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Test Verification and Design of the Bicycle Frame Parameters

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Abstract: Research on design of bicycles is concentrated on mechanism and auto appearance design, however few on matches between the bike and the rider. Since unreasonable human-bike relationship leads to both riders' worn-out joints and muscle injuries, the design of bicycles should focus on the matching. In order to find the best position of human-bike system, simulation experiments on riding comfort under different riding postures are done with the lifemode software employed to facilitate the cycling process as well as to obtain the best position and the size function of it. With BP neural network and GA, analyzing simulation data, conducting regression analysis of parameters on different heights and bike frames, the equation of best position of human-bike system is gained at last. In addition, after selecting testers, customized bikes based on testers' height dimensions are produced according to the size function. By analyzing and comparing the experimental data that are collected from testers when riding common bicycles and customized bicycles, it is concluded that customized bicycles are four times even six times as comfortable as common ones. The equation of best position of human-bike system is applied to improve bikes' function, and the new direction on future design of bicycle frame parameters is presented.

Keywords: bike modeling, data mining, fatigue, dynamics simulation, oxygen uptake

1 Introduction

In recent years, with increasing urban population and motor vehicles, urban traffic has become more and more crowded. At the same time, with the increase of emission from motor vehicles, environment has also suffered from serious pollution. On the one hand, as one convenient and environmental transport tool, bicycles have received attention again[1]. On the other hand, cycling belongs to the aerobic exercise. With long-term cycling exercise, riders can effectively improve endurance and immunity[2]. The cycling exercise has been popular with the masses of fitness enthusiasts. However, with the increasing sales of bicycles, there are growing problems brought out by bicycles. The mismatch between the structural size of bikes and riders' body poses the rider in an unreasonable cycling posture, which will cause worn-out joints and muscle strains in the long term[3–4]. As for the problems above, this paper has quite practical significance in solution with one new design of bikes for customers.

At present, a lot of experts and scholars have studied bikes. XU[5] used the method of motion capture to obtain the motion track of people in the process of cycling. The trajectory as people-cycle movement simulation was inputted and loaded on a bicycle in the cycling process so as to get the specific method of load in biking of certain riders. According to sports anatomy, exercise physiology and sports training methods, GUO[6] discussed the athletes' training theoretically and methodologically by analyzing athletes' pedaling action of low limbs during cycling. With the method of EMG measurement way, the basic functions of 14 major muscles of human lower limbs during cycling were firstly studied and analyzed by HOUTZ and FISHER[7]. HUANG, et al[8], used electromyography tester to study the athletes' pedaling of full load revealing that surface EMG median frequency index can reflect functional status of different stages of muscle. LI, et al[9], evaluated the fatigue comfort of two bicycles through surface electromyography signal(EMG) experiment, in which the lower limb muscle groups, surveyed objects and the average EMG(AEMG) and median frequency(MF) were chosen as the evaluation index. Combined with the analysis, frame structures and related parameters of domestic postal bicycles have been improved under Japan postal bicycle as well as the theory of biomechanics. ZHAO, et al[10], applied video recording in riding movement of female cyclists in riding. Regarding athletes' shoulder, hip, knee and wheel as key points, change of joint angle and cycling speed parameters in the process of cycling have been analyzed in detail on individual athletes. REDFIELD, et al[11–12] of US Air Force Academy, studied

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dynamic characteristics of the mountain bike in the process of large-amplitude motion, and proposed a new method, image processing, to study characteristics of motion. BRIAN and LI[13] analyzed the antagonistic relationship of human lower limb muscles during cycling by measuring riders' EMG. DUC, et al[14–15], not only studied the electromyography signal when athletes riding on the slope, but also analyzed the different influence of riding postures on arm and leg muscles, finally getting the relationship between the active state of muscles and joints as well as force of the pedal and saddle. WILSON, et al[16],with the electromyography signal meter, not only studied athletes cadence in the process of cycling but also obtained human leg electromyography signal figure. The studies above take riders as objects under research of bike to design.

