

Boundary Manikin Modeling and Application of Chinese Anthropometry

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Abstract

At present, owing to the different size between the SAE manikins used in seat comfort evaluation and the Chinese anthropometry, and the poor representation and coverage percentile manikin had to actual manikin, it is necessary to establish a new seat comfort manikin model based on the Chinese anthropometry characteristics. In this paper, the principal component analysis was used to reduce the multidimensional data set of the Chinese anthropometry by using eigenvectors and eigenvalues. The goal was to establish a three-dimensional confidence ellipse with 95% confidence, and then select the anthropometry data corresponded to the 26 feature points on the ellipse as boundary manikins. Then established the vehicle seat and boundary manikin by CATIA, carried out the sitting posture simulation analysis, and compared with the verification results of the SAE manikins and the Chinese percentile manikins. The results show that the sitting posture results of the three models are quite different. The established model can more accurately reflect the results of the sitting posture distribution of the Chinese anthropometry data, and can provide a reference for seat design and seat comfort evaluation.

Keywords

Boundary Manikin; Chinese Anthropometry; Seat Comfort; Principal Component Analysis.

1. Introduction

As a component that directly contacts the driver, the vehicle seat is a main factor affecting vehicle driving comfort. The existing evaluation methods of vehicle seat comfort include subjective evaluation methods and objective evaluation methods. Among them, the subjective evaluation method [1,2] is mainly used by many OEMs to evaluate seat comfort, which is based on the researcher's subjective evaluation of the seat. The process of subjective evaluation is time-consuming and expensive, and the result is greatly affected by the researcher, various subjective and objective factors. Objective evaluation methods [3] examination the comfort of seat by establishing simulation models of vehicle seat and digital manikin. Objective evaluation indicators could be used to predict seat comfort, which can reduce costs and shorten evaluation time. Objective evaluation methods include digital manikin model method and body pressure distribution method. For example, Zhang Xiaoyi [4] established three finite element models of SAE boundary manikin, and analyzed the driving posture through the finite element model, which provides a reference for the seat stroke adjustment. Liu Gang[5] established a body pressure distribution simulation model to provide guidance for seat design; Huang Shenrong[3] established a driving posture model of a seat based on Hybrid III dummy, simulated and analyzed the dummy's driving comfort level of different thickness seat; Montmayeur N et al.[6] used the 50th percentile male manikin model to simulate the influence of weight and sitting

posture on the body pressure distribution, and then verified the simulation results by experiments.

At present, scholars mainly simulate the actual driving posture to evaluate seat comfort by modeling seat and driver. However, SAE manikin is different from the Chinese manikin in body size, the verification results of the SAE manikin are not applicable to Chinese manikin. In addition, percentile manikin model is selected based on one-dimensional or two-dimensional univariate percentiles, which only can represent a small number of extreme populations distributed at both ends of height or weight, therefore, percentile manikin cannot represent extreme populations of different sizes in other dimensions [7]. Some scholars in other fields have proposed a boundary manikin model [8,9] and applied it to industrial design, clothing design, architecture and other fields. Applying the boundary manikin model to the comfort evaluation of vehicle seats can be realizing the on-machine evaluation of the real human body. The evaluation process can be faster, higher quality, more convenient and less experimental cost compared to use percentile manikin model. In this paper, a Chinese boundary manikin model is established based on the measured human body data of a certain city in China. Then, based on ergonomics, establishing a virtual model of a certain car seat in CATIA, predicting the pose of the manikin model, and analyzing the comfort level of different parts of the model's body, and finally comparing the evaluation results of three different manikin models.

2. Size Difference between Chinese Manikin and SAE Manikin

We compared the SAE manikin with the actual human body data of a certain city in China. The main content of the comparison is the 95th percentile male manikin, the 50th percentile male manikin and the 5th percentile female manikin. The comparison results of main dimensions of the human body are shown in Figures 1, 2 and 3.

