

3-D SURFACE ANTHROPOMETRY

accurate determination of body dimensions

H.A.M. Daanen
TNO Human Factors Research Institute
P.O.Box 23, 3769 ZG Soesterberg
Email: Daanen@tm.tno.nl

Abstract - Body dimensions of the user population have to be the starting point of design and evaluation of many workplaces and products. Insufficient attention to these aspects may lead to uncomfortable, unhealthy, or dangerous situations. Few up-to-date anthropometric databases are available. The shortage of anthropometric databases may in part be attributed to the time consuming and expensive traditional measurement techniques. 3-D surface scanning seems a good alternative: it is cheaper for large scale surveys, fast, reliable and yields reproducible results. Some challenges remain: reduction of human movement artifacts, optimisation of body postures during the scan, development of dedicated software to process the data. The whole body scans have applications mainly in three areas: improvement of fit of clothing and equipment, improvement of workplace design and evaluation, and a variety of medical applications. It can be expected that in the near future new and comprehensive databases of human dimensions emerge.

INTRODUCTION

For the design or evaluation of many products information is needed on the user population and the task to be performed with the product. In particular the body dimensions of the user have to be known. Data sets with recent and correct body dimensions are rare. This is due to the fact that the collection of these data is labourious and that the actual data change in time. The traditional measurements are performed with manually operated instruments like callipers and tape. The measurements have to be performed and documented very accurately, which costs additional time.

Data sets of the military population are available, although limited in number and accuracy, but there is almost no data set available of the civilian population of any Western country (Kroemer, 1993). The absence of adequate anthropometric data sets leads to guesses and approximations. For instance, new data sets are drawn from old ones, using transformation formulas.

The use of outdated data sets generally leads to underdimensioned products, because most populations continue to increase in body dimensions. Ellens (1991) described an underdimensioned cockpit in which the tall Dutch pilots were having serious problems. The lack of leg space forced the ankles in a strong dorsal flexion for a long period of time. During the landing a slight relaxation of the ankle would activate the brakes, which unintentionally happened. This led to tyre-bursts during the landing phase.

Design based on current body dimensions only may also be inadequate. The average Dutch 20 years old male becomes over 1.5 mm taller every year (Werkhoven, 1996). Therefore, the estimated body dimensions at the end of the life cycle of the product is a better base for design. For instance, when an aircraft is meant for operation till the year 2020, the stature of the prospected user population may roughly be estimated as 35 mm taller than it is now.

3-D SURFACE ANTHROPOMETRY

At this moment, it is possible to scan (parts of) the human body within seconds. The outside of the human body is captured in 3-D coordinates, which can consecutively be processed. At this moment eight commercially available whole body scanners are identified on the world market. Their scanning times range from subsecond values to about 20 seconds. Fig. 1 shows an example of a whole body scan made by the Cyberware WB4 scanner.



There are large differences in the technical design of scanners. The base principle, however, is almost always identical: an optical triangulation method. For instance, a horizontal laser line is projected on the body which is seen by a digital camera above and below the scanning line. The image on the CCD-chip of the cameras shows a curved line, corresponding to the shape of the body. The distance from the subject to the camera can be calculated from the vertical position of the curve on the CCD-chip.

Fig. 1 A whole body scan

COMPARISON OF 3D-SURFACE ANTHROPOMETRY TO TRADITIONAL ANTHROPOMETRY

The information that is retrieved from 3D whole body scans is different from the data that is gathered by traditional anthropometry. In traditional anthropometry only linear measures are available, like distances or circumferences. The measures are unrelated, e.g., the height at which the chest circumference was determined remains unknown. In 3D-surface anthropometry this information is available. The measurements are independent of the human measurer and are consequently more reliable. Moreover, the surface or volume of body parts can be calculated easily.

One of the greatest advantages of 3D-surface anthropometry over traditional methods is that the measured subjects are permanently available. In traditional anthropometry the subject is measured and then leaves the measurement room. Errors detected afterwards are thus hard to correct. Body scans are stored in the computer and can be retrieved several years later. It can be expected that more sophisticated methods to process whole body scans will emerge in due time. These methods can still be applied to the data sets sampled before.

