Shape Modeling: From Linear Anthropometry to Surface Model

Ameersing Luximon
Institute of Textiles and Clothing
The Hong Kong Polytechnic University
Hong Kong
tcshyam@polyu.edu.hk

Huang Chao
Institute of Textiles and Clothing
The Hong Kong Polytechnic University
Hong Kong
huang.chao@connect.polyu.hk

***Abstract*— Due to technological innovations, there is a shift from linear anthropometric measures to surface model. This is essential since body surface information is needed in medical, archaeological, forensic and many other disciplines. As a result, there is a need to shift from linear anthropometry tables to surface anthropometry databases. This study provides a general modelling technique, to convert linear anthropometry to complex surface anthropometry using recursive regression equations technique (RRET) and scaling technique. In order to build the model, scanned data of a 3D body part for a selected population is needed. After scanning, the parts are aligned along a reference axis before extracting cross-sections perpendicular to the reference axis. Using the cross sections, a 'standard' part is computed based on an averaging method. The 'standard' part provides the shape information of a given population and thus it can be stored in a database for shape prediction. Using the recursive regression equations technique, regression equations are constructed based on selected anthropometric measures of each cross section. During 3D part shape prediction, only few anthropometric measures are used and the anthropometric measures of all the other cross sections are predicted recursively using the equations developed from RRET. Eventually, the predicted measures are used to scale the 'standard' part in order to generate a predicted 3D shape of the selected part. Previous studies published by our team on foot shape modelling have given accurate results of about 2mm. Thus, depending on different applications, this technique can be applied to generate 3D shape from anthropometry and can be applied to reconstructive surgery, forensic, anthropology, design, psychology and other fields.**

Keywords-anthropometric; surface antropometry; recursive regression equation.

I. INTRODUCTION

According to the World Health Organization [1], anthropometry, a method to assess the size, proportions and compositions of the human body using simple equipments, is universally applicable, inexpensive and non-invasive. Anthropometry, even though dating back to Renaissance [2], emerged in the nineteenth century largely by German investigators in the physical anthropology discipline, while they needed to study the quantitative description of the human body reliably [3, 4]. The basic anthropometric techniques were developed during that time and they are still used today [3]. The different anthropometric measures are represented in percentile values in anthropometric tables [2, 5] and since the values are statistical values, they cannot be combined to create a single human body [6]. The anthropometric percentage values are generally used to compare different populations and to design for a given population. Anthropometric data has been widely used in fields ranging from engineering to arts. It has been used in equipment and workplace design [6, 7], forensic investigation [8, 9], growth and nutrition evaluation [4, 10], medicine [11-13], archaeology and cultural studies [14-16], and sports science and fitness evaluation [17-19]. Anthropometric studies have been widely carried out because of its non-invasiveness [1], inexpensiveness [4], simplicity [1], portability [20] and reliability [21]. Furthermore, as the anthropometric dimensions vary among different groups of population, anthropometric tables have been developed based on age, race, region, and occupation [2]. Even though, there are many studies on anthropometry, most of the tables have only linear anthropometric data. Since surface geometry is required in many applications, more research is required to enhance the existing data on linear anthropometry.