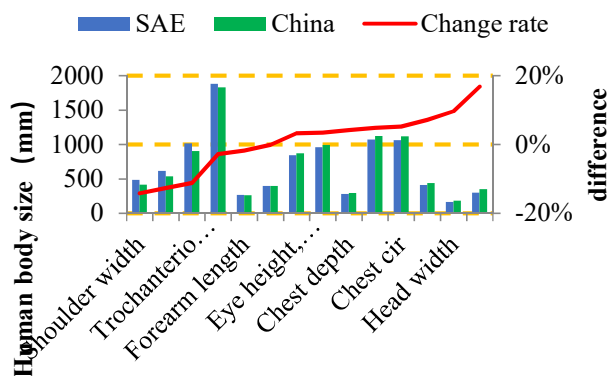


Figure 1. Comparison of main dimensions of 95th percentile male manikin

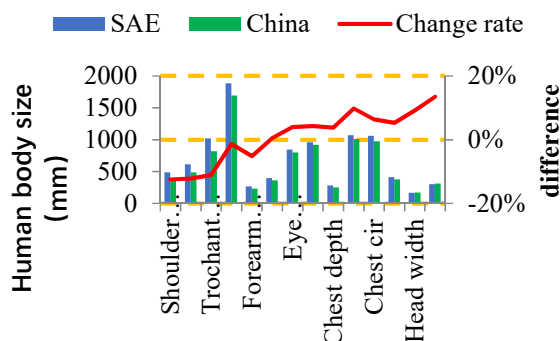


Figure 2. Comparison of main dimensions of 50th percentile male manikin

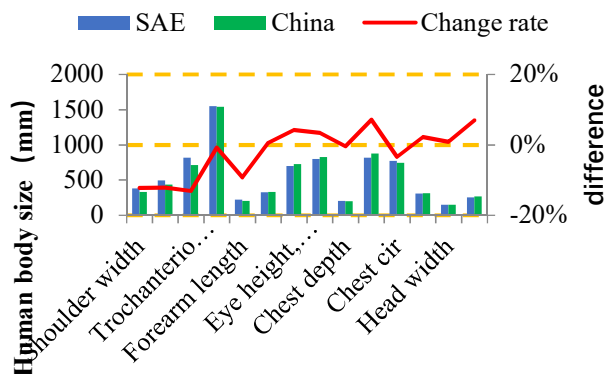


Figure 3. Comparison of main dimensions of 5th percentile female manikin

It can be seen from the figure that, whether male or female, there are obvious differences in many parameters of the Chinese human body and the American human body. Since the seat comfort research in Europe and America is based on the data of SAE seat comfort manikin, in view of the differences in race, lifestyle, eating habits, etc., the European and American evaluation methods and standards are obviously difficult to directly applying to the Chinese population. The application of the SAE standard will result in lower reliability of seat comfort evaluation, which cannot meet the requirements of the Chinese people. Therefore, a digital manikin model that conforms to the characteristics of the Chinese human body needs to be established.

3. Establishment of Chinese Boundary Manikin Model

3.1. Chinese Body Size Measurement

In order to obtain accurate Chinese anthropometric data that can truly reflect the characteristics of Chinese, we measured standard posture human body size according to GB/T 5703-2010 and GB/T 10000-1988, with reference to SAE J833-2003. The measurement data included 83 human body size data of 183 driver samples in a city of northern China. Human body data collection used three postures as shown in Figure 4. Part of the human body size data measured is shown in Table 1.

