Research of body dimension of Chinese adult male and application

Xuejing Du*, Huanhuan Guo, Zhanyu Wang

Institute of Transportation, University of Northeast Forestry, 150040, Harbin, China

Received 1 July 2014, www.cmnt.lv

Abstract

The goal of this study is to obtain accurate human dimension of current Chinese shape. Anthropometric data of adult male in GB10000-88 is adopted as sample observation data in this paper. Based on similarity theory of human body and the correlation of human body static dimensions, by statistical analysis of the sample date, the regression equation is established which determines the relationship between measurement of each part of the male body and height, weight. The maximum measurement error is within 5% by comparing the measurement data with calculating dimension data obtained by regression equations established in the paper, which verifies the rationality and accuracy of the regression equations. Once parameters of height and weight are given, the regression equations can quickly and easily provide effective body dimensions data used to build crash simulation model specifically for Chinese and man-machine product.

Keywords: automobile crash, dummy model, human dimensions, occupant restraint, regression equation

1 Introduction

Human body dimension determines the geometry space and range the human body occupied, which is a basic data for industrial product design, architectural design, and military industry, the technical reformation, equipment update and labour safety and protection [1]. The crash test dummy model made according to accurate human basic data is beneficial to design and evaluate automobile occupant restraint system. Chinese had carried on the human body measurements for the first time from1986 to1988 according to standards GB3975 [2] and GB5703 [3], and established a national database of human body dimension. Then, the national standard GB 10000-88 is drew up [4]. However, the data of human body dimension has strong timeliness. With the living standards improving greatly in China, body dimensions changes correspondingly since 1988. Hence, many body data can't meet the needs of life and survival design. Accurate information of Chinese human body size is important.

In order to obtain the accurate information of human body, Yu et al [5] studied body surface area measurement, using 3D scanner, and derived a simple body surface area measurement estimation formula for Chinese adults. Han et al [6] analysed the difference between body scan measurement and manual measurement, and the comparative analysis provided guidelines to use body scan measurement for obtaining accurate body measurement result. Wang used three statistical methods [7] to collect and analyse the body measurement data in static and dynamic measurement. In China, the China National Institute of Standardization carried out a sampling measurement pilot investigation about Chinese adult body dimension in Beijing and other three big cities in china in 2009, the collecting data showed that the adult male's height and waist circumference have increased 2 centimetres and 5 centimetres, and the size variance of bust and waist has diminished. On November 27, 2013, the project of "Chinese adults ergonomics basic parameter survey" was launched officially by China National Institute of Standardization as a leader, and was expected to complete by the end of May 2018, then the database of Chinese human dimensions would been fully updated at that time. In this case that the database has not been updated yet now, Bai and Cao [8] made the height and weight data of Chinese human acquired from the National physique monitoring reports in 2000 as two basic parameters, and then used empirical formulas of human body to obtain the main parts sizes and posture dimensions of Chinese human, and modified the frontal crash dummy to meet Chinese human characteristics. Zhang [9] divided the human body model into 15 parts, and then made correlation analysis and regression analysis of the 15 parts about height and weight respectively.

Zhang [10] proposed and proved mathematically the similarity theory of human body; he found that the same group human has similar shape. According to the similarity theory of human body [10] and the correlation of human body static dimensions, the relationship between human body parts dimension and human height and weight of Chinese adults is studied based on the data of human statistical parameter provided by GB10000-88. Then, the prediction linear regression equations of measurement parts of human adults male is established by using methods of correlation analysis and regression analysis. According to the linear regression equations, Chinese human

**Corresponding author* e-mail: duxuejing99@163.com

dimensions with body height and weight can be predicted, which can provide current body data for human body simulation modelling and guide man-machine product design. The simulation dummy of frontal crash is made in Madymo environment, which is as an application of the updated Chinese human dimensions in this study.

2 Methodologies

In order to study Chinese current human body dimensions, the sample observation data of body measurement in static state is from national database established in 1988. After analysis and discussion, height and weight are as two regression variables, and regression analysis method is applied to build the binary linear regression equation of human dimension. Human dimensions can be derived in single body and group human according to the regression equation in this paper.

