3D IMAGING CAPTURE OF THE FOOT AND DATA PROCESSING FOR A DATABASE OF ANTHROPOMETRIC PARAMETERS

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Manufacturing high quality footwear with an optimal degree of comfort, adapted to the needs of various pathologies of the consumer, with effects on the size and shape of the foot, is conditioned by mastering techniques of processing anthropometric data obtained by 3D foot scanning, transposition of the anatomical, morphological, and biomechanical information into parameters for the design and modeling of shoe lasts and models. Anthropometric measurements are also required because of the specificity of each population, either in terms of length, width, height and foot conformation and consequently, the correlation between them, or growth rate during certain periods of time, depending on socio-cultural conditions, climate, food, etc. The current technological progress makes it possible to obtain 3D anthropometric data and use them in many industrial and research applications. Setting up a database of anthropometric data for the citizens of a country becomes a necessity. Digitized anthropometric data management enables their application in various professional disciplines such as medical studies, anthropometry studies, CAD/CAM footwear design, design of medical devices. This study aims to demonstrate the necessity and importance of creating a database of anthropometric parameters for the Romanian population.

Keywords: anthropometric parameters, database, foot.

INTRODUCTION

The development of the practical application of anthropology in the world was determined by the war industry, that required anthropometric sizes to manufacture equipment (footwear, clothing, accessories), as well as to size weapons.

The first anthropometric measurements were performed in England, in the years prior to the Hundred Years' War (1337–1453).

In Romania, the first mass anthropometric measurements were performed in 1968. In 1981–1982 and 1994–1995, these measurements were performed again, using the same methodology, on a much lower number of subjects, however (0.02–0.03% of the population). The analysis of anthropometric parameters measured in the two periods shows a series of changes, as well as size increments for manufacturing footwear.

The anthropological structure of a population, its dimensional and conformational variability are genetically and mesologically determined. When analyzing the anthropological structure of a population, many factors that influence this structure and make the distinction between different populations or within these populations are taken into account (gender, ontogenetic evolution, geographical factor) (Kozma *et al.*, 2014).

Thus each country builds its own anthropometric database necessary to establish dimensional standards for shoes, clothing, adapting environmental objects in the workplace, in private life, medicine, etc.

MEASURING INSTRUMENTS AND METHODS

Anthropometric foot data determine the spatial shape of shoe lasts. Over time different ways of measuring the human foot were developed in order to get initial data for shoe last design process.

Direct Method (Direct Contact with the Subject)

In the classical method or the method using direct contact with the subject, measurements are taken manually and specific tools are used: graded tape, caliper, pen, tissue paper, photographic developer.

Indirect Method (No Direct Contact with the Subject)

Advanced and integrated technologies, such as optical measurement, electronic signal and digital data processing, software and hardware, have directed the traditional 2D anthropometric data measurement to a new trend, the use of the 3D scanning system. In this case, foot conformation and specific sizes are obtained by means of 3D scanning systems that enable the storage and processing of data using specialized software.

The main advantages of 3D scanning systems are the accuracy and correctness of measurements, high speed scanning and processing, the possibility of data storage and database creation, the possibility of saving the 3D shape of the foot for further use and processing using dedicated software for modeling shoe lasts (Mortazavi *et al.*, 2008), designing shoes (Zhao *et al.*, 2010) and prototyping (McPoil *et al.*, 2009).

In the ongoing anthropometric survey in Romania, in order to calculate anthropometric parameters, the 3D shape of the foot is taken using USB INFOOT system (Fig. 1) consisting of a 3D scanner and dedicated software MEASURE 2.8. The system scans the foot shape and can recognize and automatically place up to 20 anatomical measurement points. It is intended for research, designing shoe lasts, selecting proper footwear, etc.

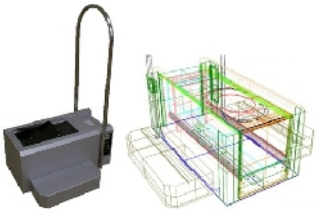


Figure 1. INFOOT USB 3D scanner

Configuration of INFOOT Application and Scanning Conditions

Prior to foot scanning and obtaining anthropometric parameters, equipment calibration is required, through the software's configuration interface (Scanning config), as well as verification of scanning conditions, setting recognition mode of anatomical points (manual or automatic), position of foot axes and toe angles, data processing module, printing template, saving format, etc.