For large scale surveys, 3D-surface anthropometry will be cheaper due to the reduction in the costs of labour. It is estimated for a survey of 8000 subjects that the costs will be about 50% of the costs of a traditional survey.

A disadvantage of 3D-surface anthropometry is that a large investment has to be made in the technology. Whole body scanners are available in a price range of roughly 150,000 to 400,000 US\$. Moreover, in this early stage of development considerable costs of software development have to be incorporated. For instance, the recognition of body landmarks has to be automated to speed up the measuring process. Nurre (1997) discusses this problem. Some technical issues of whole body scanning have to be resolved. During the scan people have to stand still. However, some sway can not be prevented. Therefore, it was advised to put a positioning device on the head, as is shown in Fig. 1 (Daanen et al., 1997). In this way the forward/backward sway is reduced by about 50% and the standard deviation of the sway is limited to a few millimetres. Another aspect is the positioning of people, so that the coverage of the body is optimal (Brunsman et al., 1997).

It can be expected that the results from 3D-surface anthropometry differ from traditional measures, even if the same parameters are determined. For instance, when the chest circumference is determined manually some soft tissue compression will be present. When the computer calculates the circumference from the 3D scan, this compression is absent. Therefore, one has to be extremely cautious to use traditional and 3D-surface anthropometric datasets simultaneously for a comparison or to assess secular trends (e.g., growth).

MILITARY APPLICATIONS OF 3-D SURFACE ANTHROPOMETRY

Since the 3-D surface scanning technique is relatively new, the entire palette of applications is not yet discovered. However, several publications already indicate existing and future applications in the military field. A miscellany of these publications is given below.

Clothing

Military clothing has to fit the soldier. In most countries the essential dimensions are retrieved from the body manually and converted to sizes of the trousers, vests etc. This process is time-consuming and error prone. For instance, some measurers pull harder on the tape to determine the circumference than others. This causes considerable percentages of returned goods, since the supplied clothing does not fit properly. Telmat succeeded in reducing the total garment stock volume of the French Navy by using a shadow scanner in stead of manual measurements. This led to savings of several ten millions of French Francs (Telmat, Soultz, France). Since scanning is fast, high throughput rates can be attained to process large groups of soldiers.

To investigate the fit of clothing, subjects can be scanned with and without the clothing. The images can be aligned and then the clothing can be made transparent. This technique is shown by Brunsman et al. (1996). One can easily identify the body areas where clothing and body meet and areas where thick air layers are present.

For tight fitting clothing, the body scan can serve as the starting point for individually tailored clothing. The surface can be converted to clothing patterns.

Fit of helmets and protective equipment

Robinette and Whitestone (1994) used a head scanner to optimize the fit of helmets. They scanned heads with and without helmets. The shape of the face was used as a reference to superimpose the two scans. The helmet was then shown transparent (Fig. 3).

