3D Digital Anthropometric Study on Chinese Head and Face

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Abstract

SizeChina-Hunan collects the latest data of Chinese head and face which will provide critical information for ergonomics. The accurate figure of the human head and face can provide vital advantages by designing wearable products, such as virtual reality (VR) and augmented reality (AR) headsets or safety glasses. However, the complex surface geometry of the human head and face presents a challenge for designers and engineers on account of the traditional ways of anthropometric surveys has numbers of limitations. The anthropometric survey of SizeChina-Hunan makes a combination of the traditional measurement way and high-resolution 3D scanning. The total number of subjects required at each site recruit 275 subjects with individuals ranging in age from 18 to 70 years and two sexes. Consequently, the goal was to recruit 2200 individuals totally ranging in 7 regional location respectively.

Keywords: Chinese head and face, Anthropometry, Ergonomics, 3D

1. Introduction

Various anthropometric surveys containing traditional and 3D anthropometry have been conducted around the world with the aim of improving the design of products or related ergonomics research. Traditionally, anthropometric surveys of the human body using tape and callipers to capture the body's dimensions to compare differences between various cultures [1-3] and to enhance the safety, comfort, and design of wearable products or equipment [1-5].

3D scanning methods provide accurate, fast and standardised measurements that include information concerning the contours and shapes of the subject. 3D human data are readily adaptable to computer-aided design. Extensive 3D anthropometric studies have been undertaken worldwide, including whole-body surveys and measurements of heads and faces. The Civilian American and European Surface Anthropometry Resource (CAESAR) project was the first 3D whole-body surface anthropometric survey to collect both traditional measurements and 3D data on North American and European civilian populations and was conducted for design and engineering purposes [6]. 3D full-body anthropometric surveys of army personnel have been conducted ever since, e.g. the 2012 anthropometric survey of U.S. army personnel [7] and the 2012 Canadian Forces Anthropometric Survey (CFAS) [8]. Human Solutions [9] developed iSize [10], an international body dimensional portal that offers access to body dimensions, size tables and market shares for Germany and France, as well as interactive analyses and the optimisation of in-house product development and production. The North America Size survey [11] conducted large-scale 3D whole-body anthropometric measurements in the United States and Canada to collect human data for apparel and automotive industries. They plan to integrate their results and data into the iSize web portal for research and usability in the future. In China, CNIS (China National Institute of Standardization) is using 3D scanning and subsequent repair techniques to develop estimation formulae for the total human body volume of adult Chinese males from anthropometric measurements [12].

In addition to a full-body scan, there's also a group of survey focused on head and facial scans. Zhuang et al. [13] used advanced 3D scanners to capture the facial shape variability of U.S. respirator users in the NIOSH (National Institute for Occupational Safety and Health) survey [14]. Thierry et al. [15] conducted a 3D anthropometric investigation of head and facial characteristics of Australian cyclists for the design and testing of various head and facial products for the Australian market. The 3D Facial Norms Database [16] is the craniofacial dataset for both the clinical and research communities. A 3D anthropometric survey mapping of the head and face shapes of Dutch children [17] was conducted to design a ventilation mask for young children. There has also been a number of 3D anthropometric surveys on heads and faces done for human facial aesthetics or morphology, e.g. anthropometric investigations of attractive Caucasian women [18] and of North Sudanese individuals from childhood to young adulthood [19].

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2. Scan survey

2.1 Sampling locations

The method for sample size development applied in SizeChina [24] requires the coefficient of variation from a critical dimension in a previous survey. To capture variations in the Chinese population, seven different regional locations spread widely across different regions of the mainland were chosen. The seven selected sites were based on the China population distribution, which were Guangzhou in South China, Hangzhou in East China, Changsha in South Central China, Chengdu in Southwest China, Xi'an in Northwest China, Beijing in North China and Harbin in Northeast China (refer to fig.1).

Figure.1. Sampling locations in China

2.2 Subject demographics

The necessary sample size for anthropometric data collection is based on the variability of the dimensions in question and on the desired accuracy and precision of the final population estimates. The necessary sample size for each of the seven geographic regions was calculated based on the sample strategy used in SizeChina [24].

The sample size development method applied in SizeChina requires the coefficient of variation from a key dimension in a previous survey. The U.S. Army database was used in SizeChina as a substitute because there was no pre-existing head and face surveys of Chinese adults available at that time. For our measurements, a new coefficient can be calculated from a key dimension in the SizeChina survey.