Some scholars adopt simplified human model to design the bicycle; for example, LIU, et al[17], in the study of analysis of human bicycle mechanism and optimization design, simplified the human lower limb parts into linkage, drew the corresponding performance index map and established the method of optimization design of human body -bicycle；WANG, et al[18] of Southeast University, studying the full suspension mountain bike, simplified the human body frame into a lumped mass block when carrying out the bike's design. Obviously, the human body modeling has mainly relied on rigid body, but the study shows that there is a very big error in this simplification. Though human bones can be simulated through linkage or other rigid body models, in the process of human movement, muscle and other soft tissues still play the leading role. There are spaces of 3 degrees of freedom in human body. The plane 1 degree of freedom of rotation simulation may result in a certain error. There are also some scholars using the reverse method to design bicycles, for example, ZHANG[19] in his master's thesis, took the method of self-organizing data mining to establish the quantitative relationship between the human body size and bicycle frame size. DENG, et al[20], utilized the data base of human body size, database of bikes on national standards and database of bike experience combined with the principle of ergonomics to design. MCLEAN and PARKER[21] of Australia, studying domestic athletes, took the method of statistics. It is concluded that the saddle height should be about 100% across the high altitude.

In conclusion, it can be seen that the bicycle design research abroad is mainly considered in the view of mechanism and statistics. In fact, in the process of bicycling, the relative position among the pedal, the handlebar and the saddle for the rider has greater influence on the riding posture, which directly affects the rider's health. Therefore, according to the theory of ergonomics and human biomechanics, the design method of bicycle on human physiological factors is worthy of further research. With simulation of human-bike coupled system model, on the basis of data mining, the equation relation of structural parameters between the rider and bike has been established, which thereby obtains bike frame sizes satisfying the demand of riders under different height. This provides a certain theoretical basis for bicycle frame parameters based on human body fatigue design.

2 Dynamics Simulation of Man-Bike Coupled System

First of all, the human body model was established under biomechanics with lifemode software, human body model of which has mainly been divided into two steps, first to create the human limb segments model and then to create human tissue model. When creating human limb model, it also needs to create human body joints in the joint of human body limb segment model. Then, with help of three-dimensional modeling software Pro/E, a three-dimensional model of a bicycle has been established. Local coordinate system was located in the center of the bicycle pedal. At last, the human body model and the bicycle model were inputted into the ADAMS software. To adjust the human model's position and posture in ADAMS, then to add bushing in the contact point between the human body model and the bicycle model, a human-bike system coupling model was built up. The adopted modeling method is from WU[22], as shown in Fig. 1.

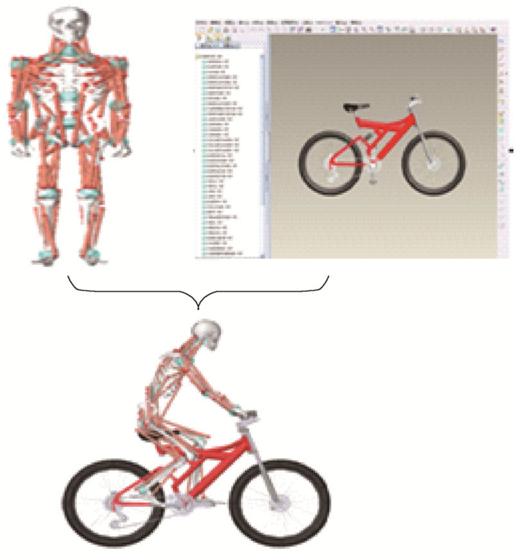


Fig. 1. Configuration of the exoskeleton arm system

In ADAMS, the dynamic simulation of human-bike coupling model was divided into forward dynamics simulation and inverse dynamics simulation. Forward dynamics simulation was the system movement simulation in which the human body model serves as an active unit. Inverse dynamics simulation was the system movement simulation in which the human body model serves as a passive unit.

In the process of simulation, the inverse dynamic simulation was conducted first. In Fig. 2, movement of the crank on the bike model can make the pedal rotate and all wheels move to conduct the cycling simulation. At the same time, the contraction of muscle was recorded and used for forward dynamics simulation. After the inverse dynamics simulation, forward dynamics simulation was conducted. Given gravity for 9.8 m/s^2 directly vertical downward, running time of 5 s, step length of 0.01 s, forward dynamics simulation was designed to implement active cycling of the human body model to get muscle strength in the process of cycling. So we can get muscle force of muscle, providing data for subsequent verification.

