and means of design [2]. The technical side of designing an internal shape of shoes is diverse and complex. Anthropometric data about the shape and size of the foot, taking into account its physiology and biomechanics, must be converted into parameters of a shoe last and based on them, determine the outlines of curved surfaces of the shoe last. Thus, it is relevant to develop a system for designing shoe lasts taking into account gender, age and regional factors.

The objective is to create a technology that performs anthropometric analysis and allows to design shoe lasts on a set of 3D foot scans for various population groups.

II. Known solutions

With the development of technologies for manual measurement of anthropometric parameters of the foot and the design of a shoe last is already unprofitable.

Modern foot scanning technologies allow to quickly get 3D models of people's feet. The so-called foot scanners [3] are designed to produce an accurate 3D model [4] of the entire foot. The scanners are equipped with state-of-the-art cameras and lasers. The scan is completely automatic: put the foot in the correct position and the 3D model is ready in a few seconds.

Currently existing solutions do not offer a holistic approach to the transition from the base of 3D models to lasts or at least to target foots.There are solutions that try to divide the feet into subgroups within the size / gender. For example, one solution uses cluster analysis to separate models by type of foot [5]. The foot type cluster analysis included measurements of the medial ball length, lateral ball length, 50% elevation of the foot length, orthogonal ball width, and orthogonal heel width. Two clustering methods are used: 1) Ward hierarchical method for assessing the number of clusters; 2) nonhierarchical method (Quick Cluster) for optimizing results.

Another solution is also based on two-stage cluster analysis using PCA [6]. The Ward's minimum variance method is used to determine the number of clusters for the hierarchical approach. Next, the K-means method is used to cluster homogeneous individuals into groups for a non-hierarchical approach.

There are also solutions that allow you to build average foots, but without automatically dividing them into foot types [7]. Average foot models can be generated using the ICP algorithm based on data obtained from measurements.

As you can see from the description, existing solutions either divide the feet into different types of feet using clusterization or design a average foot without clusterization. As for the proposed solution in this article, it will allow to design different unique lasts for each gender/age/size, will simplify and improve the quality of the design of shoe lasts.

III. Implementation

A software solution was developed to ease the process of shoe lasts creation with bank of 3D feet models acting as an input. 3D models are represented as files in the STL (Stereo Lithography) format (Fig.1). The STL file stores information about the 3D model. The format represents the raw surface of the model, which consists of small triangles. The more complex and detailed the structure, the more triangles will be used to represent the model. The STL model is represented as a grid.

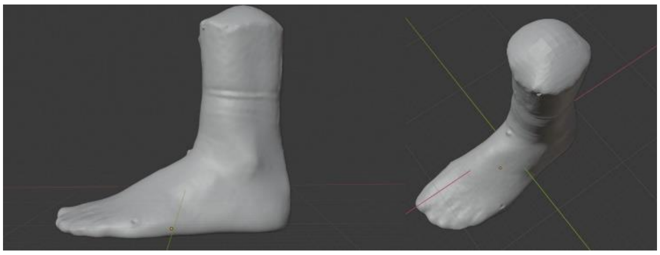

Fig. 1. STL model

A grid is a set of vertices, edges, and faces that describe the shape of a three-dimensional object:

- A vertex is a single point.
- An edge is a straight line segment that connects two vertexes.
- A face is a flat surface bounded by edges.

To design a shoe last, it is first necessary to analyze the anthropometric parameters of the feet of the people for whom this shoe will be produced. Foot models are presented in stl format. All manipulations on the models will be performed using the trimesh library [8].

First step of analyze is determining the feet size. To do this, the foot length is calculated by searching for the x-coordinate of points corresponding to the most prominent point of the heel and the most distant point of the fingers. The difference between these values is the length of the foot. The size is determined based on the length of the foot. The size is determined using the metric system based on the original size and step (1):

$$Size = nominal\ size\ \pm step \quad (1)$$

An example of the distribution of stop with “nominal size” = 270 mm and step = 7 mm is presented in table 1.

TABLE 1. Example of the distribution of sizes

Foot length, nominal (mm)	**Foot length, mm**	
	minimum (inclusively)	***maximum (exclusively)***
249	245.5	252.5
256	252.5	259.5
263	259.5	266.5
270	266.5	273.5
277	273.5	280.5
284	280.5	287.5
291	287.5	294.5

To build an average foot, cross-vertical sections are needed build [9], which will be further divided into groups and averaged. Cross-vertical sections are constructed starting from the farthest point of the heel, perpendicular to the longitudinal-vertical section passing through points 3 and 9 (Fig. 2) (axial section) [10]. There are two ways to specify the discreteness of a section:

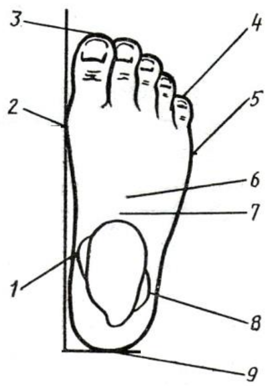

Fig. 2. Basic size parameters of the foot

- Pitch (mm) - distance between sections
- List - sets a list of sections to build.