Regression analysis is a statistical analysis method which studies the correlation relationship between a random variable and a (or several) controlled variable. The forecast model of human body dimensions is established based on correlation theory and linear regression analysis methods, which can better reflect the variability of each dimension of human body part and make the results more reasonable and credible. Regression analysis mainly includes three aspects:

1) Establish the empirical formula containing related variable (mathematical relationship).

2) Significance test:

Firstly, test whether the empirical formula established is valid, and then give the test of significance of each variable factor respectively;

Secondly, modify the empirical formula according to the situation;

Finally, determine the optimal regression equation.

3) Prediction and control according to the empirical formula.

2.1 ESTABLISH THE EMPRICAL FORMULA

After analysis, height and weight of human body are selected as two variable factors to establish the binary linear regression equations of Chinese human adults body dimensions, the mathematical relational expression is:

$$y = B_0 + B_1 x_1 + B_1 x_2 , \qquad (1)$$

where, y is the dependent variable, dimension of part of human body that changing with height or weight; x_1, x_2 are variables of height and weight; B_0 is regression constant; B_1, B_2 are regression coefficients of height and weight.

When the regression empirical formula is determined, the next step is to analyse and calculate the sample data, and then work out the unknown regression coefficients B_0, $B_1$and B_2 in Equation (1). In view of the large amount of data, Excel software is used to make regression analysis of the sample data and calculate the regression coefficients in this paper.

2.2 SIGNIFICANCE TEST

2.2.1 Regression equation of significance test

F criterion is used to test the linear regression equation determined initially.

Examine whether the regression coefficients of B_1 and B_2 are all zero, if they are all zero, then the linear relationship is not significant; otherwise, linear relationship is significant. The step of F criterion is as follows:

1) Suppose H_0: $B_1 = B_2 = 0$

2) Calculate the observed value of F according to the observation sample:

$$(x_{11}, x_{12}, y_1), (x_{21}, x_{22}, y_2) \ldots (x_{n1}, x_{n2}, y_n),$$

where, F is test statistic, $F = \dfrac{S_R / m}{S_e / (n-m-1)}$, S_R is regression sum of square, S_e is residual sum of square, for binary linear regression equation m=2. The calculation process in detail is omitted here.

3) Check if F meets the condition:

$F \geq F_{1-\alpha}(m, n-m-1)$, then refuse H_0 , consider that linear regression effect of the linear regression equation is significance.

If F meets the condition as: $F < F_{1-\alpha}(m, n-m-1)$, then accept H_0 , It means that linear regression effect of the linear regression equation is not significance.

2.2.2 Significance test of each variable factor

For the binary linear regression, it is not enough to only make test of significance of regression equation, test of significance of each regression coefficient also needs to be done. Eliminate the insignificant variable from regression equation, through test of significance of each regression coefficient and then re-establish regression equation containing all significant variable factors. Here, t criterion is used to examine whether the single variable factor is significance, respectively.

It is similar with F criterion; build the test statistic of t, and calculate the observed value of t according to the observation sample.

If t meets the condition: $|t| \geq t_{1-\alpha/2}(n-m-1)$, then consider regression variable factor x_k has significance effect on dependent variable y;

If t meets the condition: $|t| < t_{1-\alpha/2}(n-2)$, then consider regression variable factor x_k has insignificance effect on dependent variable y, then eliminate the unremarkable variable factor x_k and re-establish regression equation.

2.2.3 Correlation coefficient test

r-statistics is used to test whether the dependent variable y has linear correlation with variable x_k in correlation coefficient test. In the similar way like F-test and t-test. The observed value of r is calculated, if $|r| \geq r_{\alpha}(n-m-1)$, then there is linear correlation between dependent variable y and variable x_k; if $|r| < r_{\alpha}$, then there is not linear correlation between dependent variable y and variable x_k; and the more $|r|$ close to 1, the greater the correlation; he more $|r|$ close to 0, the smaller the correlation.

2.2.4 Determine the optimal regression equation

The method named "all out without in" is applied to determine the optimal regression equation, as the regression variables determined are only height and weight of human. That is, firstly make significance test for linear regression equation containing selected regression variables, if the equation is significance, make significance test for each regression variable, and secondly eliminate variable factor that has min effect on regression equation in non-significant factors and re-establish regression equations, thirdly, make significance test for the new equation. Do as the three steps until the optimal regression equation is obtained.