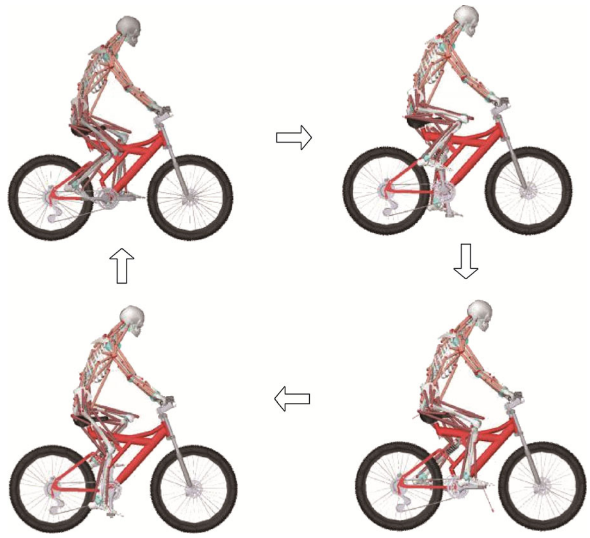


Fig. 2. Dynamic simulation

CROWNISHIELD, et al[23], put forward the muscle stress squares and measurement method of muscle fatigue, which has been the most common evaluation standard. The smaller the muscle sums of squares of the value are, the lower the degree of muscle fatigue will be. This paper takes the evaluation standard to judge the degree of muscle fatigue of riders in the process of cycling. The lower the degree of muscle fatigue means the higher degree of comfort of riders. A muscle stress square is

$$J = \sum \sigma_i^2 = \sum (F_i/S_i)^2. \quad (1)$$

Since ZJUESA is designed by the following physiological parameters of the human upper-limb. Under this kind of device, the human operator can control the manipulator more comfortably and intuitively than that with the joystick or the keyboard input.

J is the muscle stress squares, σ_i is the muscle stress of muscle i, F_i is the muscle tone of muscle i, and S_i is the physiological cross-sectional area(PSCA) of muscle i.

In the process of cycling, the lower limbs fatigue of the human body has the greatest effect on riding comfort. Thus, the sum of the squares of the lower limb muscle stress is taken as evaluation index of riding comfort.

Parts of human body touching bikes in bicycling are as follows: saddle, handle and pedal. The contact area of each position determines the riding posture of the rider. Under different cycling postures, the lower limb muscle stress squares of human body are various. In the case of constant crank length, the interaction among the saddle, the handle and axial location is bicycle frame parameters. To obtain fatigue minimum frame parameters of specific rider in cycling, a series of simulation experiments need to be done.

As shown in Fig. 3, the plane rectangular coordinate system is set up with middle axis as the origin, the saddle surface as point A with horizontal x_A and ordinate y_A. On the basis of bicycle industry experience, the angel between the riser supporting saddle and the ground is generally set empirical value in the range of 68°–73°, based on which the value will be expanded to 65°–75°. With parameters of the human body model, when the pedal moves to the lowest position, rider's legs and foot were proved to be stretching under the maximum state and in horizontal state to the highest position.

Fig. 3. Plane rectangular coordinate system of bike

Thus, the four boundary point position of the saddle is determined. Finally, the variable scope of design is 126 mm $\leqslant x_A \leqslant$ 230 mm, 443 mm $\leqslant y_A \leqslant$ 526 mm

The design method of uniform experiment was adopted to design simulation experiment to obtain data needed for modeling samples. In order to gain distribution of samples of experiments, the two-factor method was adopted to determine the position of the saddle point A. By choosing the one whose two factors were the 11, a table of distribution experiment of saddle point A of specific rider had been concluded.

In Table 1, according to height of 1600, 1640, 1680, 1720, 1760, 1800, 1840, 1880 and 1950 mm, different human body models have been established and hip of the human body model defined. The rigid body should be fixed in accordance with the best comfortable angle. From the table, the position for saddle point A has been obtained and adjusted, which resulted in the change of body postures of specific riders. Under different cycling postures, inputted into ADAMS of people-bike system dynamics simulation, the muscle stress squares of each rider of the lower limbs of 17 major muscles have been measured.

In ADAMS, the dynamics simulation software achieved the coupling of human-bike model and gained the lower limb muscle stress squares of human body model under different height, which provided data source for subsequent data mining.