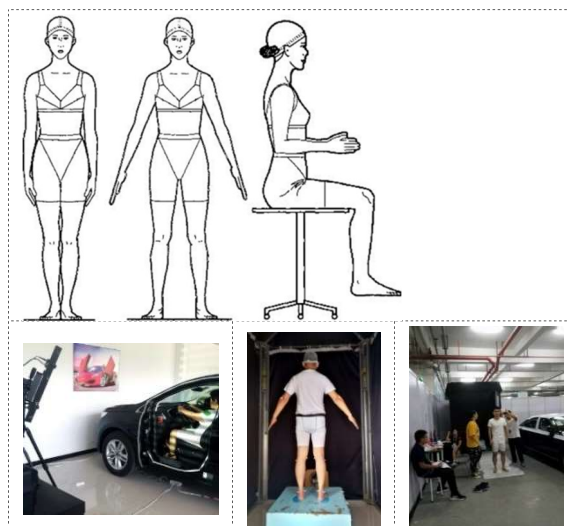


Figure 4. Human body data measurement posture

Table 1. Some human body data indicators

Ref. no.	Explanation
us2	Sitting abdomen extension thickness: the horizontal distance between the front point of the lower abdomen and the lower back point at the same height in the sitting position
us3	Standing shoulder height: the vertical distance between the standing ground surface and the acromion at the top of the arm
us4	Sitting shoulder height: the vertical distance between the sitting surface and the acromion at the top of the arm
us5	Shoulder radius length: the distance between the acromion point and the elbow point
us6	Ankle circumference: the smallest ankle circumference in the horizontal direction
us7	Armpit height: the distance from the axillary point on the armpit folds of the torso to the ground surface when standing
us8	Axillary arm circumference: the circumference of the upper arm at the axillary point of the upper arm and perpendicular to the upper arm
us9	Foot circumference: the circumference of the foot past the protruding point of the first and fifth toes

3.2. Principal Component Analysis

Principal component analysis (PCA) is a statistical method that reduces the dimensionality of the data by calculating the eigenvectors and eigenvalues of the anthropometric data, and can save most of the data fluctuations in the original data.

The principle of PCA is to rotate the data into a new coordinate system, each principal component is a coordinate axis, the principal components are orthogonal to each other, and the observations on these axes are not related. Generally, the first principal component has the largest variance, the second principal component is orthogonal to the first principal component and has the second largest variance, and so on. The calculation steps of principal component analysis are as follows:

The measured body size data is composed of the following sample set:

$$(\mathbf{X}_1, \mathbf{X}_2, \dots, \mathbf{X}_p) = \begin{pmatrix} x_1(1) & x_2(1) & \dots & x_p(1) \\ x_1(2) & x_2(1) & \dots & x_p(1) \\ \vdots & \vdots & \ddots & \vdots \\ x_1(m) & x_2(m) & \dots & x_p(m) \end{pmatrix} \tag{1}$$

Among them, $x_i(k)$ represents the i -th sample value in the k -th acquisition index. Now the p high-dimensional acquisition index mapping is reduced to q principal components. In this paper, a three-dimensional confidence ellipse is established, that is, $q=3$.

Next, calculate the sample covariance σ_{ij} and sample correlation coefficient r_{ij} of the collected data:

$$\sigma_{ij} = \frac{1}{p-1} \sum_{k=1}^p (x_i(k) - \bar{x}_i)(x_j(k) - \bar{x}_j) \tag{2}$$

$$r_{ij} = \frac{\sigma_{ij}}{\sqrt{\sigma_{ii}\sigma_{jj}}} \tag{3}$$

Among them,

$$\bar{x}_i = \frac{1}{p} \sum_{k=1}^m x_i(k) \tag{4}$$

Thereby, the covariance matrix V and correlation matrix R of the collected samples are obtained;

Find the eigenvalues and eigenvectors of the correlation matrix V , the characteristic root is denoted as $\lambda_1 \geq \lambda_2 \geq \dots \geq \lambda_m \geq 0$. According to the above steps, we can extracted three principal components of the Chinese human body size variables, and the cumulative percentage of the three principal components is 85.6%.

3.3. Confidence Ellipse Establishment

The eigenvalue is used to determine the length of each axis of the confidence ellipse, and the eigenvector is used to determine the coordinates of each sample. Therefore, the confidence ellipse of the Chinese human body data and the scatter plot representing each sample are obtained.

Take a two-dimensional ellipse drawn by two principal components as an example, as shown in Figure 5, data points with the same confidence constitute a standard ellipse. The data point near the center of the ellipse represents the average object of the anthropometric data, and the boundary points of the ellipse represent the limit anthropometric data, that is, the boundary manikin model.

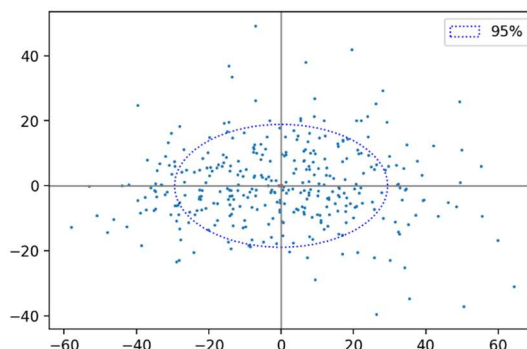


Figure 5. 2-dimensional confidence ellipse and scatter plot of human body data

In this paper, a 95% confidence ellipsoid is selected as the boundary, and the radius of the confidence ellipsoid is determined by the first three eigenvalues. 26 characteristic points of the ellipsoid are selected, which are located at the midpoint of each quadrant, the axis intercept and each Four points in a plane [8], as shown in Table 2.