The minimum sample size, n, for each cell was calculated using the following formula:

$$n \geq (1.96 \times CV/a)^2 \times 1.534^2,$$

$$n \geq (3.006 \times CV/a)^2,$$

where 1.96 is the critical value (the z value) from a standard normal distribution for a 95% confidence interval, CV is the coefficient of variation:

$$CV = SD/X \times 100,$$

where X is the mean and SD is the standard deviation of the population for the body dimension in question, and a is the percentage of the desired relative accuracy. Taking the Menton–Sellion length as the key dimension with an accuracy of 1% at the 5^{th} and 95^{th} percentiles, SizeChina calculated their required sample size to be 254.

For our survey, the head circumference in SizeChina was selected as the key dimension for the calculation, which resulted in a new CV smaller than that used by SizeChina; therefore, the corresponding sample size was smaller than that of SizeChina. To ensure the accuracy, however, the project team decided on a larger sample size than that used in SizeChina, 254, for the required sample size in this survey.

Distributing the sample size of 254 between three age categories and two sexes, a total of 43 individuals were required for each category. For ease of communication with local sites, this number was rounded up to 45 individuals for each group. The total number of individuals required at each site therefore increased to 275.

Consequently, the goal was to recruit 2200 (1925 + 275 additional scanned data) individuals ranging in age from 18 to 70 years, with 275 individuals for each regional location. No restrictions were placed on the height, weight or social status of the subjects; however, all the participants at each site needed to be residents whose previous family generations (at least their parents and grandparents) were local residents. All subjects were paid volunteers.

In the end, 275 subjects were scanned at each of the locations to ensure the accuracy and robustness of the processed data. A total of 2200 adult datasets were collected in the seven Mainland China cities (refer to Table 1).

Location	Site Total
Guangzhou	275
Hangzhou	275
Changsha	275
Chengdu	275
Xi'an	275
Beijing	275
Harbin	275
Additional scanned data	275
SURVEY TOTAL	**2200**

Table 1. Sampling Matrix for the SizeChina-Hunan Survey

2.3 Scanning Process

2.3.1 Physical field conditions

The data collection phase involved travelling to the seven different regions in Mainland China to scan 2200 adult subjects using a high-resolution laser scanner. Each of the seven locations varied widely in terms of the physical areas provided for the operations, the organisational support available and the living conditions for visiting staff. However, the specifications provided in advance to each local contract officer defined the minimum type and number of physical areas necessary. Participating sites were financially compensated for their collaboration in the project.

2.3.2 Collection process

The measurement process includes the following steps (refer to Fig. 2):

Introduction and questionnaire survey. A short introduction was presented by the study staff to each subject to explain the project. Participants then filled out a questionnaire that the demographic information such as age, gender and location are recorded

Reference numbering and photography. A reference number assigned to each subject was used to facilitate subsequent data processing; this number was noted on the questionnaire and written on an adhesive label fastened to the participant's upper left shoulder. Consequently, the number can be seen in the photographs and can later serve as a reference if necessary. After fastening the reference number, the subjects posed for high-resolution front view, left and right-side profile photographs taken against a neutral grey backdrop. The photographs serve as a visual reference for comparison against the 3D scans in the event of confusion in the numerical reference system.

Traditional anthropometric measurements. After numbering and photography, the traditional anthropometric measurements were conducted next. The heights and weights of the subjects were measured using an eye-level physician scale and recorded; then, their head widths and head lengths were measured using a spreading calliper and their head circumferences were measured using a tape measure.

Wig cap. Participants were asked to remove any jewellery or accessories that could interfere with the scanning process; then, a wig cap was fitted to the subjects to reduce the effects of their hair and to ensure that the ears and forehead of each subject were completely exposed. In addition, it was necessary for female participants to fix their hair underneath the cap to prevent interference during scanning of the head and neck.

Landmarking. Physical palpation of each subject's face was used to locate bony landmarks on the underlying skull. A total of 20 selected palpation landmarks were labelled directly on each participant's face using 5-mm adhesive-backed red dots to identify the critical positions. The 20 landmarks were the chin, glabella, pronasale, sellion, frontotemporale (left and right), tragion (left and right), infraorbitale (left and right), zygion (left and right), zygofrontale (left and right), superior cymba concha (left and right), otobasion posterius (left and right) and mastoid process (left and right) (refer to Table 2).

Scanning. Participants then had their head and face shapes captured via the laser scanner. During scanning, the participants was asked to sit in roughly similar positions. Each participant was asked to keep their eyes open and to stare at a fixed spot marked on the board and to maintain a neutral and relaxed facial expression during the whole scanning. The scan was implemented using a portable high-resolution 3D scanner, Artec Eva, and a full head and face scan was completed in 1–2 mins.