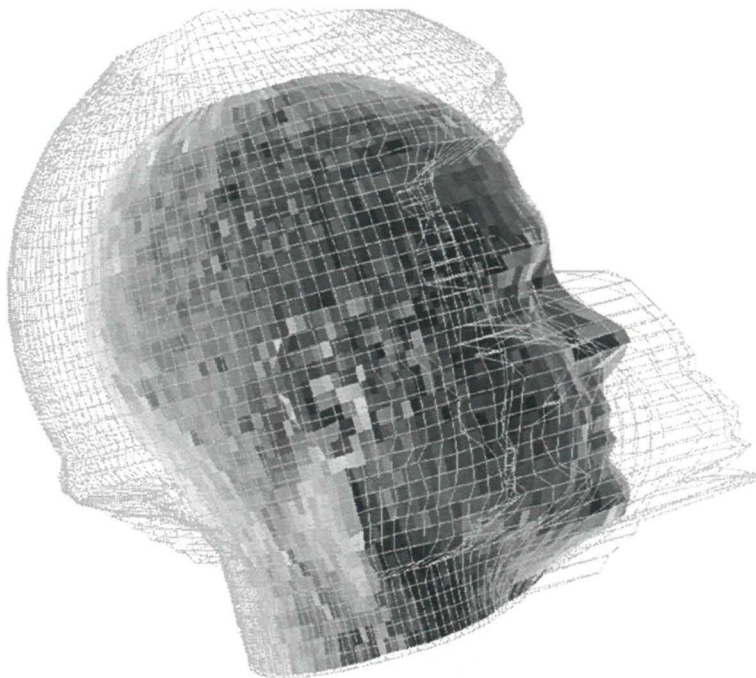


Fig. 3 Transparent helmet on a human head (Courtacy of Mrs. Robinette, WPAFB)

This was done for several subjects and the helmet was taken as the reference. It was shown that the shape of the top of the head and the shape of the helmet were closely related. Traditional techniques used the Frankfurter plane as the reference. With this human centered reference frame, variation in locations of the ears and eyes made it impossible to gain insight in true fit of helmets.

Using the new method, Robinette and Whitestone (1994) found that only two helmet sizes would be sufficient to accommodate the investigated population, instead of the proposed six sizes. The same technique seems fruitful for the determination of fit of glasses, gloves, protective masks, shoes, etc.

Workplace design

The use of 3-D scans to improve workplace design has yet to be started. It is a complex process, and this may explain the absence of literature on this topic.

The first step is to transform the measured values of the human body into a 3-D man model. In order to enable movements, this transformation has to include data about joint positions, joint mobility and interrelations between joints. Much work has to be done to achieve this goal.

In a new design for a workplace controls, displays, furniture etc. have to be shaped around the 3-D man model. For this purpose a variety of computer programs exist. It seems attractive to design under direct visualization (as in a virtual environment), but for this method software is still scarce. If an existing workplace has to be evaluated, the 3-D man model and the workplace have to be combined, for instance in CAD software. The visibility of the displays, reach of the subjects etc. can be evaluated with the computer program.

There are many 3-D man models currently available (such as Jack, Sammie, Antropos and Cadpeople), but the anthropometric background is often not optimal, both static and dynamic. It is unknown if the modelled movement trajectories conform the reality. A comparison of some models by Alexander (1994) shows that there are large differences between the tested models concerning movement trajectories. The Society of Automotive Engineers (SAE) is currently undertaking an effort to validate man models.

In spite of the mentioned difficulties in using 3-D scans for workplace design, it is a promising application, and it seems worth the effort to perform more research in this area.

Virtual environments

The use of virtual environments (VE) for the design and evaluation of workplaces is steadily increasing. The user wears a head mounted display, showing computer generated images to both eyes. Based on head position, the computer continuously calculates the images from the right point of view. Thus, the subjects can look the whole way around and feels immersed in what appears as a more or less real environment.

3-D scans of humans can be transferred to VE, after transformation. The basic 3D surface data would only allow to treat the scanned human as a rigid body. Therefore these data have to be converted to a 3D human model. This model can be rendered (visualized), including colour, lighting and texture.

Using the model, the virtual subject can be adjusted in different positions and the interaction with the environment can be investigated. The observer can walk around the virtual subject, take a closer look, measure distances, look at the posture, access the visual field, investigate the movement space etc. One step further is the construction of animations in VE, in which the virtual subject moves by himself or is live copying the movements of the observer. In this

way the observer can try out the design, in the virtual body of other humans. The connection between 3-D man models and VE may be a handy tool for the design of workplaces.