Table 1. Lower limb muscle stress squares of different human body models $(\mathrm{N/mm})^2$

LABELS	1600	1640	1680	1720	1760	1800	1840	1880	1950
1	7904	6458	9480	6727	4967	6708	7332	4997	8569
2	8466	6728	6666	5217	5352	4526	5387	5184	9949
3	6518	5039	4034	5250	6530	6006	7725	6478	9243
4	6990	4512	4577	3226	4553	5709	6843	5086	8583
5	8149	5673	6320	4546	6849	6385	6506	6991	9526
6	3378	4976	4932	4282	5837	5451	4677	4565	8537
7	7863	5146	4369	4780	6371	6672	4998	6644	10 503
8	8616	6114	6632	4536	4959	7018	6588	6884	9059
9	5131	4524	4850	5529	6102	6771	6963	7151	9543
10	4501	7521	9117	6255	8844	9908	8255	8569	11275
11	6395	6261	9061	5951	7811	9832	8469	8785	8991

3 Human-Bike Best Position Equation

With the data, the trained neural network has been employed. The smaller the value of muscle sum of squares is, the lower the degree of muscle fatigue will be. Coordinates of saddle position of the sample point with minimum muscle stress squares are optimum parameters of frames of saddles. By applying the genetic algorithm, coordinates of the best corresponding saddle position have been found. With regression algorithm, the best position equation relation between human body size and height and the bicycle saddle has been built up. Finally, according to the theory that the angle between the chest and upper arm in ergonomics for 500 around is the most comfortable position in riding, a best position equation of the body height and handlebar has been set up. Eventually, the human-bike best position(handlebar, pedal, saddle) equation relation has been built up.

3.1 BP neural network

BP neural network in training process will make signal propagate forwards and errors back. Signals from the input layer are first to the hidden layer and then to the output layer. Processed step by step, neurons of each layer can only affect the next layer. If the accuracy of output value of the output layer cannot meet requirements, the counter propagation of errors will occur and the neural network in the global scope will adjust the network weights and threshold so that the final output can satisfy needs. The neural network topology is shown in Fig. 4.

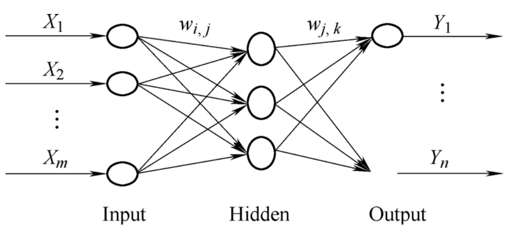


Fig. 4. BP neural network topology structure

In Fig. 4, $X_1, X_2, \cdots, X_m$ are inputted values of neural network, $Y_1, Y_2, \cdots, Y_n$ are outputted values of neural network. $\omega_{i,j}$ are weights between neurons from the i neuron of input layer to the j neuron of hidden layer. $\omega_{j,k}$ are weights between neurons from the j neuron of hidden layer to the k neuron of output layer. Take the bicycle saddle position coordinates as input values X, corresponding to that is the human lower limb muscle stress squares, as the output value of Y. The creation process of BP neural network is as follows.

We adopted the double BP neural network. The hidden layer of the BP neural network applies the sigmoid to transfer the equation and the nonlinear relation between the input and the output can be established. The output layer employs linear transfer equation, thus can output the value of any size. The most reasonable number of nodes in hidden layer can refer to

$$L < \sqrt{m+n} + a, \tag{2}$$

where L is the number of nodes in hidden layer, m and n are the number of nodes in the input layer and that of output layer respectively, and a is the constant between 0 to 10. In this paper, the number of input and that of output nodes are both11, which determine the number of nodes in hidden layer being 5.

Before training the neural network, the normalization processing of input/output data is needed. The normalization mainly uses the method of maximum minimum, shown in Eq. (3):

$$X_k = (X_k - X_{\min}) / (X_{\max} - X_{\min}), \tag{3}$$

where $X_{\min}$ and $X_{\max}$ respectively represent the minimum and maximum in the data set. X_k indicates the need of the normalized processing for data.

Selecting the equation of momentum gradient descent to train, the previous data of change in network weights and threshold each time are aggregated. In the process of the k loops, change quantity of weights and threshold are respectively shown in Eq. (4) and Eq. (5):

$$\Delta w(k+1) = A_k G_{w(k)} + mc \bullet \Delta w(k-1), \quad (4)$$

$$\Delta b(k+1) = -A_k G_{b(k)} + mc \bullet \Delta b(k-1). \quad (5)$$

$G_{w(k)}$ and $G_{b(k)}$ are the weight value and threshold value of current performance equation. A_k is the learning rate, if the value is too large, the stability of network will be reduced. Its value is usually supposed to be 0.05. MC is the momentum coefficient with the value, 0.9. In order to satisfy requirements of accuracy, it is usually required that the training times should be as much as possible, so we usually do the training 100 times. In order to avoid local minimum, the value should be tuned larger, but if too large, over-fitting will occur. Thus, the number of iterations is set as 20 times.