To satisfy more people, it is needed to identify the same type of foot in separate groups, formed depending on gender, age and size. To do this, the stop is clusterized according to certain parameters and the following sections are additionally constructed [11]:

- 0.18D - the widest point of the heel
- 0.68D - middle of the beams
- 0.5D - middle of the foot

- 0.62D/0.73D - cross section passing through the middle of the inner and outer beam.

D is the length of the foot (the length of the "contour").

An example of building a cross section. A cross section is the shape we get when cutting straight through an object. The section shows only what is obtained directly in the secant plane. First, the point through which the section will pass is determined. Take half the length of the foot (section of the Oc Fig. 3). The result is a section that calculates the girth, width, and height (Fig. 4).

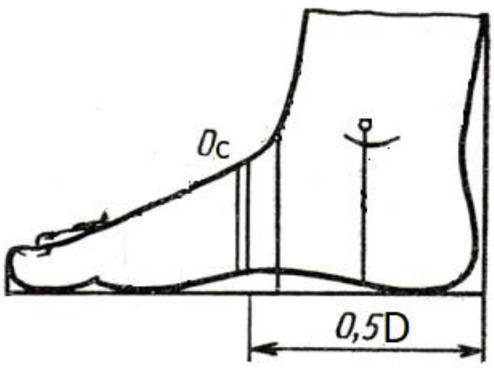

Fig. 3. Midfoot section

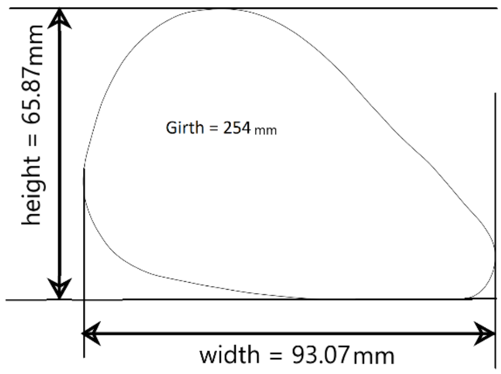

Fig. 4. An example of midsection section

The cross-section width is calculated for 0.18 D and 0.68 D, and the section girth is calculated for 0.5 D and 0.62/0.73D. Based on the calculated parameters, the selection is divided into clusters.

Agglomerative hierarchical clustering is used to divide stop models into selections. Hierarchical clustering is clustering in which clusters are nested within each other. First, all objects form a cluster, then the nearest clusters are joined into a single cluster, and this happens until only one cluster remains [12]. Clusters are merged based on the distance between them. There is a Lance-Williams formula that generalizes many different ways to enter distances between clusters. It expresses the distance between the cluster that is obtained by merging two U and V, and some third cluster, cluster S. the Formula is recursive, that is, it defines the distance between clusters through the distance between simpler clusters. That is, for example, if U, V, and S are clusters from the same point, then we use the Lance-Williams formula to get a definition for the distance, for example, between a cluster of two points and a cluster of one point [12]. The number of clusters is determined by splitting the data into 1,2,…k clusters and selecting the partitioning with the highest average Silhouette score. The distance between objects in the p-dimensional feature space is chosen as the measure of difference.in our case, we use the Euclidean distance [13]. The Euclidean distance in n-dimensional space is calculated using the following formula (2):

$$d_{pq} = \sqrt{\sum_{i=1}^{n}(p_i - q_i)\char`^2} \qquad (2)$$

In each cluster, the same cross-sections are averaged by superimposing (Fig. 5). Next, to calculate the average cross section we propose so-called “ray” method. The ray method involves building a beam through a point in the desired direction. All rays are constructed from the same origin (43, 0) at an angle of 1 degree (Fig. 6, angle between rays on figure is 10 degrees for better readability). Next, an intersection points of the ray and cross-sections are determined. Resulting points for each ray are averaged and the average cross-section is built on them.