Table 2. 3-dimensional confidence ellipse feature points

Points along each Plane	Axis Intercept Point	Mid Quadrant Points
(+,+,0)	(+,0,0)	(+,+,+)
(+,-,0)	(0,+,0)	(+,+,-)
(-,+,0)	(0,0,+)	(+,-,+)
(-,-,0)	(-,0,0)	(+,-,-)
(+,0,+)	(0,-,0)	(-,+,+)
(+,0,-)	(0,0,-)	(-,+,-)
(-,0,+)		(-,-,+)
(-,0,-)		(-,-,-)
(0,+,+)		
(0,+,-)		
(0,-,+)		
(0,-,-)		

Calculate the distance between the scattered points of human body features and the feature points of confidence ellipse:

$$r = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2} \tag{5}$$

The data point that closest to the feature point is selected as the boundary manikin point, as shown in Figure 6. The red points represent the ellipse feature points, and the green points represent the selected human feature data points, that is, the boundary manikin points.

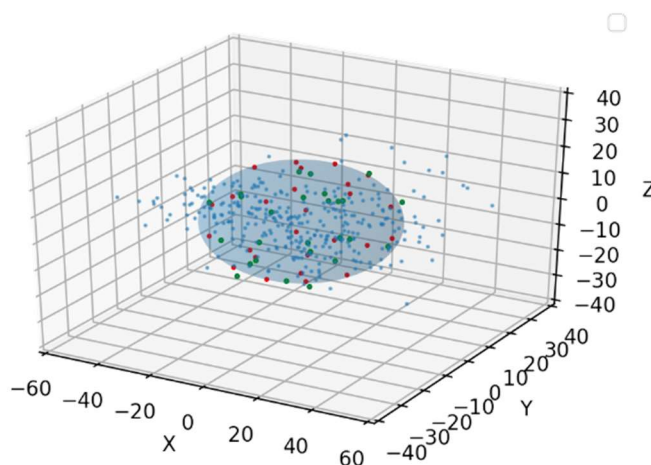


Figure 6. 3D confidence ellipsoid and boundary manikin scatter plot

4. Comparison of the Seat Comfort Evaluation Result based on Three Kinds of Manikin Model

4.1. Human Sitting Preferred Angle

Figure 7. shows the human sitting position joint angle, and Table 3 shows the human sitting preferred angle.

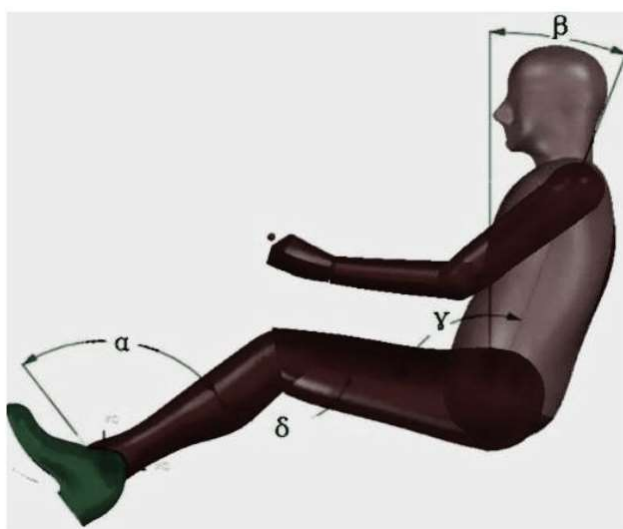


Figure 7. Human sitting position joint angle

Table 3. Driver’s preferred angle of sitting position

Signal	Angle name	Comfortable range
β	Torso angle	20°-30°
γ	Torso and thigh angle	95°-120°
δ	Knee angle	95°-135°
α	Ankle angle	87°-110°

4.2. Seat Comfort Evaluation Model Establishment

Based on the CATIA ergonomics module, we established three manikin models for comparative analysis, including SAE seat comfort manikin, Chinese percentile manikin model and Chinese boundary manikin model. The Human Posture Analysis module in CATIA can evaluate the comfort angle of the manikin model. Then put the manikin model into the vehicle seat model to obtain the driving posture of the manikin. Measure the comfortable angle of the manikin model in the driving posture, and calculate the evaluate result of the seat comfort. Figure 8 shows the driving model of a certain boundary manikin. By checking the human comfort angle, the result of the seat comfort level can be obtained, as shown in Figure 9.