Medical applications

Most applications of 3-D surface anthropometry in the literature are in the medical area. Jones and Rioux (1997) give a good overview. Some examples are:

- deviations in body shape can be quantified (e.g. enlarged livers, scolioses, warts, skin tumours, progress of wound healing, development of scars)
- a non-invasive global indication of the progress of gravity can be mapped by regular scanning of the belly;
- the results of plastic surgery can be evaluated by comparison of pre-, peri- and postoperative scans; the patient can have a good indication of the expected result; the surgeon can estimate the success of the operation by the comparison of the desired and final result;
- scans can be used to design prosthesis; this includes both the irregular shape of the contact surface and the desired shape of the front end of the prosthesis. After removal of a breast, the prosthesis may have the same dimensions as the removed breast, which may ease the acceptance. In dentistry jackets are instantaneously made from synthetic material and mounted, after scanning the prepared tooth.
- the difference in volume between a thorax scan in inspiration and expiration can be used as an indicator of lung function;
- when serious burning wounds at the face occurred, a good face mask can be manufactured based on a scan (Whitestone, 1995);
- scanned images can be used for education and telemedicine (e.g. anatomy).

CAESAR

Considering the magnitude of applications the 3-D scanning technique seems to offer, AGARD WG 20 proposed a large scale anthropometric survey, called CAESAR, of about 15,000 subjects in three countries: USA, the Netherlands and Italy. The proposal is partly based on a Dutch preparatory study (Lotens et al., 1993). This kind of survey would be very expensive when performed with traditional anthropometric methods. The 3-D scanning technique may increase the efficiency to an extent that the shortage in adequate anthropometric data may be alleviated. In Japan (HQL, 1995) a large scale survey has taken place already, financed by the governmental MITI. About 34,000 Japanese of different age groups have been scanned. The body was scanned in less detail than the head and extremities.

The NATO survey is planned to start towards the end of 1997 and will result in a large database. The database may be used to improve fit of clothing and equipment, and improve the design of machines and workplaces.

References

Alexander T.: Analyse unterschiedlicher anthropometrischer Hilfsmittel zur Gestaltung eines Flugzeugcockpits. Bericht Nr. 110. Forschungsinstitut für Anthropotechnik 1994 (FAT-FGAN), Wachtberg, Deutschland.

Brunsmann, M.A., Daanen, H.A.M., Robinette, K.M.: Optimal Postures and Positioning for Human Body Scanning. Proceedings of the International Conference on Recent Advances in 3-D Digital Imaging and Modeling. Ottawa, Ontario, Canada, May 12-15: 266 - 274, 1997.

Brunsmann, M.A., Daanen, H.A.M., Files, P.: Earthquake in anthropometry: The view from the epicenter. Cseriac Gateway 7(2): 1 - 6, 1996.

Daanen, H.A.M., Brunsmann, M.A., Robinette, K.M.: Reducing movement artifacts in whole body scanning. Proceedings of the International Conference on Recent Advances in 3-D Digital Imaging and Modeling. Ottawa, Ontario, Canada, May 12-15: 262 - 265, 1997.

Ellens E.: P3 Orion: Ergonomics of pedal activation and shoe wear in relation to unwanted brake activation (in Dutch). Report IZF 1991 A-47.

HQL: Report about a project to construct a database for measurement of the human body (in Japanese). Febr. 1995.

Jones, P.R.M., Rioux M.: Three-dimensional surface anthropometry: Applications to the human body. Lasers and optics in Engineering 17, 1997 (in press).

Kroemer K.H.E.: Modelling the human-equipment interface. In: B. Peacock, W. Karwowski (Eds.): Automotive Ergonomics. Taylor & Francis, London, 1993.

Lotens W.A., Brisland C.E.S., Havenith G.: Definition of an anthropometric survey of the Dutch population (in Dutch). Report IZF 1993 C-28.

Nurre, J.: Locating Landmarks on Human Body Scan data. Proceedings of the International Conference on Recent Advances in 3-D Digital Imaging and Modeling. Ottawa, Ontario, Canada, May 12-15: 289 - 295, 1997.

Robinette, K.M., Whitestone J.J.: The need for improved anthropometric methods for the development of helmet systems. Aviat. Space Environ. Med. 1994 65 (5, suppl.): A95 - A99.

Werkhoven, P.J.: Extrapolation of anthropometric data (in Dutch). TNO-report TM-96-A45, 1996.

Whitestone J.J.: Improving total contact burn masks: three-dimensional anthropometric imaging techniques. CSERIAC Gateway 1995 V(3): 1-4.