3.2 GA (genetic algorithm)

First of all, encoding and decoding of chromosome have been done.

Encoding: the value range of the dependent variable is to be [U_1, U_2]; if the length of the binary code is k, the dependent variable will have the method of encoding up to 2^k in total. The encoding corresponding relationship of dependent variable is shown in Fig. 5.

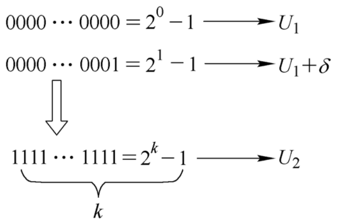


Fig. 5. Diagram of encoding corresponding relationship

Decoding: if a particular individual is coding like $b_k b_{k-1} \cdots b_2 b_1$, then the decoding is shown as

$$X = U_1 + \left(\sum_{i=1}^{k} b_i \bullet 2^{k-1} \right) \bullet \frac{U_2 - U_1}{2^k - 1}. \quad (6)$$

In order to gain satisfactory optimal value, the selection process of controlling parameters was introduced as follows:

(1) The crossover probability value is 0.4;

(2) The mutation probability value is 0.1;

(3) The number of species is 40.

Number of iterations refers to the times of the evolution of chromosome in genetic algorithm, commonly 100 times Do the intersecting and mutation of individual chromosome. Select the individuals which meet the requirements of fitness to the next round of iterations. After 100 times, select the individual that meets the requirements of fitness to the most as the optimal value to output and finally do the decoding. Then, achieve the best position between body height and the saddle. By genetic algorithm, after the calculation of neural network, best position of saddle under different height is got, which is shown in Table 2.

Table 2. Best position between body height and saddle

Height h/mm	Saddle abscissa x_A/mm	Saddle ordinate y_A/mm
1600	183	493
1640	188	520
1680	188	510
1720	200	556
1760	188	580
1800	196	630
1840	219	631
1880	211	661
1950	240	687

3.3 Regression analysis

Based on Table 2, the equation relation has been established with height as the independent variable, the horizontal value x_A and ordinate value y_A as dependent variables, with the help of SPSS software to conduct regression calculation. In the curve estimating process, a total of 11 kinds of mathematical models have been established, not all of which had practical significance.

Therefore, a test was required if the optimal regression equation could be selected out from numerous models. There are three main inspection methods of regression equation: square difference test method, correlation coefficient test method and residual test method. Correlation coefficient test method was employed in this paper. The correlation coefficient can describe the closer degree between variables. Correlation R^2 is defined as

$$R^2 = SSR / SST = 1 - SSE / SST, \quad (7)$$

where SSE is residual sum of squares, SSR is regression square sum and SST is total sum of squares.

R^2 is on behalf of good fitting degree of regression model. The equation shows how SSR increases in proportion to R^2. The bigger R^2 is, the higher the correlation degree between x and y, and the better model fitting degree will be. The size of R^2 should be considered when choosing the best model. There are 11 different regression analysis methods applied in this paper to deal with best position axis coordinate data of the human body height and the x- axis of saddle. The results are shown in Table 3.

From the table above, cubic polynomial R^2 is largest in the 11 equation models, with value, 0.881. The second is quadratic polynomial, its value is 0.88. Since the numerical difference of the two regression models is delicate, a significance test on two regression equations needs to be done in order to select the best model.

In the regression equation, regression square sum SSR reflects influence of independent variable x on the dependent variable y. For a given significance level α, if $F>F_{\alpha}(m, n-m-1)$, then x on y is significant. "m" is the number of independent variables, while "n" is the number of test. If α equals to be 0.01, look it up in table, then $F_{0.01}(1, 7)$shall be 12.25. Since value of F in the quadratic polynomial regression model and cubic polynomial regression model is bigger than 12.25, so the independent variables and dependent variables of the two models have significant relationships. With smaller value of F, the connection degree of sample variables can be much easier to reflect the whole variables in the degree of correlation From the table above, the quadratic polynomial is chosen as the final regression equation. Eventually, the equation relation of body height and the x-axis of saddle best position can be built up, such as

$$x_A = 1396.902\,5 - 1.499\,1h + 0.000\,4h^2, \tag{8}$$

where x_A is the x-axis coordinates of the saddle, h is the body height.