Surface anthropometry describe the size and shape as well as the 3D surface geometry of the human body [22]. It is possible to combine surface scan data and internal measurements [23], thus anthropometric techniques can be used to find the size, shape and proportion of the external as well as internal structures of the body. Thus in this modern world, data collected from Magnetic Resonance Imaging (MRI), Computed Tomography (CT) or Computed Aided Tomography (CAT), sound, optical (laser or structured light) or any scanning devices can be used to create surface anthropometry of the external as well as the internal structures of the body. Since surface anthropometry provides information on the complex surfaces of the human parts, in addition to the common linear anthropometry measures, it can be used for many applications such as planning and assessment of facial surgery, design and manufacture of implants and prostheses, facial reconstruction in forensic applications, archaeology, psychology, genetics, and comparative and evolutionary anatomy [24]. In addition, there are growing uses of synthesize 3D digital animated images of human models in science fiction movies and 3D digital dummies for equipment testing [25]. Although surface anthropometry seems to be very useful, it has several disadvantages. Surface scanning equipment is relatively expensive and is not widely available. It is relatively difficult to operate and require special skilled technicians to capture the dynamic and complex body shape. Furthermore, the data obtained from the scanning equipment requires additional processing and statistical data analyses are not trivial resulting in only few large-scale studies. Still, surface anthropometry is very useful for different applications and there is a need to simplify the method to acquire surface anthropometry, reduce the cost of equipments and develop surface anthropometry databases. In this study, a method to predict accurately the surface anthropometry by using simple, reliable and non-invasive linear anthropometry measurement techniques are proposed. As a result, the use of expensive surface scanning devices is minimized to model building and simple cost effective linear anthropometry measures can be used for surface anthropometry prediction.