2.3 PREDICTION

It can predict the value of y if the fixed values of x are given, according to the linear regression equation established. In other words, the dependent variables of dimensions of body parts can be obtained with the indicators of height and weight according to the regression equation established with variables of height and weight. Prediction methods are point prediction and interval prediction. Point prediction can get fixed value of y when the x_1, x_2 are assigned according to the identified regression equation: $y = B_0 + B_1x_1 + B_1x_2$. Interval prediction is suitable for the situation that confidence level ($1-\alpha$) is demanded, the prediction interval of y with confidence level ($1-\alpha$) can be calculated according to following Equation (2):

$$(y - \sigma t_{1-\alpha/2}(n-m-1), y + \sigma t_{1-\alpha/2}(n-m-1)), \quad (2)$$

where, σ is standard deviation of observation sample.

It depends on a specific situation, which method to choose (point prediction or interval prediction).

3 Determine the regression equations of Chinese adult male dimensions

Excel software is used to calculate the all parameters of the regression equation, because the size of the observed data provided by the GB10000-88 is large. The final linear regression equations of parts of human body are determined by regression significance analysis.

Eye height and shoulder height are discussed as examples to introduce the process of establishment of regression equation and prediction. The preliminary parameters related to regression equations of eye height and shoulder height are in the following Table1. Where, $\alpha = 0.05$, n =7, m =2, the results can be obtained by table lookup [11].

$r_{0.05}$ (4)=0.8114; $F_{1-0.05}$ (2,4) =6.94; $t_{1-0.05/2}$ (4) =2.7764.

For eye height: r = $0.99989 \geq r_{0.05}(4)$ =0.8417, then eye height has significant correlation between height and weight.

As F =90092.52 $\geq F(2,4)$ =6.94, then the linear regression equation of eye height about height and weight is significant. As $t_1 = 42.9528 \geq t_{1-0.05/2}(4) = 2.7764$ and $t_2 = 3.5629 \geq 2.7764$, then the regression variables of height and weight are all has significant effect on eye height, and we can know that the variable of height has more significant effect than variable of weight according to the calculation result.

Finally, the regression equation of eye height with variables of height and weight is determined as follows:

$$y = 0.2077 + 0.9153x_1 + 0.5302x_2.$$

We can make prediction eye height of a Chinese adult male with his height and weight.

For example, make point prediction and interval prediction as the height and weight are assigned as 1,700 mm and 65 KG.

The eye height of point prediction is 1,590.68 mm.

When $\alpha = 0.05$, $(y - \sigma t_{1-0.05/2}(4), y + \sigma t_{1-0.05/2}(4))$ is the confidence interval of eye height, take data into the confidence interval model we can get (1587.65, 1592.35)

For shoulder height, we can know that the variable of weight is non-significant factor for regression equation of shoulder height based on the calculation shown in Table 1, for $t_2 = 1.9866 < t_{1-0.05/2}(4) = 2.7764$, and then re-establish the regression equation without variable of weight. The parameters of the correction regression equation of shoulder height are shown in the Table 1. The correction regression equation is the optimal regression equation through significance test.

The regression equations of the other parts of the body dimensions are determined as above, the regression equations of Chinese adult male dimensions are shown in Tables 2-5.

TABLE 1 Parameters for regression equations of height of eye and height of shoulder

Items (mm) \ Parameters	B_0 (Constant coefficient)	B_1 (Regression coefficient of height)	B_2 (Regression coefficient of weight)	Value of t	Value of F	r (Correlation coefficient)	σ (Standard deviation)
Eye height	0.2077	0.9153	0.5302	t_1=42.9528 t_2=3.5629	90092.52	0.999989	0.601475
Shoulder height	-68.7784	0.8352	0.5627	t_1=20.5926 t_2=1.9866	21225.36	0.999953	1.144811
Correction of shoulder height	-168.661	0.91530	0	t_1=-163.4247	26707.62	0.999906	1.44324

TABLE 2 Dimensions regression equations of Chinese adult male in standing posture[a]