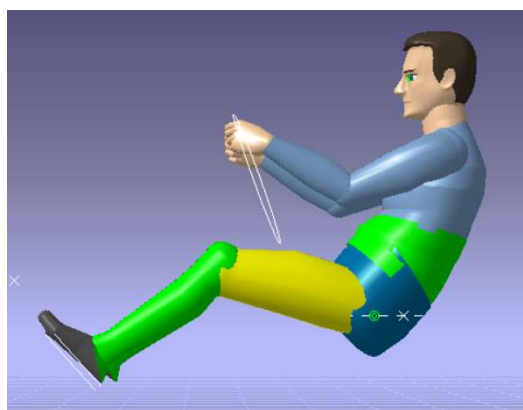


Figure 8. Driving posture of boundary manikin

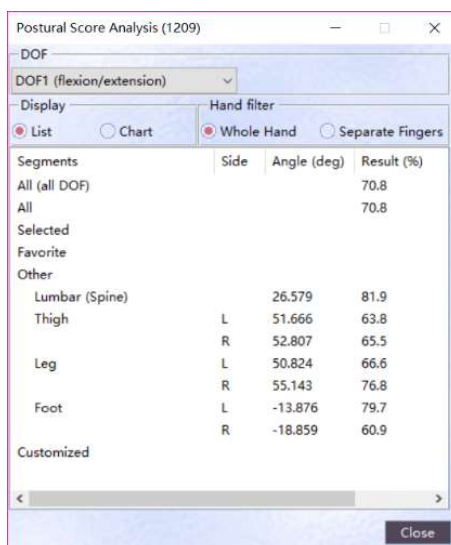


Figure 9. Evaluate result of boundary manikin’s preferred angle

As shown in Figure 9, the preferred angle’s evaluate result shows torso angle, angle between left/right thigh and torso, left/right knee angle and left/right ankle angle. The scoring results are obtained according to the difference between each included angle and preferred angle. The weighted average of each item gets a total score of 70.8.

4.3. Comparison of Evaluation Results

Select the SAE 95th percentile male manikin, SAE 5th percentile female manikin, China 95th percentile male manikin, 5th percentile female manikin, and three boundary manikins for comparison. Sitting angle of these manikin model are shown in Table 4, and the comparison difference is shown in Figure 10. It can be found that there are big differences in the joint angle of SAE manikin and Chinese manikin, which also proves that the SAE percentile manikin is not suitable for the seat comfort evaluation in China.

Table 4. Three kinds of manikin sitting joint angles and evaluation results

		SAE		China percentile manikin		Boundary manikin		
		95th	5th	95th	5th	1	2	3
Torso angle(°)		24.845	25.531	27.206	25.631	26.579	25.993	26.272
angle between thigh and torso(°)	L	118.789	119.907	129.544	122.508	128.334	137.535	133.886
	R	119.634	122.266	126.818	127.873	127.193	136.16	133.157
Knee angle(°)	L	120.526	128.732	132.9	122.606	129.176	139.222	143.891
	R	119.061	130.638	123.335	138.623	124.857	140.163	138.468
Ankle angle(°)	L	78.348	71.055	74.146	78.8	76.124	64.297	61.584
	R	80.277	72.643	71.992	70.507	71.141	63.819	61.881
Score		86.4	93.9	74.3	71	70.8	45.3	43

5. Conclusion and Discussion

This paper explores boundary manikin calculate methods which make it possible to represent the Chinese anthropometric data to evaluate vehicle seat accommodation. This paper proposed PCA to reduce a multidimensional dataset to a more manageable size. The eigenvectors and eigenvalues are calculated by transforming a multidimensional dataset of correlated variables into a smaller set of variables that account for the greatest amount of variability within the dataset, or principal components. In the analysis done in this paper, using the confidence ellipse method resulted in the creation of just 26 manikins, without any loss in the variability. These boundary manikins contain realistic anthropometry, with different combinations of lengths, widths, and circumferences for body segments. This variation provides a realistic assortment of body shapes to design a more comfortable vehicle seat for Chinese.

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