CHAPTER 3

FOOT MEASUREMENT SURVEY METHODOLOGY AND INSTRUMENTATION

3.1 POPULATION GROUPS

3.1.1 General Principles

Adult male and female individuals have visible and measurable differences regarding their body dimensions, but these differences are less or not at all visible among small children. In any case the girls and boys, women and men should form independent groups when conducting an anthropometric survey, i.e. Gender is a major distinct feature (Parkinson and Reed 2009).

A country’s population is normally is a mix of various ethnic, anthropological or geographic groups of people. Nations, tribes, societies have their native origins in terms of geographic locations. Some of them lived isolated in a given territory (e.g. in islands) for thousands of years and did not have any contacts with other human population. Others had been on constant move (e.g. those making their living from hunting), therefore they had intensive contacts with other ethnic groups. Since certain anthropological and related anthropometric features of the human body are genetically coded, different ethnic groups have fairly characteristic features regarding height, weight, proportion of their limbs etc. As a rule larger countries (states) and those being subject to migration have complex ethnic structures. Therefore substantial differences may be between dimensions of the body (including
feet) of people leaving in different geographic regions of the country. It should be noted the size of feet, their form and the arch structure are inherited features. This fact makes even more evident that ethnic groups do have their specialty as far as foot dimensions are concerned.

Such differences should be known when designing comfortable apparel and footwear and supplying these commodities for the local population. For orientation purpose the literature on anthropology and (or) respective specialists should be consulted. Based on this initial information (ethnic and/or geographic) regions should be determined where feet should be measured during the survey (Reed and Dowell 2001).

Another source of differences between body dimensions of people is their lifestyle - with special references to kind of footwear they wear: this is the urbanization effect (Ekezie et al 2011). Generally speaking urban population wears more (in terms of duration and quantity) closed footwear, while people living in villages, under tropic weather conditions walk and work mostly barefoot or wear some very simple sandals leaving their feet (especially the toes) free most of the time. Unfortunately fashion has a negative impact on foot health (e.g. wearing shoes with pointed toe and/or high heel generate serious problems or even defects needing later orthopaedic treatment (Gwatkin et al 1999). Experience shows that there may be apparent differences between foot sizes, their distribution and especially proportions of urban and rural population (Lohman 1988).

3.1.2 The Population in India

The most significant attempt to find a system of racial classification is that of B. S. Guha (Guha 1929). In Guha's system there are six main races with nine subtypes:
1. Negrito

2. Proto–Australoid

3. Mongoloid
   a) Paleo–Mongoloid
      (i) long–headed
      (ii) broad–headed
   b) Tibeto–Mongoloid

4. Mediterranean
   a) Paleo–Mediterranean
   b) Mediterranean
   c) Oriental Mediterranean

5. Western Brachycephals
   a) Alpinoid
   b) Dinaric
   c) Armenoid

6. Nordic

The negrito survives in India among the Andamanese, the Kadans and Palayans of Kerala, the Irulas of Wynad, and the AngamiNagas of Assam and the Rajmahal Hills of eastern Bihar. The Negritos were largely absorbed by the Proto-Australoids. Originating in the west, the Proto-Australoids survive in Dravidian tribal populations and are connected with the tribes of Australia. Long-headed Mongoloids represent a more ancient stratum of the population and prevail among the Assam tribes (Guha 1935). The round–headed Mongoloids are found in Burma and the Chittagong Hills. Tibeto-
Mongoloids are found in Sikkim and Bhutan and appear to be recent arrivals from Tibet. The Paleo-Mediterranean type of medium stature, dark skin, and slight build is found largely in Mysore, Andhra, Chennai, and Kerala (Abe and Tamura 1983). The “true” Mediterranean type is taller and fairer than the Paleo-Mediterranean and occurs in the Punjab and Upper Gangetic valley. This group represents the “civilized” Dravidian people of India who became Aryanized. The Oriental Mediterranean type characterized by a long nose and fair skin is found in the Punjab, Sindh, Rajasthan, throughout India. Dinaric types occur in Bengal, Orissa, Mysore and Madras. Alpinoids predominate in Gujarat, Armenoids occur in dispersed groups along the west coast, in central India, along the Himalayas, in western Uttar Pradesh and Bihar. The nordic types descend from the ancient Aryan invaders and are strongly represented in the northwest frontier, the Punjab, Rajasthan, and the upper Gangetic Valley (Guha 1937). They are also represented among high caste groups scattered throughout the country (Figure 3.1).