The data were recorded by a 3D software package (Artec Studio 12 Professional), and each scan was inspected in real time to ensure the quality of the 3D surface; additional captures were obtained as needed.

Data check. After a visual confirmation that the scan was satisfactory, the study staff collected the questionnaire forms from the subjects and confirmed that the forms were properly completed.

Data collected from each person included traditional 1D measurements of weight, height and key head dimensions (i.e. head breadth, head length and head circumference); demographic data (i.e. date of birth, location of birth, age, ethnic group, years living at the current location and the origins of the father, mother, grandfather and grandmother); high-resolution digital photographs of the front and side profiles and the 3D digital scan pieces**.**

Figure.2. Data collection process

3. 3D Data Process

3.1 Data processing

The 2200 raw scans collected during the field scanning required extensive post-scanning processing before they were suitable for use in the extraction of measurements. The data processing includes the following steps (refer to Fig. 3):

Data Alignment. Since every scan file consisted of two or three pieces of head and face surfaces due to the discontinuous capture operation. Those pieces were aligned and combined in one head in Artec Studio 12 professional software.

Noise elimination. The original complete scan data include large amounts of 'scan noise', which consist of extra data points or holes of missing data. In the Artec Studio 12 Professional software package, extra data can be eliminated using 3D editing tools (e.g. eraser, filtration and smoothing brushes), especially the redundant hair on the outside of the wig cap of female subjects.

Global registration. To acquire a complete 3D scan model of the head and face of a subject, the two or three scan pieces in the scan file were aligned and combined to form a complete 3D head using Artec Studio.

Sharp fusion. Due to loss of data in the process of scanning commonly, the final documents may have different size of holes and it is difficulty to completely eliminate redundant data in noise elimination process, so sharp fusion can make the files more complete.

Mesh simplification & hole filling. In Artec Studio, the number of polygons in each remaining scan was reduced from millions to thousands while maintaining the high quality of the mesh to optimise the size of the final file. Then remaining holes in the model were repaired using an advanced 3D processing algorithm.

Mesh smoothing. Excess bump was data grind off by using the smooth brush, in order to make model surface smoother.

Texture mapping. In order to make the model more reducible, a high-quality texture was added to every model and the light in the environment was adjusted to obtain a clear coloured and textured head and face scan model.

Coordinate system unification. Each participant sat in roughly similar positions and kept still. However, there was still some amount of variation in their postures. In addition, the position scans in the software were affected by how the scanner held by the scan expert moved during the scanning process and the change in position when the scan pieces were registration to a large extent. Before the scan landmarks and measurements could be accurately extracted and calculated, it was necessary for all the scans to be reoriented to a common orthogonal coordinate system.

The Frankfurt horizontal is defined as the standardised Frankfurt plane in anthropometrics and was used to align all the scans into a common x, y and z position. In Artec Studio, the operator used the left and right tragions and the left infraorbitale sites to create the XOY plane of the coordinate system based on those three points. Then, on the XOY plane, the coordinate origin was translated to the middle of the straight distance between the left and right tragions, resulting in an X-axis pointing to the right tragion, a Y-axis pointing to the axle wire of the nose and a Z-axis pointing to the top of the head. All the scans were treated using the above procedures so that they were aligned to an identical orthogonal coordinate system.

3D File exporting. After step-by-step processing, each scan model and texture were exported to a single file, consisting of an OBJ scan model file, a JPG texture file and a coloured and textured MTL scan model file, which can be opened by a wide range of commercial and free 3D image visualisation programmes.

