

Characterization of Foot Morphology through 3D Optical Measures

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ABSTRACT

The aims of this work were: the definition of an experimental protocol for foot shape anthropometry characterization through advanced 3D scanning technologies; the assessment of the effects of load and position on foot morphology; the creation of a consistent database of both anatomical and standard shoemaking measures. 3D foot shapes from 89 subjects were captured by using a stereophotogrammetric scanning system. A set of dedicated measures were extracted from each individual foot in 5 different conditions in terms of lower limbs position and load. Results gave some interesting indications concerning foot morphology and suggested that position and load do not seem to deeply affect foot measures.

INTRODUCTION

The customization of shoe design pass through the achievement of more insight into foot-footwear biomechanics and into the new technologies for capturing individual anatomical and functional peculiarities. The proper acquisition of the foot shape, and the measures derived thereof, are key points in this process. In fact, the thorough knowledge of foot morphology may help the design of a proper foot last (i.e. the wooden or plastic model which the shoe is assembled on) and may drive the realization of shoe components (midsole, upper, ...) that match anatomical and functional needs. It also may help the development of a modularity inside the product to better fit the end user requirements [2]. Hence, there is the need of suitable technologies for 3D surface capture, and of valid measuring protocols for a consistent description of foot geometry. The former issue has already been examined [4,5]; the latter represented one of the aims of the present research. The foot may change in shape during the execution of a movement (during locomotion in particular) and its measure might even change under static conditions, depending on the position we are assuming or on the load born by the supporting limb. Therefore, the influence of load and of different static positions on foot shape characteristics was investigated.

This was intended as the first stage toward the more complex and still unexplored analysis of dynamic conditions.

MATERIALS AND METHODS

INSTRUMENTATION - The foot shape analyzing system was made up of a stereophotogrammetric 3D scanner, Nexgen (CSM3D, UK), and a software tool for measuring, Fotofit rel.3.52 (CSM3D, UK) [1]. Nexgen scanning system (Figure 1a) consisted of a platform which the subject must stand on, placing the foot on the glass surface that lies in the centre (Figure 1b).

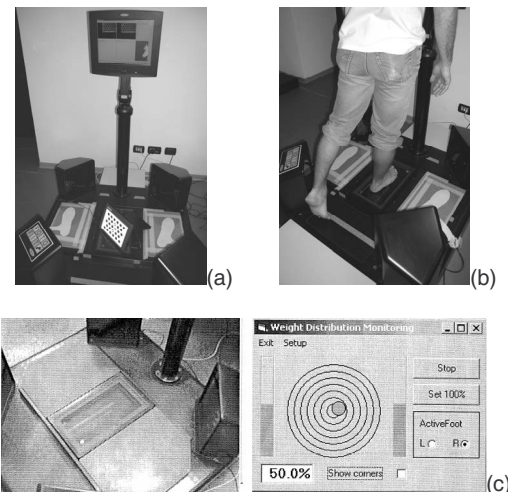


Figure 1. The adopted stereophotogrammetric 3D scanner with the grid pad for calibration (a). An example of foot shape acquisition (b). The central frame with the glass surface and the embedded force platform (c, left), and the related software for load assessment (c, right).

An embedded force platform assessed the percentage of the body weight (%BW) that was loaded on the acquired foot (Figure 1c). Five couples of optical sensors and five cameras, placed in the four corners of the platform and below the supporting glass, allowed the reconstruction of a full 3D model (plantar surface included) of the foot in a *wrl* format output (Figure 2).

The scanner, before use, needed to be calibrated by means of a special back lighted grid pad. Fotofit software provided CAD-environment tools to carry out either semi-automatic measures (between reference anatomical landmarks or pre-applied markers, both recognized by the operator), or automatic ones taken through preset section planes based on conventional shoemaking reference measures [1,3,4]. The reliability of the measuring system was assessed by using a prosthetic foot and resulted suitable for the purposes of the current research [4]. The mean accuracy, computed over 14 linear distances was 1.1 mm (SD = 1.2 mm). Intra and inter-day repeatability manifested coefficients of variation (CV) between 0.2 and 0.8%.