Table 3. Regression analysis results of saddle *x*-axis data

Equation type	Model Summary				Estimate of Parameter			
	R_2	F	df_1	df_2	Constant	b_1	b_2	b_3
Linear equation	0.792	26.576	1	7	–53.057	0.144		
Logarithmic equation	0.776	24.206	1	7	–1684.513	252.367		
Reciprocal equation	0.759	22.044	1	7	451.636	–439 503.019		
Quadratic polynomial	0.880	21.907	2	6	1396.902	–1.499	0.000	
Cubic polynomial	0.881	22.277	2	6	518.775	0.000	0.000	1.606×10^{-7}
Compound equation	0.804	28.707	1	7	58.880	1.001		
Power equation	0.790	26.256	1	7	0.022	1.217		
S-model	0.774	23.989	1	7	6.510	–2122.234		
Growth model	0.804	28.707	1	7	4.075	0.001		
Exponential equation	0.804	28.707	1	7	58.880	0.001		
Logistic-model	0.804	28.707	1	7	0.017	0.999		

In the same way, this paper uses 11 different regression analysis methods to tackle best position axis coordinate data of the human body height and the y-axis of saddle. The results are shown in Table 4.

Table 4. Regression analysis results of saddle *y*-axis data

Equation type	Model summary				Estimate of parameter			
	R_2	F	df_1	df_2	Constant	b_1	b_2	b_3
Linear equation	0.963	187.218	1	7	–469.518	0.598		
Logarithmic equation	0.963	188.425	1	7	–7311.835	1056.751		
Reciprocal equation	0.963	179.799	1	7	1643.526	–1 858 892.093		
Quadratic polynomial	0.964	81.410	2	6	–880.423	–1.064	0.000	
Cubic polynomial	0.965	81.410	2	6	–768.112	0.852	0.000	-2.692×10^{-8}
Compound equation	0.959	162.130	1	7	95.660	1.001		
Power equation	0.961	172.875	1	7	0.001	1.810		
S-model	0.962	175.646	1	7	8.181	–3188.167		
Growth model	0.959	162.130	1	7	4.561	0.001		
Exponential equation	0.959	162.130	1	7	95.660	0.001		
Logistic-model	0.959	162.130	1	7	0.010	0.999		

From the above table, cubic polynomial' R^2 is largest in the 11 equation models, its value is 0.965. The second is quadratic polynomial, its value is 0.964. Since the fine numerical difference of the two regression models, with reference to the x-axis analysis method of saddle, the F value of Quadratic polynomial regression equation is smaller than cubic polynomial regression equation, thus the quadratic polynomial is chosen as the final regression equation. Eventually the equation relation of body height and the y-axis of saddle best position can be built up, such as Eq. (9):

$$y_A = -880.423\,4 + 1.063\,9h + 0.000\,1h^2, \tag{9}$$

where y_A is the y-axis coordinates of the saddle, h is the body height.

Based on the height of the human body, the corresponding optimal handlebar position can be got. According to the theory that the angle between the chest and upper arm in ergonomics for 50° around is the most comfortable position in riding, the position of handles can be defined, so can the best position of handles under different body height. Upper body best riding position is shown in Fig. 6.

Based on the best position of handles under different body height, best comfortable angle of upper body can determine the position of the handlebar relative to the saddle. Therefore, the handlebar coordinates can be determined. Finally, the best position of the handlebar has been established under different height sizes. The best position between human height parameters and handlebar is shown in Table 5.

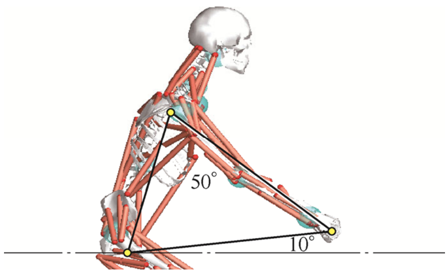


Fig. 6. Upper body best riding position

Table 5. Body height and the corresponding handlebar best position

Height h/mm	Handlebar abscissa x_c/mm	Handlebar ordinate y_c/mm
1600	–380	593
1640	–399	651
1680	–416	625
1720	–413	671
1760	–444	707
1800	–445	753
1840	–432	757
1880	–466	791
1950	–442	818

With reference to the best position determination method, the equation relation of best position can be built up, such as Eq. (10) and Eq. (11):

$$x_h = 2196.434\,1 - 2.743\,2h + 0.000\,6h^2, \quad (10)$$

$$y_h = -1192.235\,5 + 1.364\,3h - 0.000\,5h^2, \quad (11)$$

h is the body height, x_h is x-axis coordinates of the handlebar, y_h is y-axis coordinates of the handlebar.