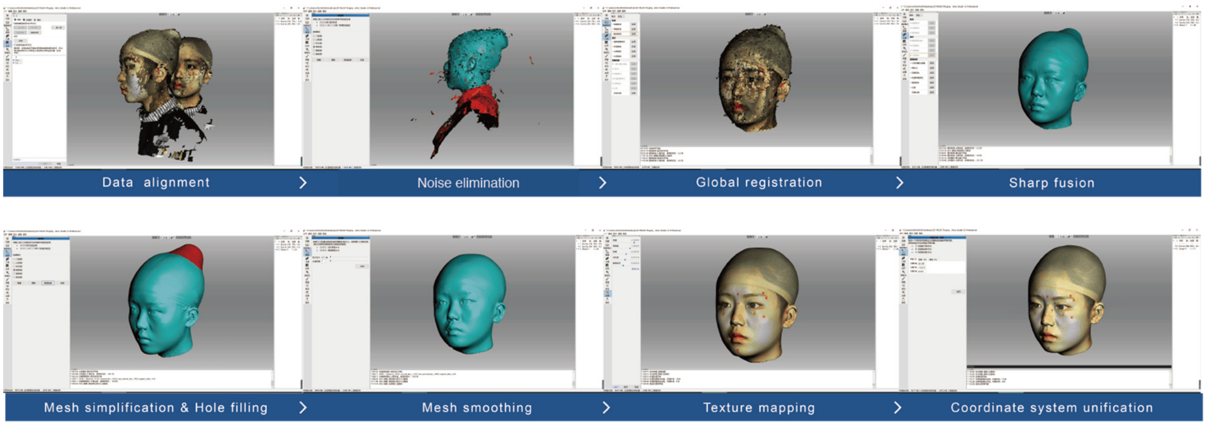

Figure.3. Data processing

3.2 Facial measurement extraction

After the low-quality scans were removed and all the scans were processed and aligned to an identical orthogonal coordinate system, feature extraction and statistics could be performed could be performed.

Landmarks. Each anthropometric study uses different landmarks because no standard exists that defines a consistent set of parameters. In this survey, 33 facial landmarks and 28 ear landmarks were referenced (refer to Table 2). The 20 palpated landmarks were the same as those used in SizeChina and offered a high level of descriptive accuracy, as well as computational economy [32]. In addition, 19 landmarks closely related to the nose and eyes were identified and captured based on identifiable facial features by a post-scanning operator in the Geomagic Wrap 2017 software package with the aim of obtaining additional detailed data for use in the design of eyeglasses.

In Geomagic Wrap 2017, each of the 20 landmarks (refer to Table 2) covered with small adhesive red dots was captured by click and their coordinates were recorded in an Excel file. The 19 additional landmarks (refer to Table 2) were marked on the facial surface of the scan model in Geomagic Studio 2013 at the same time, and their coordinates were written in the same spreadsheet file.

1	vertex
2	glabella
3	sellion
4	pronasale
5	subnasale
6	chin
7	frontotemporale left
8	frontotemporale right
9	zygofrontale left
10	zygofrontale right
11	ectocanthus left
12	ectocanthus right
13	palpebrale superius left
14	palpebrale superius right
15	entocanthion left
16	entocanthion right
17	nasal root point left
18	nasal root point right
19	palpebrale inferius left
20	palpebrale inferius right
21	infraorbitale left
22	infraorbitale right
23	zygion left
24	zygion right
25	alare left
26	alare right
27	otobasion superius left
28	otobasion superius right
29	tragion left
30	tragion right
31	otobasion inferius left
32	otobasion inferius right
33	menton

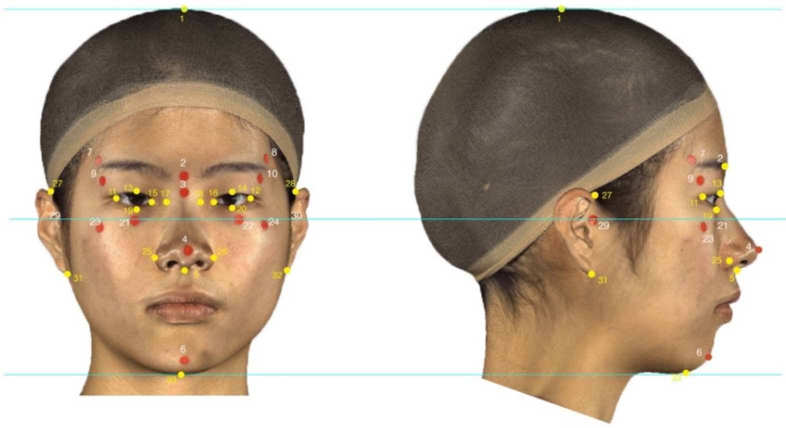

Table 2. 33 Landmarks on the head, face and ears

Measurements. For facial anthropometry measurements using the completed 3D modelling data (refer to Fig. 4), a total of 26 items, consisting of linear measurements, were measured and extracted as shown in Table 3. For the linear measurements, the landmarks obtained on the subject's face were used as measuring points, two of which were captured in Geomagic Studio 2013, and the required distances (e.g. the vertical distances) were recorded by the study staff in the spreadsheet file.