![Figure 3.1 Tribal areas in India](image-url)
3.1.3 Sample Sizes

The sample is a relatively small group of people which will be measured during the survey. Since not every foot in the given population will be measured a certain error is expected from the investigations (assuming a normal distribution of foot measurements):

\[ |d| = \frac{\lambda \sigma}{\sqrt{n}} \sqrt{1 - \frac{n}{N}} \]  \hspace{1cm} (3.1)

Where \( d \) is the absolute value of the error due to the sampled survey, \( \lambda \) is a coefficient depending on the confidence level of the statistical investigations, \( \sigma \) is the variance of the measurement, \( n \) is the sample size (number of feet measured), \( N \) is the size of the population (total number of individuals) (Peck and Devore, 2008). Normally the sample is much smaller than the population, i.e. \( n << N \), therefore

\[ \sqrt{1 - \frac{n}{N}} \approx 1 \]  \hspace{1cm} (3.2)

Substituting this Equation (3.2) into Equation (3.1) and taking into consideration that the best estimate for the variance is the standard deviation \( s \), after elementary transformation we receive:

\[ n \geq \left( \frac{\lambda s}{|d|} \right)^2 \]  \hspace{1cm} (3.3)

The latter formula in Equation (3.3) indicates that size of the sample depends on the targeted confidence level \( \lambda \), the degree of deviation within the measured dimension \( s \) and the permitted absolute error of the survey \( d \), but it does not depend on the size of the population (Peck et al 2008).
In practice anthropometric surveys are made at 90% confidence level: for this $\lambda=2$. The value of the standard deviation may either be taken from the latest similar survey or by taking an a very small sample (30-50 people) and measuring only the most significant dimension: the length of feet (Aitken 1999).

The total error should not be more than the unit of measurements used for expressing the characteristic dimension of the foot. Since the smallest unit is a half English size $d\leq 4.23$ mm. We should differentiate the physical error - in our case it is $\pm 0.5$ mm, so the total error of the statistical investigation should be $d\leq 3.23$ mm, i.e. the absolute error should be $|d|\leq 1.63$ mm.

Certain compromises may be required when setting the size of samples (e.g. if too many measurements are taken and the process is too slow or laborious) (Alonzo et al 2002), (Bochmann et al 2007). On the other hand some reserve should be made (i.e. the actually number of feet measured should be somewhat higher than the computed minimum requirements as there may be errors, incomplete data or the feet may be of not “normal character”) (Branscum et al 2006).

### 3.2 THE MEASUREMENT PROGRAMME

After having determined and selected the characteristic geographic areas and having computed the minimum sample sizes appropriate places were selected for taking foot measurements (Campbell et al 2001). The more the number of people accessible in one location the more suitable is the given organization for undertaking part of the survey. In case of children and youth, kindergartens and schools are natural choices as a large number of individuals can be handled in an orderly manner (Casagrande et al 1978). Army stations (barracks) are other places where measurements can be carried out efficiently.
The most difficult thing is to find organizations or companies where a large number of adult female feet can be measured (Connor 1987).

Administrative arrangements were made with authorities (management) of the selected locations and organizations (Daly 1991). This covered timing, organization of flow of individuals, provision of a suitable place for setting up measuring devices and portable computers for data collection (Delucchi 2004). Finally a thorough travel programme was prepared - again with reserves to cover unexpected losses in time (e.g. breakdown of devices, transport problems). It is important to take into consideration local or national holidays to prevent unproductive time during the survey.

3.3 THE MEASURING TECHNOLOGY

The measuring method may range from a fully manual to a well mechanized approach. The manual (or traditional) methods are based on drawing the plantar projection of foot on a sheet of paper and taking its dimensions using simple tools such as liners or measuring tapes. Semi-mechanized methods use plantograms or mechanical devices for determining dimensions of feet. The modern measuring technology takes advantage of high-tech optical, electronic and computer technique. The technology together with the objective of the survey influence also the number and distribution of measurements to be taken from each person (Greenland 1985).

In case of the foot survey made in India the most advanced computerized photometric method and respective equipment were used.
3.4 DATABASE STRUCTURE

The photometric method registers two orthogonal projections of each person’s foot or feet in digitized form on magnetic data storage device of the computer. The plantar (bottom) and the side views of feet can later be displayed on the computer screen and be analyzed to the required details. Beside these graphic data other characteristics such as sex, age, geographic location, body height and weight etc. should also be recorded. Since perimetric data such as ball, waist, heel and ankle girths are indispensable measurements for shoe last and footwear design, they should also be taken (manually) on the spot.

The set of primary data to be collected on the spot should be determined as there will be no chances to collect missing data at later stages of the survey (Kelley et al 2003).

3.5 MEASURING CONDITIONS

The most important condition is the body position of the person while the images of his/her foot projections are taken by the digital cameras, as well as when girths are measured. The person should stand on both feet, whereby the two feet should be placed parallel approximately in a distant equivalent to the shoulder span (width), while the body weight should be equally distributed between the two feet. It is sufficient to measure only one of the person’s feet, and the right feet were measured in this survey.

Mass surveys should be restricted to people having healthy feet, i.e. those who’s feet do not suffer from orthopaedic diseases, the differences between left and right feet are not visible in the first sight, the person can walk and run without any difficulties. A special (orthopaedic) survey may be
launched to analyze orthopaedic deviations from normal feet, but these serve medical purposes rather than industrial.

3.6 **ANTHROPOMETRIC FOOT MEASUREMENT INSTRUMENTATION**

The Foot Measurement System (FMS) was developed for podological studies, i.e. foot surveys aiming at assessing special geometric and orthopaedic properties of one person's feet, as well as for carrying out mass measurement programs to establish size ranges and shoe last standards for a footwear company or even for the customer population of a state or a region. It can be used in research, surgical shoe manufacture, made-to-measure services, retail studies, medicine, demography, criminology etc. The FMS consisted a set of high-tech equipment and specifically designed computer software, coordinated by a well elaborated methodology.