4 Experimental Verification

To illustrate the correctness of the equation relation of best position between people and bikes, we designed and worked out a customized bike and compared it with one common bike. There are two standards of evaluating cycling effect: maximum oxygen uptake(VO2MAX) and electromyography signal of the body. VO2MAX is also known as oxygen limit. It is an important evaluation index of body equation of cyclists. The bigger the value of VO2MAX of the athletes is, the longer the body can bear the high levels of lactic acid produced under exercise of high intensity, which can obtain better results[24]. The laboratory equipment is the German architecture exercise cardiopulmonary equation tester and the Instant Heart Rate. The body's muscle electromyography signal can be a very effective evaluation of degree of muscle activity. According to the signal above, with the help of Noraxon measurement instrument, we can accurately determine whether muscles are fatigue or not.

First, select a tester with a height of 1730 mm. According to the equation relation of the best position between human and bikes, design and work out a suitable bike for the tester. Then, buy one bike with the same configuration of the customized bicycle.

Before carrying out the experiment, let the rider wear breathing mask and be installed an automatic recorder of heart rate. Breathing mask aims to measure parameters such as the respiratory exchange ratio and the oxygen uptake of the rider. The automatic recorder of heart rate is to gather parameters of human heart rate in the riding process. Then, put detecting electrodes in the femoral muscle, rectus muscle and vastus lateral muscle.

Then, carry out the experiment. The testers were required to ride continuously for 15 min respectively at the speed of 50 r/min, 60 r/min and 70 r/min, riding 5 min under a speed level. With the electromyography instrument, we recorded one-minute-long electronic data of the lower limb muscle in the initial and the end of each phase per speed level, and then cut out a smooth continuous signal data of 10 seconds from the EMG data. For those testers with better body conditions, they may not reach the state of exhaustion after the experiment, so the maximum value of oxygen uptake of testers in the process of riding can't be the VO2MAX. The well-used criteria to judge the VO2MAX was to observe whether a peak value appears; if this peak value occurs, and then that will be the VO2MAX. In the riding process, testers have to control the respiratory frequency and cycling speed so as to ensure stability of the measurement signal. After riding customized bikes, testers would have a rest for three days to ensure the body could recover from fatigue sound, and then conduct the riding experiment of a common bike. The experiment is shown in Fig. 7.

Evaluation index is signed as the mean frequency of surface EMG The calculation method of the median frequency is shown as Eq. (12):

$$MF = \frac{1}{2}\int_0^{\infty} S(f)\mathrm{d}f, \quad (12)$$

Where f is the frequency; $S(f)$ is power spectral density character curve. The median frequency values of electromyography signal for each time period is shown in Table 6.

TIAN[25] confirmed that the median frequency of time multi-channel semg linear fitting equation can effectively evaluate muscle fatigue, the greater the slope of the linear fitting equation, the smaller muscle fatigue and the more comfortable the cyclists ride. With linear fitting of data in Table 3, fitting equation is shown in Fig. 8.