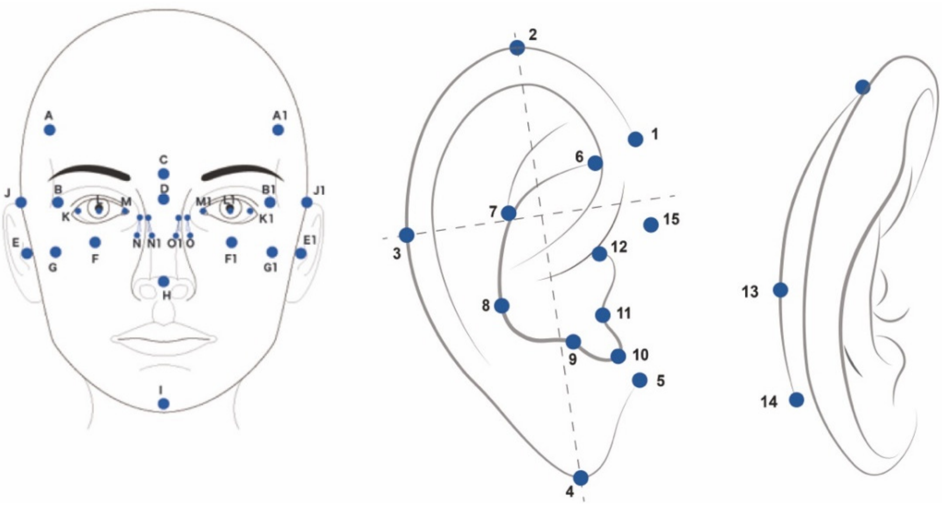

Figure.4. The 3D facial Measurements

Table 3. The 3D facial measurements

Head 、 face and ear measurements	Region	Landmarks involved	Category
Traditional measurements			
Head Circumference	Head	Glabella，Opisthocranion，Euryon Left ，Euryon Right	Perimeter
Head Length	Head	Glabella - opisthocranion	Length
Head Breadth	Head	Euryon Left - Euryon Right	Breadth
3D facial measurements			
Frontotemporale Distance	Face	Frontotemporale left-Frontotemporale right	
Glabella - Pronasale Distance	Face	Glabella- pronasale	Depth
Infraorbitale - Pronasale Distance	Face	Infraorbitale - Pronasale	Depth
Tragion Distance	Face	Tragion Left -Tragion right	Breadth
Zygofrontale Distance	Face	Zygofrontale left - Zygofrontale right	Breadth
Otobasion Superius Distance	Face	Otobasion superius left - Otobasion superius right	Breadth
Otobasion Superius - Glabella Distance	Face	Otobasion - Glabella superius	Length
Vertex - Glabella Distance	Face	Vertex - Glabella	Depth
Vertex -Tragion Distance	Face	Vertex -Tragion	Depth
Infraorbitale Distance	Eye	Infraorbitale left - Infraorbitale right	Breadth
Glabella - Infraorbitale Distance	Eye	Glabella - Infraorbitale	Depth
Biocular Diameter	Eye	Ectocanthus left - Ectocanthus right	Breadth
Interocular Diameter	Eye	Entocanthion left - Entocanthion right	Breadth
Interpupillary Distance	Eye	Pupil left - Pupil right	Breadth
Otobasion Superius - Pupil Distance	Eye	Otobasion Superius - Pupil	Length
Sellion - Pronasale Distance	Nose	Sellion - Pronasale	Depth
Sellion - Subnasale Distance	Nose	Sellion - Subnasale	Depth
Pronasale - Subnasale Distance	Nose	Pronasale - Subnasale	Depth
Alare Distance	Nose	Alare left - Alare right	Breadth
Otobasion Superius - Otobasion Inperius Distance	Ear	Otobasion Superius - Otobasion Inperius	Depth
Ear Length	Ear	Superior - Inferior Auricle	Depth
Ear Breadth	Ear	Posterior Auricle - Otobasion Superius	Depth
Cavum Concha Length	Ear	Superior Cavum Concha - Incisura Intertragica	Length
Cavum Concha Width	Ear	Posterior Concha - Tragion-e	Length
Superior Cavum Concha to Anterior Cymba Concha Length	Ear	Superior Cavum Concha - Anterior Cymba Concha	Length
Posterior Concha to Anterior Cymba Concha Length	Ear	Posterior Concha - Anterior Cymba Concha	Length

4. Conclusions

The survey collected data on 2200 (1925 + 275 additional scanned data) individuals in seven representative cities (275 individuals per city). In the scanning phase, the survey combined traditional anthropometric survey methods with a high-resolution 3D scanner. To obtain a complete 3D scan model of the head and face of a subject, two or three scan pieces in a scan file were aligned and combined to form a complete 3D head in Artec Studio. The accurate digital head and facial shape data will become the data basis for the SizeChina-Hunan, which will provide critical information for the design and development of wearable products with a good fit for heads and faces.

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