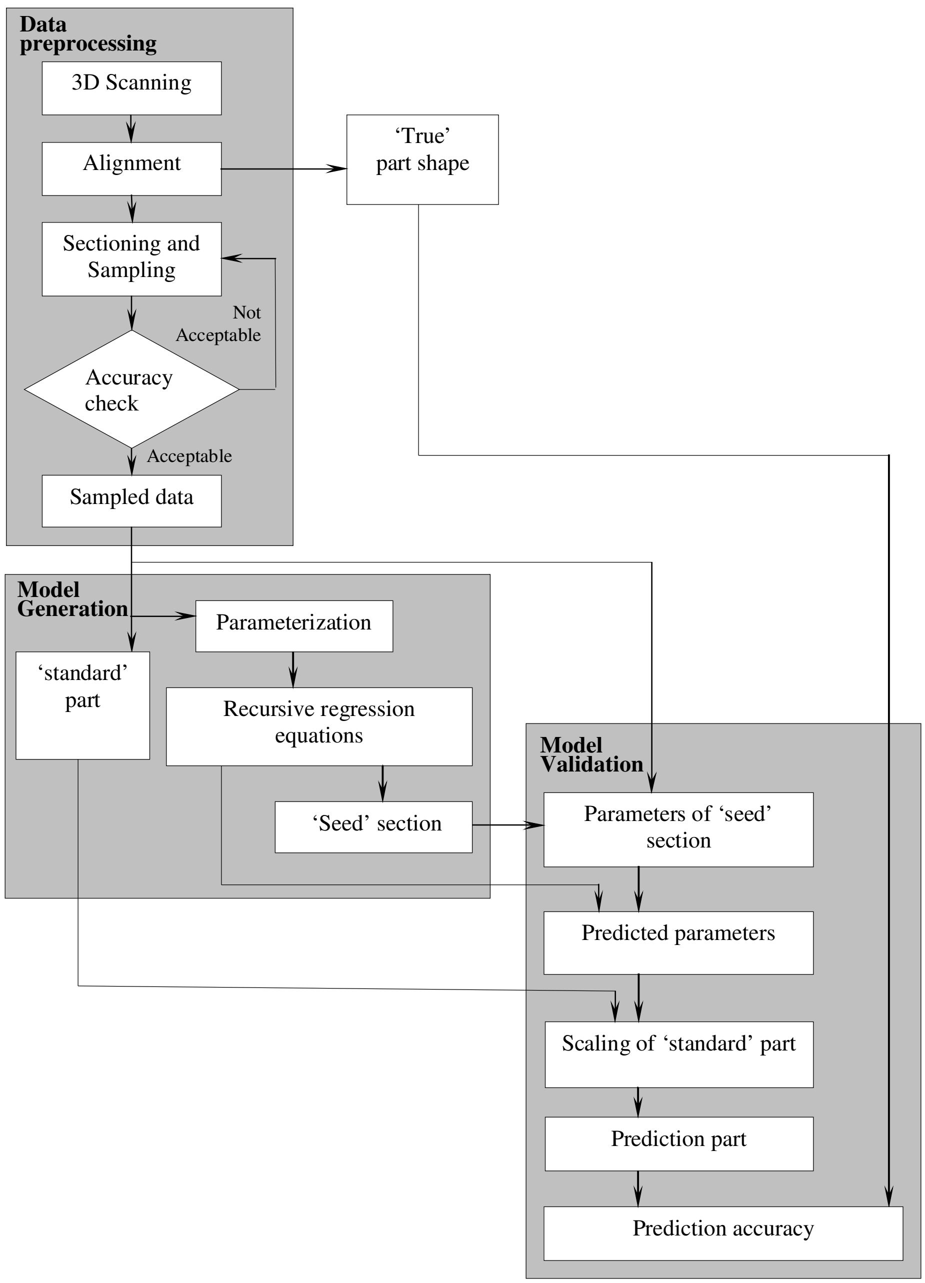

Figure 1. Flowchart of the prediction model.

Copyright (c) IARIA, 2013. ISBN: 978-1-61208-250-9

Surface anthropometry prediction involves spline curve and surface fitting [26], recursive regression equations [27, 28] and scaling techniques [27]. Luximon and Goonetilleke [28] have used the RRET technique and proportional scaling to predict the feet of Hong Kong Chinese to an accuracy of less than 2.5 mm, while using only four anthropometric parameters and a 'standard' foot. Since RRET and scaling techniques seems to provide an accurate method for shape prediction, in this study, a general prediction model with several variations is provided so that more body parts can be predicted using this simple method. The flow chart for the development and validation of the prediction model is shown in Figure 1. The main parts are data pre-processing, model generation and model validation. Data pre-processing includes scanning, and alignment and sampling. Model generation includes creation of a standard shape, section parametization, and generation of regression equations between the parameters. Validation includes checking of accuracy based on a different data set. These are discussed in details in the following sections.

II. DATA PRE-PROCESSING

A. 3D scanning

For 3D scanning, any type of scanner to capture the external shape of the body (Figure 2) or any specific part can be used. Since a general method to build the prediction model has been proposed, some changes may be required to adopt for specific parts. It is assumed that N_s number of participants is used for the model development. In this formulation, left and right sides of the parts are not distinguished, but during the formation of a specific part, the differences between left and right sides can be included as in Luximon and Goonetilleke [28]. For the i^{th} participant the scanned part has P_i number of points. The points are p_{ik} (where $i = 1,...,N_s$; $k = 1,...,P_i$). The coordinates of the point p_{ik} is (x_{ik}, y_{ik}, z_{ik}).

Figure 2. Laser scanned data

B. Alignment and sampling

Since all the scanned part might not be aligned in the same reference axis, all the parts have to be aligned on a consistent axis. The axis of alignment can be based on some anthropometric landmarks, commonly used axis or based on mathematical and statistical methods (such as principle component methods). For example, for the case of the human foot, heel centre line is commonly used [27-29]. For the arm, leg and body principal component can be used. For head data, eye location can be used for alignment. After alignment, the coordinates of point ${}_ap_{ik}$ is $({}_ax_{ik}, {}_ay_{ik}, {}_az_{ik})$ as shown in figure 3. The part is aligned to have the axis with the highest variation along the Z-axis.