3.6.1 **The Measuring Principle**

The human foot is a complex three dimensional living object covered by free form surface, which changes its exact dimensions during walking, by changing the human body's position, with time and age. The shoe last, the very basic tool used in shoemaking is in fact a model representation of the feet - a kind of average of the given person's or population's feet. Fit and comfort, i.e. consumers' satisfaction - as well as design and pattern engineering, tooling of the production, component supply (coordination) all depend on the successful design of the shoe last. For this purpose very accurate data are required on the geometry of foot.

The heart of FMS is a high precision, fully automated equipment capable of capturing image of the human foot in form of orthogonal projections (Telfer and Woodburn 2010). These images are stored and later
processed by finding their boundaries, determining linear measurements and typical angles according to a predefined network. Along with the foot shape, a set of body characteristics (e.g. age, weight, height, working conditions, geographical region) are registered by the system. These data are used for the sophisticated mathematical–statistical analysis of the given or selected population. Based on the results of earlier mass foot measuring projects, the program system of the FMS applied an essentially new method for data sampling. This method is the “video digitizing” methodology (Robinette et al 1999).

Two video cameras were used to monitor the measured object from orthogonal (bottom and side) positions. The live pictures were grabbed and digitized. The digitized data were stored as “picture-files”, ready for later computer procedures of data retrieve. These procedures included the transformation of pixel-graphic picture-file into a vectorized data stream describing the contour of shapes. The curve of this contour was analyzed by mathematical methods and the measuring data, e.g. sizes, distances, angles were retrieved from the computer (Luximon and Goonetilleke 2004).

3.6.2 The Hardware

The data collection hardware of the FMS consisted of the Foot Measurement Unit (FMU) and a set of portable microcomputers controlling the image capturing and data collection process (Figure 3.2). The FMS is portable, so data collections related to determining shoe size ranges, children feet variation by geographic regions or age groups etc. can be carried out on the spot with minimum efforts wasted in setting up the system (Redaelli et al 2006).

The FMU looks very much like a trunk - in fact the lighting and the primary image capturing devices are mounted in a sturdy, inside well-padded
luggage providing reliable conditions for transporting. When opened shields surround the heavy glass surface where the foot is placed and the person can put all or portion of his/her body weight on that foot. The foot projections appear on the screen of the Image Processing Unit (IPU). The light sources are halogen lamps armed with special coloured filters. The amount of lights used in image capturing process is set from the Control Unit (CU) linked to the IPU. Two digital cameras also controlled by the IPU through the CU captured the projections of the foot. After having ensured that the picture quality meets the quality requirements the image was saved on the hard disk of the IPU. The image files were also copied to a backup drive as well (Witana et al 2006).

The Data Processing Unit (DPU), is in fact a portable computer integrated into FMS to collect personal data entered through its keyboard and/or collected from the optional electronic devices such as a balance to take body weight and a height measuring unit. Both the DPU and IPU are equipped with barcode readers to take the identity numbers assigned to the persons measured (these are especially useful in mass measurement surveys where unique labels are attached to each person).

All hardware components are portable. Moreover they are mounted into a comfortable transport system which also served as stands during the measurement process. The complete FMS could easily be placed in the booth of a personal car. The entire system is connected to the source of electric power through the Universal Power Supply (UPS) providing continuous and stable power for each unit integrated in the system (this is again useful in areas where the power supply is unreliable).
3.6.3 The Firmware and Software

The FMS consisted of four packages of computer programs. The FootGrab program *controls the image capture process*: takes the identity number (from barcodes or from the keyboard), sets the amount of lights and controls the digital cameras through the CU, stores the images on hard disk and produces backups on tape. The FootDat program takes also the identity number, *collects personal data* keyed in through the keyboard or received from measuring devices - all in standard database format (Goonetilleke et al 2009).

A separate programmed package FootProc was designed for *processing images* stored on backup devices. The views of the feet are brought to the screen and then linear measurements were taken from it. The view contours and a set of these measurements such as foot length, distance between the heel and the small toe, heel and forepart widths, toe angles and heights etc. were captured automatically. Furthermore the system had the flexibility for the operator to take any additional linear measurements and angles using the mouse of the system. All this numeric information was added to the database consisting personal data.

The *mathematical analysis* of all collected data was made by the fourth computer program FootStat. It sorted the data, created groups (e.g. age, geographical regions, occupation), computed statistical parameters, carried out correlation and regression analysis and it also consists of a cluster analysis module. The results included age and size groups, recommended size grading parameters for various sizing systems, data to be used in shoe last and footwear design and pattern engineering. The “by product” produced by the system was a set of information which would be useful in orthopaedics, demography, anthropology, ergonomy and many other areas of the science and technology (Nácher et al 2006).
All the above mentioned modules are interactive, menu driven and are capable of producing a variety of printed and plotted output.

3.6.4 Composition of the System

Figure 3.2 The Foot Measurement System (FMS)