Obtaining the 3D Shape of the Foot

Steps to obtain the 3D shape of the foot using the INFOOT scanner and dedicated software MEASURE 2.8 are: input of subject-specific data and of the scanning conditions (full name, year of birth, height, weight, gender, practiced sports, position of the subject during scanning, country, ethnic group), placing the foot in the working area of the scanner, scanning using the "Scan to" command and saving the data on the subject and the scanning results.

Positioning Anatomical Points and Measuring Anthropometric Parameters

After obtaining 3D foot shape in order to determine anthropometric parameters, the MEASURE 2.8 software displays the scanned foot, section by section (Fig. 2) and enables correction of any scanning errors, viewing the 3D foot shape (Fig. 3) in order to check and possibly correct the location of anatomical points, manual placement of anatomical points that have not been recognized by the software, viewing the 3D shape of the foot with anatomical points in various forms (cloud, polygon, surface) (Fig. 4). Anthropometric data sheet can be visualized and analyzed after positioning anatomical points (Sarghie *et al.*, 2013).

Scanning errors can occur due to penetration of light, lint, dust, sweat stains in the working area of the scanner. We recommend checking and cleaning the work area before each scan. In case of errors that cannot be corrected, or that require too much time for correction, the scanning operation is repeated.

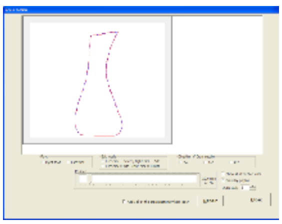


Figure 2. Sectional view of the foot

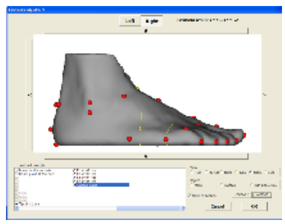


Figure 3. 3D foot shape and placement of anatomical points

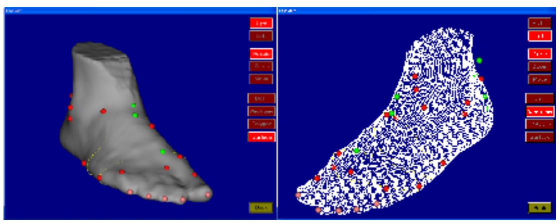


Figure 4. 3D foot shape and anatomical points in different forms (surface - a, cloud - b)

In order to calculate anthropometric sizes characterizing the foot of analyzed subjects, foot size parameters are thus processed: 16 significant anatomical points are manually set for each foot (left and right); These points are predefined and displayed in the scanning software, but are specific to the spatial conformation of each foot, and may be, therefore, changed. These anatomical points are presented in Figure 5.

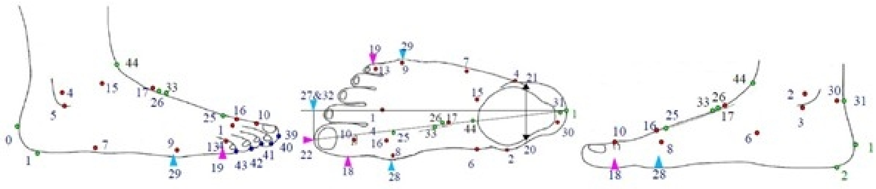
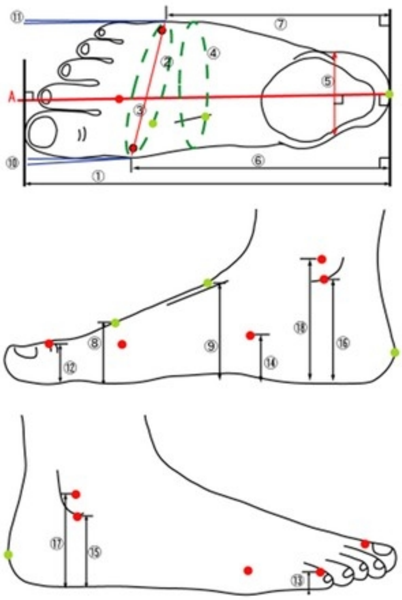


Figure 5. Significant anatomical points of the foot:

0 - Pternion
1 - Landing point
2 - Medial malleolus
3 - Sphyrion
4 - Lateral malleolus
5 - Sphyrion fibulare
6 - Navicular
7 - Tuberosity of 5th metatarsalis
8 - Metatarsale tibiale
9 - Metatarsale fibulare
10 - Toe 1 joint
13 - Toe 5 joint
14 - Tip of toe 2
15 - Tentative junction point
16 - Tip of toe 1
17 - Top of instep point

Following placement of anatomical point, foot-specific sizes will be automatically calculated (fig. 6).