Once the part has been aligned, cross sections are extracted perpendicular to the Z-axis, called the 'main' axis. The length of the aligned part along the main axis is L_i (where $i = 1,...,N_s$). Cross-sections perpendicular to the main axis at δ_j (where $j = 1,...,N_{sec}$) of L_i are extracted, where N_{sec} is the total number of cross-sections extracted (Figure 4). δ_j is monotonically increasing with j. The separation between the sampled cross sections need not be uniform, but it has to be consistent between the different participants. The extracted sections are S_{ij} (where $i = 1,...,N_s$; $j = 1,..., N_{sec}$) and the z-value for the sections are given by (1). Then, for each section, a fixed number of points are extracted using different sampling methods [28]. The number of points for section S_{ij} is sN_j. For participant I, the number of points is same. The points after sampling are ${}_sp_{ijk}$, where $i = 1,...,N_s$; $j = 1,..., N_{sec}$; $j = 1,..., sN_j$.

$$ {}_sz_{ij} = \delta_j * L_i \qquad (1) $$

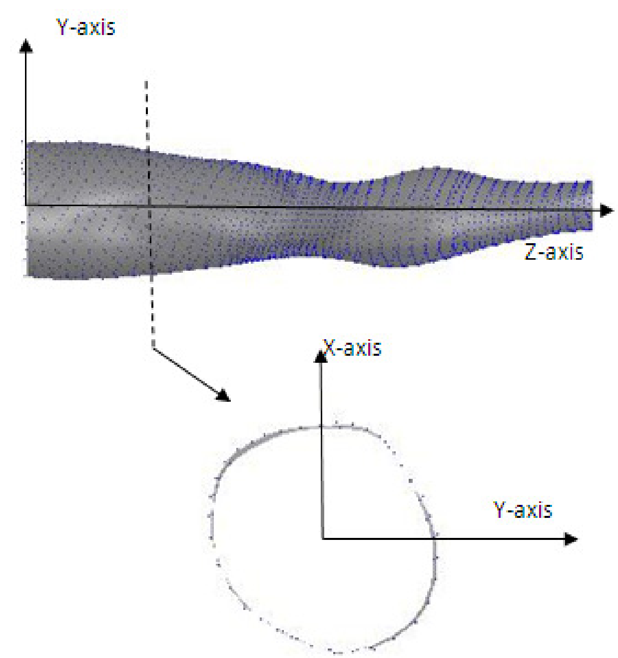

Figure 3. Alignment method

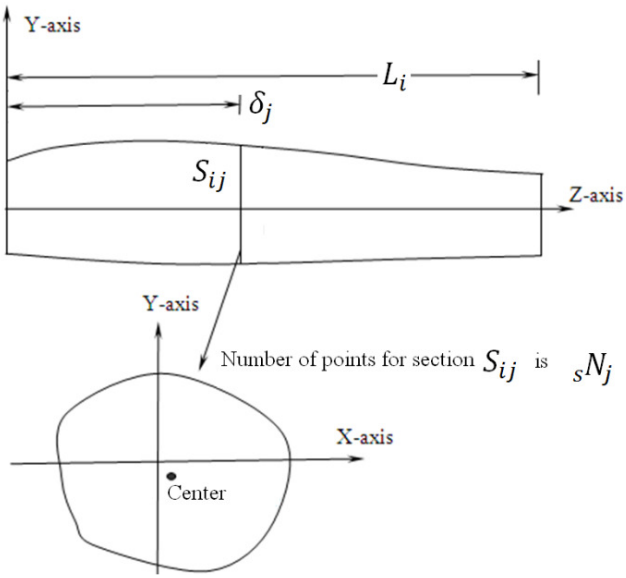

Figure 4. Sectioning and sampling

III. MODEL GENERATION

A. 'Standard part'

Some of the part shape data can be used to generate the model, while other shape data can be used for model validation [28]. Assuming that the "standard" part is generated using part shape data of N_m subjects where $N_m < N_s$. The coordinates of the point used to generate the standard part are ($_sx_{ijk}$, $_sy_{ijk}$, $_sy_{ijk}$) where where $i = 1,...,N_m$; $j = 1,..., N_{sec}$; $j = 1,..., sN_j$. The 'Standard' part is the representation of the given part for a given population. There can be several methods to generate the 'standard' part, based on different statistical methods such as geometric mean, arithmetic mean, mode, median, etc. Equations (2), (3), and (4) show the x, y, and z coordinates of the 'standard' part when arithmetic mean is used. The standard foot shape has N_{sec} number of sections.