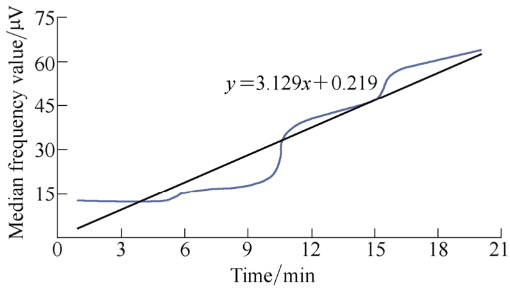
(a) Riding of an common bike

(b) Riding of a customized bike

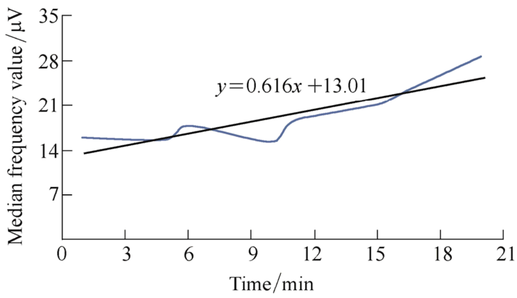
Fig. 7. Cycling test

Table 6. Median frequency values of electromyography signal

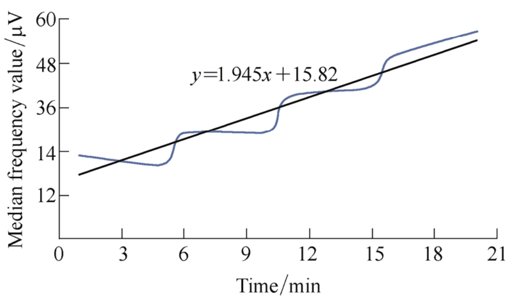
Time/min	Rectus femoris/ μV		Vastus medialis/ μV		Vastus lateralis muscle/ μV	
	Customized bike(a)	Mountain bike(b)	Customized bike(c)	Mountain bike(d)	Customized bike(e)	Mountain bike(f)
1	12.3	16	22.9	7.8	13.3	7.2
5	12.8	15.8	20.7	8.5	13.7	7.5
6	14.9	17.8	28.9	10	22.4	9.9
10	20.6	15.4	29.6	10.2	19.8	11.5
11	36.8	18.5	38.7	10.8	30	11.7
15	46.6	21.2	42.3	13.2	35	12.8
16	56.7	22.6	50.1	14.1	43.8	14.9
20	63.9	28.6	56.8	14.4	56.1	17.5



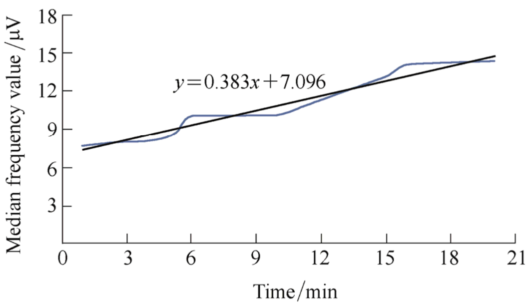
(a) Rider rectus(RecFem) of a customized bike



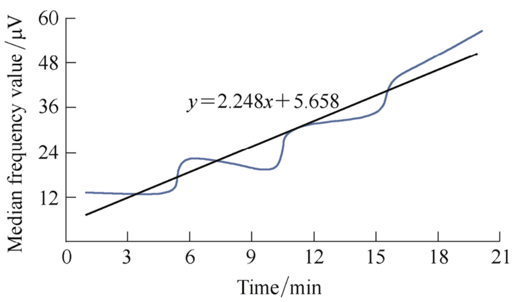
(b) Rider rectus(RecFem) of an ordinary bike



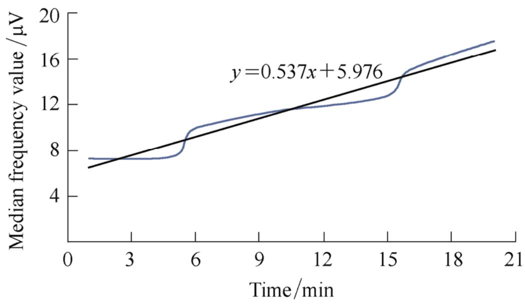
(c) Rider intrinsic(VasMed) of a customized bike



(d) Rider intrinsic(VasMed) of an ordinary bike



(e) Rider femoral muscle(VasLat) of a customized bike



(f) Rider femoral muscle(VasLat) of an ordinary bike

Fig. 8 Linear fitting equation MF slope

Fig. 8 shows that the fitting equation of rider rectus (RecFem), the intrinsic(VasMed) and femoral muscle (VasLat), the linear fitting equation MF slope of customized bike is significantly greater than that of common ones, thus muscle fatigue of testers on customized bikes is far less than that of mountain bikes. It is concluded that customized bicycles are four times even six times as comfortable as common ones. The bike customized according to the tester's height, compared to conventional ones, can better relive muscle fatigue of athletes. And the time is longer in riding the customized bike when vo2 Max appears than ordinary bikes. With customized bikes, riding will be more comfortable and easier to get good grades. Eventually, the correctness of the equation relation was proved.

5 Conclusions

(1) By using the lifemode software, the model of human and bike is built up. The common riding process is simulated; meanwhile, the muscle stress quadratic sum of lower limbs during cycling is collected.

(2) Neural network genetic algorithm is used to find the best position of human-bike system, and to obtain the size function of that position.

(3) By setting the comparison, the surface EMG and the maximal oxygen uptake of testers are obtained, testifying the rationality of the human-bike size function, under which the rationality of this function to design bikes is explained.

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