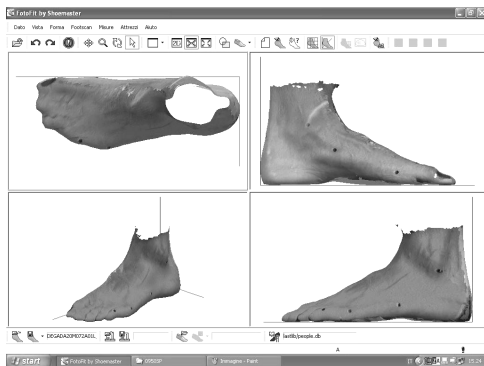


Figure 2. An example of a 3D foot surface reconstruction (wireframe with applied texture map).

PARTICIPANTS – 69 males and 20 females were the subjects of this study. Every subject was properly informed about testing procedures, personal data treating and aims of the research, so that he/she could provide written informed consent before participation. Detailed information about the anthropometric characteristics of the analyzed population are resumed in Table 1.

	N	AGE	WEIGHT	HEIGHT	FOOTSIZE
MALES	69	26.8 (10.3)	75.1 (8.8)	1.78 (0.06)	43.4 (1.3)
FEMALES	20	28.9 (9.3)	55.6 (6.6)	1.65 (0.05)	37.6 (1.5)
TOT	89	27.3 (10.0)	70.5 (11.7)	1.75 (0.08)	42.0 (2.8)

Table 1. Anthropometric characteristics of males, females and of the whole population. Data are expressed in terms of mean and standard deviation. N is the sample size, age is expressed in years, weight in kg, height in m. Foot size is indicated in the European Shoe Size Standard. It is the shoe size that the participant usually bought. This parameter was communicated by the subject by filling a specific form before he/she took part to the experimental session.

Subjects did not show any remarkable orthopedic pathology and had not undergone lower limb injuries since one year before participation. Most of them had an active lifestyle and practiced sport at different levels of proficiency.

DATA ACQUISITION

Acquisition protocol – Every subject's foot was prepared by applying 10 black round stickers (5 mm diameter with a visible center point) to 10 anatomical landmarks (Figure 3), according to the marker set described in the EUROShoE internal protocol. The reference points were:

1. the most protuberant point of the 1st metatarsal head;
2. the most protuberant point of the 5th metatarsal head;
3. the interphalangeal joint of the 1st toe;
4. the heel rearest point;
5. the lowest point of the internal malleolus;
6. the lowest point of the external malleolus;
7. the proximal interphalangeal joint of the 5th toe;
8. the 5th metatarsal styloid apophysis;
9. the scaphoid lowest point;
10. the point where Achilles tendon inserts in the calcaneus.

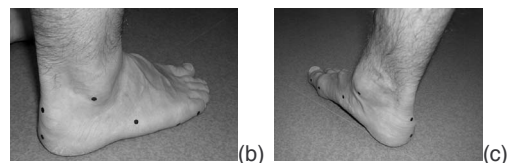
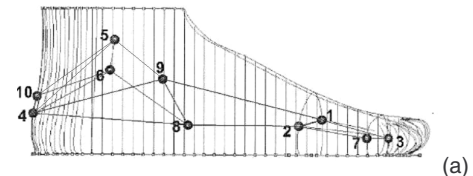


Figure 3. The experimental marker set (a) and an example of the foot prepared with anatomical landmarks (b and c).

Both the left and the right foot of each subject were scanned in 5 different position (A – E). These conditions differed in the position of the acquired limb and in the %BW it bore (Figure 4). They were thought to capture the foot geometry throughout a sequence that could resemble the standing posture and the different phases of the stance. The contribution of mass inertia could not be taken into account, because the 3D scanner did not allow dynamic capturing. However, the adopted solution appeared as being a fair compromise between survey issues and technical needs.