Items(mm) \ Parameters	B_0 (Constant coefficient)	B_1 (Regression coefficient of height)	B_2 (Regression coefficient of weight)	Value of t	Value of F	r (Correlation coefficient)	σ (Standard deviation)
Eye height	0.2077	0.9153	0.5302	t_1=42.9528 t_2=3.5629	90092.52	0.999989	1.144811
Shoulder height	-168.6610	0.91530	0	t_1=-163.4247	26707.62	0.99906	1.44324
Elbow height	-96.1686	0.6411	0.7290	t_1=17.4710 t_2=2.8450	17175.25	0.999942	1.03578
Functional hand height	-320.1850	0.6321	0	t_1=137.6817	18956.25	0.999868	1.182973
Perineum high	-157.5050	0.5272	1.0485	t_1=10.7862 t_2=3.0722	7986.99	0.999875	1.37951
Tibial height	-190.2750	0.37843	0	t_1=85.8505	7370.31	0.999661	1.135892

[a] The linear regression equation is: $y= B_0+B_1x_1+ B_2x_2$, where, B_0, B_1, and B_2 are constant coefficient, regression coefficient of height and regression coefficient of weight; x_1 is regression variable of height, the unit of measure is millimetre; x_2 is regression variable of weight, the unit of measure is kilogram; y is the dimension of parts of human, the unit of measure is millimetre.

TABLE 3 Dimensions regression equations of Chinese adult male in sitting state[a]

Items (mm) \ Parameters	B_0 (Constant coefficient)	B_1 (Regression coefficient of height)	B_2 (Regression coefficient of weight)	Value of t	Value of F	r (Correlation coefficient)	σ (Standard deviation)
Seated height	29.4508	0.5233	0	t_1=184.777	34142.54	0.999927	0.729855
Cervical height, sitting	-11.2640	0.3827	0.4368	t_1=-22.40156 t_2=3.661877	28267.74	0.999965	1.44324
Eye height, sitting	-57.9047	0.51003	0	t_1=205.8884	42390.03	0.999941	0.638347
Shoulder height, sitting	-139.463	0.43973	0	t_1=-198.4419	39379.19	0.999937	0.571013
Elbow height, sitting	-348.764	0.36442	0	t_1=183.8339	33794.92	0.999926	0.51083
Thigh clerance height, sitting	0	42.83445	1.4376	t_1=24.90017	620.018	0.99599	2.130455
Knee height, sitting	-89.3428	0.3304	0.4671	t_1=-31.89367 t_2=6.457367	61190.08	0.999984	0.292406
Lower leg-foot length	36.10362	0.18772	1.0427	t_1=11.03096 t_2=8.773861	16297.06	0.999939	0.480346
buttock-popliteal length	-122.988	0.334096	0.3231	t_1=29.40696 t_2=4.073074	46652.21	0.999979	0.32068
Hip to Knee length	-59.482	0.348349	0.4835	t_1=15.86938 t_2=3.154525	15056.88	0.999934	0.619591
Lower extremity length, sitting	-257.64	0.744658	0	t_1=107.3962	11533.95	0.99783	1.786747

[a] the linear regression equation is: $y= B_0+B_1x_1+ B_2x_2$, where, B_0, B_1, and B_2 are constant coefficient, regression coefficient of height and regression coefficient of weight; x_1 is regression variable of height, the unit of measure is millimetre; x_2 is regression variable of weight, the unit of measure is kilogram; y is the dimension of parts of human, the unit of measure is millimetre.

TABLE 4 Horizontal dimensions regression equations of Chinese adult male[a]

Parameters / Items (mm)	B_0 (Constant coefficient)	B_1 (Regression coefficient of height)	B_2 (Regression coefficient of weight)	Value of t	Value of F	r (Correlation coefficient)	σ (Standard deviation)
Chest depth	-45.6245	0.101804	1.467621	t_1=17.41333 t_2=35.94846	118350.3	0.999992	0.389786
Shoulder breadth	-238.711	0.383433	-0.51102	t_1=17.81247 t_2=-3.39955	8687.282	0.999885	0.607597
Maximum shoulder breadth	-59.9154	0.265599	0.768275	t_1=12.31861 t_2=5.102706	12616.46	0.999921	0.608576
Hip breadth	-11.0878	0.163048	0.738698	t_1=10.17592 t_2=6.601968	11697.28	0.999915	0.452264
Hip breadth, sitting	-0.5424	0.152158	1.132055	t_1=8.448848 t_2=9.001536	12652.08	0.999921	0.508334
Elbow to elbow breadth, sitting	-84.555	0.200735	2.883844	t_1=5.568218 t_2=11.45549	12045.24	0.999917	1.017552
Chest circumference	206.7272	0.215358	5.070317	t_1=12.25684 t_2=41.3238	119385.6	0.999992	0.495945
Wrist circumference	220.7002	0	8.928137	t_2=46.9323	2202.64	0.998867	7.019918
Hip circumference	159.1552	0.289085	3.943903	t_1=3.9654 t_2=7.7470	5701.406	0.999825	2.05773