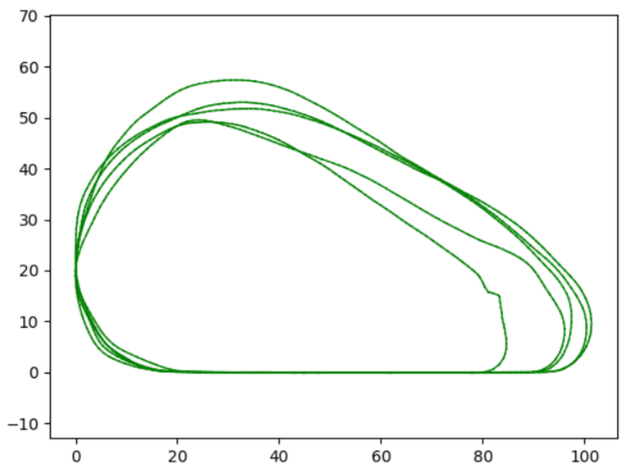

Fig.5. Overlapping sections

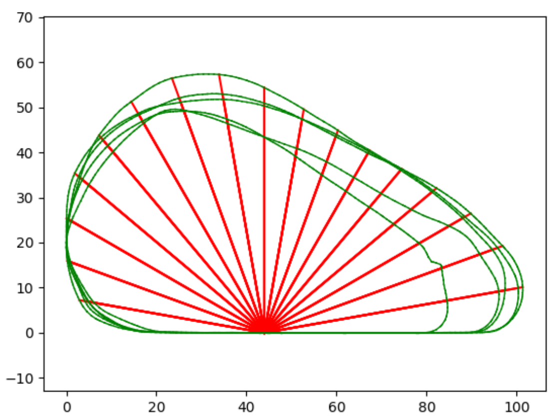

Fig. 6. Search for intersection points

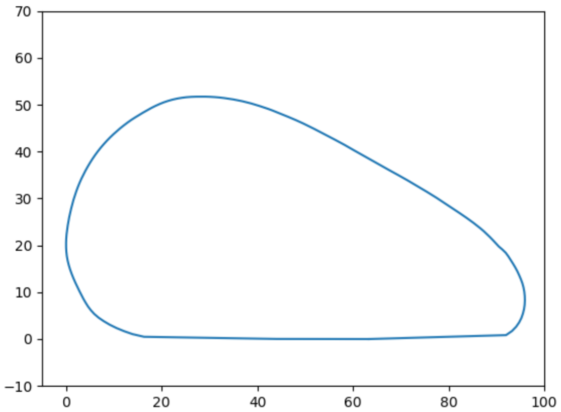

Fig.7. Midection

Each cluster also contains cross-section characteristics. For example, when processing 50 models of men's feet; in men aged 25-45 years with a foot size of 270 mm in the first cluster were feet whose with a cross-section girth through the middle of the bundles (section 0.62/0.73D) from 266 to 286 mm (Fig. 8), in the second cluster were feet with a girth through the middle of the bundles from 245 to 255 mm (Fig 9).

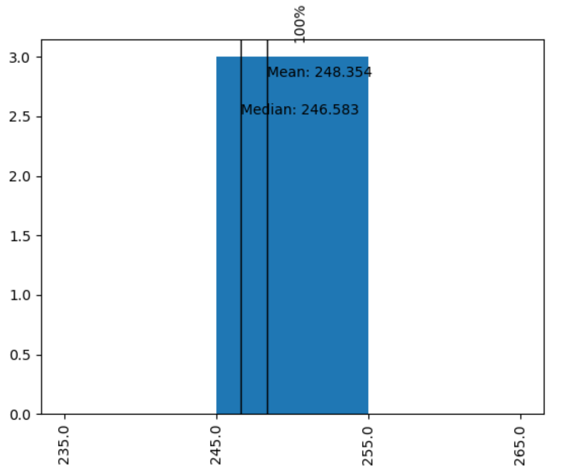

Fig.8. Cluster 1 – a girth of the section 0.62 D/0.73 D

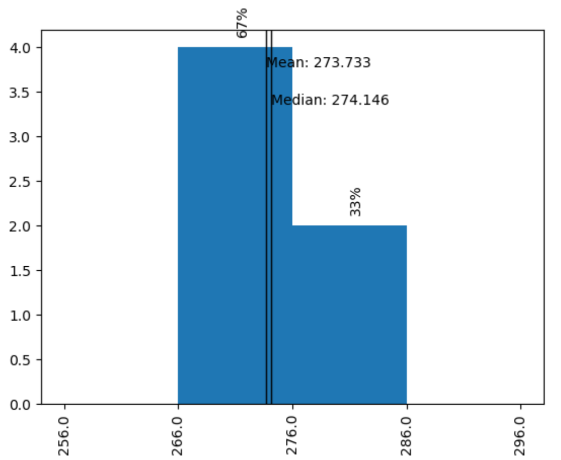

Fig.9. Cluster 2 – a girth of the section 0.62 D/0.73 D

IV. Conclusion

A database of 3D foot models was analyzed. During the analysis, the dimensions of the foot were determined, cross-sections were constructed, and cross-section measurements were made. All models were divided into groups based on gender, age, and size. Each group was clustered by calculated cross-section parameters. As a result, the same average cross-sections were created in each cluster.

In the future, it is planned to automate the creation of an average foot from the obtained average cross-sections. And implement the transition from the average foot to a last shoe.

V. Acknowledgements

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VI. References

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