1. Foot length
2. Ball girth circumference
3. Foot breadth
4. Instep circumference
5. Heel breadth
6. Instep length
7. Fibulare Instep length
8. Height of top of ball girth
9. Height of instep
10. Toe 1 angle
11. Toe 5 angle
12. Toe 1 height
13. Toe 5 height
14. Height of navicular
15. Height of sphyrion fibulare
16. Height of sphyrion
17. Height of the most lateral point of lateral malleolus
18. Height of the most medial point of medial malleolus

Figure 6. Foot-specific sizes (http://www.iwl.jp/main/mark_dimension.html)

Following foot scanning operations and placing anatomical points onto the surface of the scanned foot, values for a number of 21 anthropometric parameters, lengths, breadths, girths and angles are determined (Table 1).

Table 1. Analyzed anthropometric foot parameters

1.	Foot length	Lp	(mm)
2.	Ball girth circumference	Pd	(mm)
3.	Foot breadth	Ld	(mm)
4.	Instep circumference	Pr	(mm)
5.	Heel breadth	Lc	(mm)
6.	Instep length	Lm1	(mm)
7.	Fibulare Instep length	Lm5	(mm)
8.	Toe height	Hd	(mm)
9.	Height of instep	Hr	(mm)
10.	Toe 1 angle	Ud1	(^{o})
11.	Toe 5 angle	Ud2	(^{o})
12.	Toe 1 height	Hd1	(mm)
13.	Toe 5 height	Hd5	(mm)
14.	Height of navicular	Hn	(mm)
15.	Height of Sphyrion fibulare	Hsf	(mm)
16.	Height of Sphyrion	Hs	(mm)
17.	Height of the most lateral point of lateral malleolus	Hme	(mm)
18.	Height of the most medial point of medial malleolus	Hmi	(mm)
19.	Heel angle	Uc	(^{o})
20.	Heel girth	Pc	(mm)
21.	Ankle girth	Pg	(mm)

Transposition of anthropometric data into last design and manufacture is not carried out using a standardized method or international system – this is not possible due to the size specificity of each country and each population – but depends on the intuition, artistic sense and professional training of the designer, and is eventually confirmed by test wearing. One must know the correlations that must exist and be determined among the specific sizes of each foot, and among foot, last and footwear (Rigal, 1991; Deselnicu *et al*., 2014).

DATA ANALYSIS AND MANAGEMENT

Database analysis and management consists in: (i) primary 3D database; (ii) statistical processing and analysis of 3D data for the 3D anthropometric database; (iii) data processing and analysis to set footwear size increments; (iv) data processing and analysis to establish the morphological character of the foot; (v) data processing and analysis to establish size increments; (vi) data processing for medical research: diabetic foot, arthritic foot, etc.

APPLICATIONS

There are a number of current and potential applications for 3D scanners in commercial, clinical and research areas related to the human foot. The foot scanner's role in orthosis and customized shoe design and manufacture has been established.

The utility of scanning systems for clinical and research purposes has been successfully demonstrated, particularly for anthropometric measurement. 3D scanners allow large numbers of subjects to be scanned quickly and easily, with the data available for analysis at a convenient time for the researcher. There would appear to be scope for the expansion of scanner-based research into the investigation of a range of foot conditions, for example those that require monitoring the progression of a deformity over time. This approach could help to reduce x-ray exposure for the patient.

CONCLUSIONS

Making high quality footwear with an optimal degree of comfort, adapted to the needs of various pathologies of the consumer, affecting the size and shape of the foot, depends on mastering anthropometric data processing techniques obtained by 3D foot scanning, transposition of the anatomical, morphological and biomechanical information into shoe last and footwear model design and modeling parameters. Correlating internal dimensions of footwear with anthropometric measurements of the foot is particularly important in order to meet comfort conditions. Setting up and using an anthropometric database are compatible and competitive with the European research area. 3D scanning technology is new to Romania and is one of the sources for new research projects. Statistical data analysis will allow the development of anthropometric standards in compliance with the real sizes of the population. 3D scanning technology can and should be the source of innovation in various industrial fields.

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