[a] the linear regression equation is: $y= B_0+B_1x_1+ B_2x_2$, where, B_0, B_1, B_2 are constant coefficient, regression coefficient of height and regression coefficient of weight; x_1 is regression variable of height, the unit of measure is millimetre; x_2 is regression variable of weight, the unit of measure is kilogram; y is the dimension of parts of human, the unit of measure is millimetre.

TABLE 5 Dimensions regression equations of head, hand and foot of Chinese adult male[a]

Parameters / Items (mm)	B_0 (Constant coefficient)	B_1 (Regression coefficient of height)	B_2 (Regression coefficient of weight)	Value of t	Value of F	r (Correlation coefficient)	σ (Standard deviation)
Head to chin height	-46.7679	0.1534	0.208854	t_1=20.83667 t_2=4.0626	25793.95	0.999961	0.207797
Sagittal arc	-91.8649	0.2629	0	t_1=87.58131	7670.485	0.999674	0.773485
Transver-sel arc	-25.1947	0.22997	0	t_1=128.1097	16412.09	0.999848	0.462575
Head breadth	-14.6533	0.1006	0	t_1=60.39968	3648.122	0.999315	0.429352
Head length	-11.3772	0.1163	0	t_1=79.75548	6360.936	0.99607	0.375763
Head circumference	118.7744	0.2633	0	t_1=135.6043	18388.52	0.999864	0.500274
Morphological facial length	-69.9696	0.1128	0	t_1=96.07359	9230.135	0.999729	0.302615
Hand length	-48.1905	0.1377	0	t_1=105.8872	11212.1	0.999777	0.335154
Hand breadth	-30.0341	0.0668	0	t_1=65.67084	4312.659	0.999421	0.26221
Index finger length	-46.3113	0.0689	0	t_1=53.06254	2815.633	0.999113	0.334408
Foot length	-52.5146	0.1785	0	t_1=103.0215	10613.44	0.999765	0.446494
Foot breadth	-35.0796	0.0781	0	t_1=42.1762	1778.83	0.998598	0.477074

[a] the linear regression equation is: $y= B_0+B_1x_1+ B_2x_2$, where, B_0, B_1, and B_2 are constant coefficient, regression coefficient of height and regression coefficient of weight; x_1 is regression variable of height, the unit of measure is millimetre; x_2 is regression variable of weight, the unit of measure is kilogram; y is the dimension of parts of human, the unit of measure is millimetre.

4 Analysis and conclusion

4.1 ACCURACY ANALYSIS OF REGRESSION EQUATION

The source of measurement data (from the Chinese human dimensions standard published in 1988) ensures the basic sample data in this study accurate and meaningful; the similarity theory of the same group human body ensures the regression equations established are reasonable. To further validate the regression equations, some Chinese male volunteers are chosen to participate in body measuring experimentation. It is found that the maximum error between actual measurement data and prediction dimension data derived from regression equations established is within 5% by comparative analysis. The theoretical analysis and actual experiment prove that the regression equations of Chinese adult male established are accurate and have practical meaning.

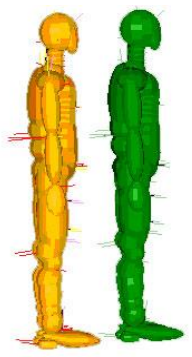
4.2 CONCLUSIONS

As the measurement, data of most of the human body in static state approximately conforms to normal distribution for single-sex group. When the indicators of stature and avoirdupois are given, the measurement values of other parts of Chinese human body can be derived quickly. The result has population statistical significance for Chinese adult male with the regression equation prediction model.