B. Parametization

$$\bar{x}_{jk} = \frac{1}{N_m} \sum_{i=1}^{N_m} {}_sx_{ijk} \tag{2}$$

$$\bar{y}_{jk} = \frac{1}{N_m} \sum_{i=1}^{N_m} {}_sy_{ijk} \tag{3}$$

$$\bar{z}_{jk} = \frac{1}{N_m} \sum_{i=1}^{N_m} {}_sz_{ijk} \tag{4}$$

The 'standard' part represents the shape of a given population and it can be stored in a database. While the 'standard' part is being developed, parameters can be extracted from the cross sections of the aligned part.

Each cross section can be parameterized using several anthropometric variables [27]. Figure 5 shows some of the parameters that can be used, such as maximum y deviation (H^+), minimum y deviation (H^-), maximum x deviation (W^+), minimum x deviation (W^-), height (H), width (W) and radius (R_θ) at θ degrees and circumference (C). The number of parameterization will determine the accuracy and complexity of the model. Furthermore, anthropometric studies are needed to determine the importance of the different parameters. Goonetilleke et al. [30] and Luximon and Goonetilleke [31] have used principle component and factor analysis to find the relative importance of different foot related parameters.

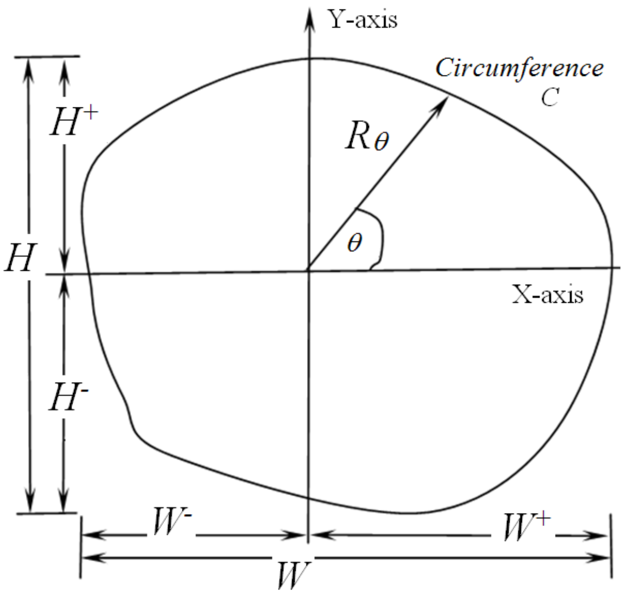

Figure 5. Anthropoemtric parametization

C. Reccursive regression equation

The purpose of the recursive regression equation is to find the relationship of the anthropometric dimensions of all the sections of the part given the anthropometric dimension of one section. For example, one regression equation is build from anthropometric measure height (H) at section i and height at section j. The R^2 values are also recorded. If we have Na anthropometric measures and N_{sec} sections, we can generate N_a x (N_{sec} - 1) equations if we consider consecutive sections. Using these regressions equations, knowledge of one set of values for N_a anthropometric measures ('seed section), we will be able to predict all the N_a x N_{sec} anthropometric measure values. There are a number of ways to find the best 'seed' section and build the regression equations. Luximon and Goonetilleke [28] developed linear regression equations between the anthropometric measures of adjacent sections. The best 'seed' section was found by using different 'seed' section to predict the anthropometric measures and choosing section that provided the highest correlation between the original set of anthropometric measures. For complex models N_a x (N_{sec} -1) x (N_{sec} -2) equations may be needed. This problem can be solved using travelling salesman method [32].

IV. Model validation

The model can be validated using 3D scanned data of a different set of N_v participants where $N_v < N_s$ and $N_v + N_m = N_s$. The model validation involves measurement or extraction of parameters of the 'seed' section, prediction of parameters of all the section based on the 'seed' section, scaling of the 'standard' part. Once the shape is predicted, the prediction error can be calculated when we compare it with the original data.