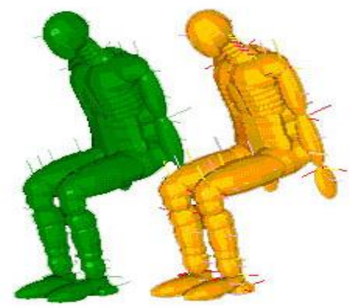
The regression equations established can provide effective method to get Chinese human dimensions quickly and easily, and complements the measurement empirical formulas of Chinese human body in static state. Meanwhile, the method in this paper applies to other groups like female and minors.

5 Application

The frontal crash dummy model with Chinese civil shapes can be built in the software environment of MADYMO. When the height and weight of 50 percentile adult male are 1,690.3 millimetre and 68.8 kilogram, the body measurement data can be calculated according to equations established in this paper. Based on this, the multi rigid dummy model with Chinese body feature is built by modifying 50 percentile dummy model in MADYMO software. The Chinese simulation dummy and original dummy model in MADYMO are in Figure 1. In the figure, the original dummy model is green and as reference, Chinese simulation dummy is yellow, we can see the Chinese simulation dummy with standing posture and sitting posture.



a) standing posture, the original dummy model is green, Chinese simulation dummy is yellow



b) sitting posture, the original dummy model is green, Chinese simulation dummy is yellow

FIGURE 1 Chinese simulation dummy and original dummy model in MADYMO

Acknowledgements

This work was supported by the National Natural Science Foundation of China (Grant No. 51108068), Natural Science Foundation of Heilongjiang (Grant No. E201350) and the Fundamental Research Funds for the Central University (Grant No. DL12CB03).

References

[1] Ren J D 2010 Automotive Ergonomics *Peking University Press: Beijing (in Chinese)*
[2] GB3975-83 1983 *Anthropometric Term (in Chinese)*
[3] GB5703-85 1985 *Anthropometric Method (in Chinese)*
[4] GB10000-88 1988 *Human Dimensions of Chinese Adults (in Chinese)*
[5] Yu C Y, Lo Y H, Chiou W K 2003 The 3D scanner for measuring body surface area: a simplified calculation in the Chinese adult *Applied Ergonomics* **34** 273-78
[6] Han H, Nam Y, Choi K 2010 Comparative analysis of 3D body scan measurements and manual measurements of size Korea adult females, *International Journal of Industrial Ergonomics* **40** 530-40
[7] Wang Y J, Mok P Y, Li Y 2011 Body measurements of Chinese males in dynamic postures and application *Applied Ergonomics* **42** 900-12
[8] Bai Z H, Cao L B, Yu Z G 2008 A Research on the difference of frontal impact response between 50th percentile Chinese male and hybridiii50th percentile male *Automotive Engineering* **30**(11) 993-7 *(in Chinese)*
[9] Zhang C H, Lin D Q 2009 Parameters research on the adult anthropomorphic phantom of china *Machine* **7** 1-3 *(in Chinese)*
[10] Zhang Y R 2012 Similarity of Human-body Shape *Acta Anthropologica Sinica* **31**(3) 299-314 *(in Chinese)*
[11] Zhuang C Q 2005 Application of Mathematical Statistics *South China University of Technology Press* Guangzhou *(in Chinese)*

Authors

Xuejing Du, born in April, 1975, Tonghua City, Jilin Province, China

Current position, grades: associate professor at Northeast Forestry University.
University studies: PhD in Transportation Engineering, Jilin University, Changchun, China, 2005.
Scientific interests: computational solid mechanics, finite element analysis/optimization, fracture mechanics and numerical simulation of damage, vehicle crashworthiness optimization for crash safety design, damage progression analysis of vehicle
Publications: 2.

Huanhuan Guo, born in February, 1989, Puyang City, Henan Province, China

Current position, grades: graduate student at Northeast Forestry University,
University studies: Master degree in reading at Northeast Forestry University, Harbin, China, 2012.
Scientific interests: Vehicle crashworthiness optimization for crash safety design, damage progression analysis of vehicle, fracture mechanics and numerical simulation of damage.
Publications: 2.

Zhanyu Wang, born in October, 1975, Jian City, Jilin Province, China

Current position, grades: associate professor at Northeast Forestry University.
University studies: PhD in Vehicle Engineering, Northeast Forestry University, Harbin, China, 2006.
Scientific interests: automobile emission control & simulation, finite element analysis/optimization.
publications: 2.