Once we have the predicted parameters of the sections, the standard part has to be scaled. There can be different scaling methods based on the different parameters. Luximon and Goonetilleke [28] have discussed proportional scaling. If the parameters are orthogonal (such as width and height) then the sections can be scaled independently (figure 6). However, if the parameters are not orthogonal different scaling methods need to be developed. After scaling the predicted shape has coordinates $({}_px_{ij}, {}_py_{ij}, {}_pz_{ij})$.

For participant i the original shape after alignment has coordinates $({}_ax_{ik}, {}_ay_{ik}, {}_az_{ik})$ where $k = 1,...,P_i$. The coordinates of the predicted foot is $({}_px_{ij}, {}_py_{ij}, {}_pz_{ij})$ where $i = 1,...,N_m$; $j = 1,..., N_{sec}$; $j = 1,..., sN_j$. The error is computed based on the shortest distance from the predicted foot to the real foot [33]. Different statistics can easily be calculated to compare prediction accuracy. Error plots are also useful to show the error distribution at different regions [28].

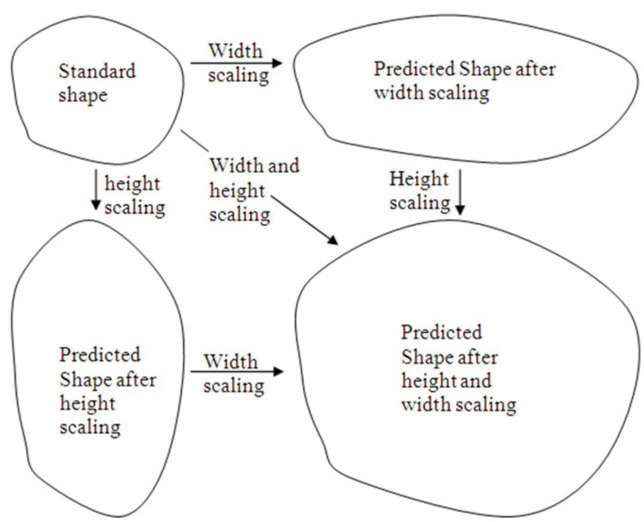

Figure 6. Scaling

V. Discussion

Anthropometric measures are widely used and due to recent advances, there are many types of equipment (3D scanners) to capture surface anthropometry. However, 3D scanners are relatively expensive and are available at few labs. It requires qualified personnel to operate and provides huge number of data points that are sometime difficult to manage. On the other hand, linear anthropometrics have existed for centuries and it is relatively very easy to measure linear anthropometric dimensions. For instance, if we want to buy custom-made shoes through the internet, it is much easier to provide few anthropometric measures (such as length, width, height, heel width, etc) than to scan the foot and provide thousands of points on the surface of the foot. As a result, methods need to be developed to capture the advantages of linear anthropometry as well as surface anthropometry. In this study, a general model was proposed to generate surface anthropometry from linear anthropometry and standard shape. The standard shape can be stored in databases based on age, sex, race and gender. When there is a need to reproduce a 3D shape of a part, there is no need to scan the part. Instead, few anthropometric measures of the part can be used to modify the standard to create accurate 3D shape of a part without the need for expensive scanning. The method has been validated for foot modelling [27, 28] and thus it can be applied to other parts of the body. The model can be modified for specific applications. Results from past studies [28] have shown that recursive regression equations technique (RRET) is a useful technique. The technique has been used for foot shape prediction.

VI. Conclusion and future work

As there are more and more technological innovations, there is a shift from linear anthropometric measures to surface anthropometric data in order to satisfy the ever-changing needs of the society. People are constantly looking for comfortable and 'proper' fitting wearable that not only match the linear anthropometric dimensions but also accommodate the complex surface of the body. In addition, more surface information is needed in medical, archaeological and forensic disciplines. As a result, the linear anthropometric table even though useful is not able to satisfy with the current needs. Thus, in order to have accurate information on body dimensions, surface anthropometry database has to be developed. Since data for linear anthropometric is widely available based on age, race, region, and occupation and methods to capture linear anthropometry are non-invasive, inexpensive, simple, portable and reliable, it is wise to use linear anthropometry to generate surface anthropometry. This study provided a general modelling technique, to convert linear anthropometry to the complex surface anthropometry. Simple recursive regression equations technique and scaling technique were used to build the prediction model. Model building involved data collection, alignment, cross sectioning, point sampling, averaging and regression equations development. Once the model has been built, given few anthropometric measures, the 'standard' part can be scaled to generate a predicted 3D shape. Studies in foot modelling have shown that this method can predict the foot shape accurately (≈ 2 mm) using only 4 parameters [27, 28] including length, width, height and curvature. The accuracy of the predicted shape will generally be better if many anthropometric measures are used. The model parameters can be adjusted to obtain the required accuracy depending on different applications.

Future plan for this study includes modelling different body parts at based on different accuracy level and

Copyright (c) IARIA, 2013.

improvement of this technique by including selected sections. The application of this study is in reconstructive surgery, forensic, anthropology, design, psychology, and other fields involving digital human models.

ACKNOWLEDGMENT

This study was supported by RGC General Research Fund (B-Q26V).

REFERENCES

[1] WHO, Physical Status: The Use and Interpretation of Anthropometry, Technical Report No 854, World Health Organization, Geneva, 1995.

[2] S. Pheasant, Bodyspace: Anthropometry, ergonomics, and the design of work, London: Taylor and Francis, 1996.

[3] A. R. Tilley and Henry Dreyfuss Associates, The measure of man and woman: human factors in design, New York: John Wiley and sons, 2002.

[4] F. E. Johnston, "Anthropometry," in The Cambridge encyclopaedia of human growth and development, S. J. Ulijaszek, F. E. Johnston and M. A. Preece, Eds. Cambridge: Cambridge University Press, 1998, pp. 26-27.

[5] M. H. Al-Haboubi, "Statistics for a composite distribution in anthropometric studies," Ergonomics, 40, 1997, pp. 189-198.

[6] W. E. Woodson and D. W. Conover, Human engineering guide for equipment designers (2nd ed.), California: University of California Press Berkeley, 1964.

[7] K. Gielo-Perczak, "The golden section as a harmonizing feature of human dimensions and workplace design," Theoretical Issues in Ergonomics Science, 2, 2001, pp. 336-351.

[8] A. Ozaslan, M. Y. Iscan, I. Ozaslan, H. Tugcu, and S. Koc, "Estimation of stature from body parts," Forensic Science International, 132, 2003, pp. 40-45

[9] M. Henneberg, E. Simpson, and C. Stephan, "Human face in biological anthropology: Craniometry, evolution and forensic identification," in The human face: measurement and meaning, M. Katsikitis, Ed. Boston : Kluwer Academic Publishers, 2003, pp. 29-48.

[10] K. R. Fontaine, G. Gadbury, S. B. Heymsfield, J. Kral, J. B. Albu, and D. Allison, "Quantitative prediction of body diameter in severely obese individuals," Ergonomics, 45, 2002, pp. 49-60.

[11] O. Giampietro, E. Virgone, L. Carneglia, E. Griesi, D. Calvi, and E. Matteucci, "Anthropometric indices of school children and familiar risk factors," Preventive Medicine, 35, 2002, pp. 492-498.

[12] N. N. Prasad and D. V. R. Reddy, "Lip-Nose complex anthropometry," International Journal of Cosmetic Surgery and Aesthetic Dermatology, 4, 2002, pp. 155-159.

[13] R. Z. Stolzenberg-Solomon, P. Pietinen, P. R. Taylor, J. Virtamo, and D. Albanes, "A prospective study of medical conditions, anthropometry, physical activity, and pancreatic cancer in male smokers (Finland)," Cancer Causes and Control, 13, 2002, pp. 417-426.

[14] B. Bogin and R. Keep, "Eight thousand years of economic and political history in Latin America revealed by anthropometry," Annals of Human Biology, 26, 1999, pp. 333-351.

[15] R. Floud, "The dimensions of inequality: Height and weight variation in Britain, 1700-2000," Contemporary British History, 16, 2002, pp. 13-26.

[16] T. K. Oommen, "Race, religion, and caste: Anthropological and sociological perspectives," Comparative Sociology, 1, 2002, pp. 115-126

[17] T. Reilly, J. Bangsbo, and A. Franks, "Anthropometric and physiological predispositions for elite soccer," Journal of Sports Sciences, 18, pp. 669-683.

[18] P. Tothill and A. D. Stewart, "Estimation of thigh muscle and adipose tissue volume using magnetic resonance imaging and anthropometry," Journal of Sports Sciences, 20, 2002, pp. 563-576.

[19] M. Westerstahl, M. Barnekow-Bergkvist, G. Hedberg, and E. Jansson, "Secular trends in body dimensions and physical fitness among adolescents in Sweden from 1974 to 1995," Scandinavian Journal of Medicine and Science in Sports, 13, 2003, pp. 128-137.

[20] C. M. Worthman, "Recumbent anthropometry," in The Cambridge encyclopaedia of human growth and development, S. J. Ulijaszek, F. E. Johnston and M. A. Preece, Eds. Cambridge: Cambridge University Press, 1998, pp. 29.

[21] S. Ulijaszek, "Measurement error," in The Cambridge encyclopaedia of human growth and development, S.J. Ulijaszek, F.E. Johnston and M.A. Preece, Eds. Cambridge: Cambridge University Press, 1998, pp. 28.

[22] P. R. M. Jones and M. Rioux, "Three-dimensional surface anthropometry: Applications to the human body," Optics and Lasers in Engineering, 28, 1997, pp. 89-117.

[23] V. A. Deason, "Anthropometry: The human dimension," Optics and Lasers in Engineering, 28, 1997, pp. 83-88.

[24] A. D. Linney, J. Campos, and R. Richards, "Non-contact anthropometry using projected laser line distortion: Three dimensional graphic visualization and applications," Optics and Lasers in Engineering, 28, 1997, pp. 137-155.

[25] D. B. Chaffin Digital human modeling for vehicle and workplace design, Warrendale, PA: Society of Automotive Engineers, 2001.

[26] B. K. Choi, Surface modeling for CAD/CAM: Advances in industrial engineering, Vol. 11, (Amsterdam: Elsevier). 1991.

[27] A. Luximon, Foot shape evaluation for footwear fitting, Unpublished PhD thesis, Hong Kong University of Science and Technology, Hong Kong, 2001.

[28] A. Luximon and R. S. Goonetilleke, 2003, "Foot shape modeling," Human Factors: The Journal of the Human Factors and Ergonomics Society, 46(2), 2004, pp. 304-315.

[29] R. S. Goonetilleke and A. Luximon, "Foot flare and foot axis," Human Factors, 41, 1999, pp. 596-607.

[30] R. S. Goonetilleke, C-F. Ho, and R. H. Y. So, "Foot anthropometry in Hong Kong," Proc of the ASEAN 97 Conference, Kuala Lumpur, Malaysia: ASEAN, 1997, 81-88.

[31] A. Luximon and R. S. Goonetilleke, Dimensions for footwear fitting, Proc of the International Ergonomics Association 2003 conference, Seoul, Korea, 2003, (CD-ROM).

[32] G. Gregory and P. P. Abraham The traveling salesman problem and its variations, Boston : Kluwer Academic Publishers, 2002.

[33] Luximon, R. S. Goonetilleke, and K. L. Tsui, "Foot landmarking for footwear customization," Ergonomics, 46, 2003, pp. 364-383.