Design and development of networked real-life cycling training system based on mixed reality technology

Zhiqiang Gong [a], Wenchang Duan [b]

School of Mathematics and Computational Science, Xiangtan University, 411100, China

[a] 201905556426@smail.xtu.edu.cn, [b] 201905820814@smail.xtu.edu.cn

Abstract. The intelligent riding platform cooperates with the PC-side riding training system to simulate the effect of outdoor riding with a certain sense of reality. With the rapid development of information technology, users have also put forward higher requirements for cycling training systems. The 3D virtual scene riding mode provided by the existing intelligent riding training system does not meet the user's preference for real riding, and the domestic riding platform cannot simulate the real road feeling, lacking realism and fun. Therefore, developing a richer and more interesting new cycling training mode and creating a more realistic and accurate real cycling experience based on mixed reality are the new demands of users for the cycling training system. At the same time, the calculation and development of rider power based on the platform is the core of it. In the original single-person riding training mode, the server framework and client-side functional modules are constructed by using the principle of network communication and related technologies such as the production of online game rooms to realize the multi-player competitive function.

Keywords: real-life cycling, Bluetooth 4.0, ANT+, mixed reality, server.

1. Introduction

With the improvement of the social material level and the improvement of the quality of life, people gradually take sports and fitness as a life pursuit, and the bicycle is no longer just a means of transportation, but also a fitness equipment[1]. Under the background of low-carbon sustainable development, the concept of green travel is deeply rooted in the hearts of the people, and the "green sport" of cycling is popular all over the world. With Chinese cyclists winning gold at the Rio Olympics, the sport has grown in popularity[1].

Cycling is not only one of the ideal forms of fitness, it can also take us away from the city full of tall buildings and relieve the stress of work while enjoying the natural beauty. As a result, cycling has become a fun and lively urban leisure lifestyle. However, due to environmental pollution and other reasons, the haze weather and cold air during outdoor riding will damage the health of riders to a certain extent; and poor sight and road conditions will also bring some safety hazards[2]. These have become important factors that hinder people from cycling. Therefore, indoor cycling machines that are not affected by riding conditions such as environment, weather, time, etc. It has become an ideal choice for the majority of riders[2].

1.1 Research status at home and abroad

The active development of cycling events not only promotes the development of cycling, but also raises riders' awareness of scientific training, and the unfamiliar field of indoor cycling training is gradually being understood by more people[3]. Thanks to the continuous improvement of the level of science and technology, the cycling training system has also developed rapidly. From the most basic mechanical trainer models to smart trainers with data logging and analysis capabilities, many new trainer categories are emerging[4].

Foreign cycling training system manufacturers represented by Tacx and Bkool have been developing cycling platforms since the 1970s[5]. After 40 years of technical precipitation, they have completed multiple sets of cycling platforms ranging from mechanical cycling platforms to smart cycling platforms. Mature product line[5]. However, almost all foreign cycling systems are charged, and for the majority of domestic cycling users, the localized services of their cycling platforms are not very satisfactory. The riding experience is relatively poor[6]. Moreover, the cycling platforms of some manufacturers are not open and cannot be compatible with multiple products, making it difficult for domestic users to conduct cycling training.

2. Model design

2.1 Force analysis

During the riding process, the rider is mainly affected by air resistance, friction and inertial force. And the inertial force $F_{\text{acc}} = am$ of the rider in the acceleration and deceleration stages, where a is the acceleration. In fact, the rider's acceleration and deceleration phases during the ride are very short, and most of the time the ride is at a constant speed. The work done by its motion is mainly used to resist the influence of resistance, so the inertial force can be ignored. In this paper, air resistance and friction are discussed separately[6].

2.2 air resistance

The expression for air resistance is:$\mathrm{F_{wind}} = \mathrm{rc_W A v_{wind}^2}/2$

Among them, r is the air density, normal dry air can take 1.293g/l, which is the air resistance coefficient, $\mathrm{c_W}$ is related to the smoothness and shape of the object, A is the windward area of the object, and v_{wind} is the relative movement speed of the object and the air.In a given track, the air resistance coefficient can be considered to be constant, so this article will discuss the air resistance of the rider from the perspective of windward area and relative movement speed.

2.2.1 Frontal area

During the riding process, the different posture of the rider will determine the difference in the windward area. Under normal circumstances, there are upper handle position (holding both hands on the handlebar cross), hand position (holding both hands on the head of the hand), lower handle position (grasping the lower bend of the handlebar), TT position, (Bend your elbows and forearms together and place them on the handlebars) in four positions. The wind resistance is generally TT posture < lower handle position < hand displacement < lower handle position.

Further subdivision, you will get nine types as shown in Figure 1:

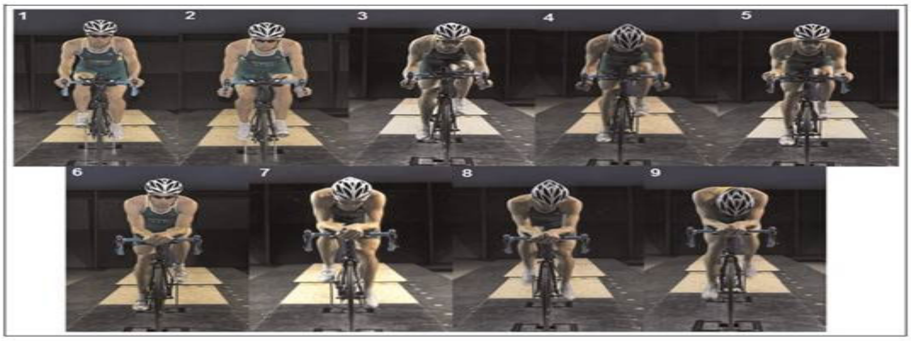

Figure 1. Nine riding postures

The corresponding windward area is shown in Figure 2:

Posture	C_DA (m^2)	Power required (W)	Delta C_DA (m^2)	Delta power (W)
1	0.343	430		
2	0.332	417	0.011	13.0
3	0.306	385	0.037	43.9
4	0.321	403	0.022	25.9
5	0.295	372	0.048	56.0
6	0.289	365	0.054	63.6
7	0.283	358	0.060	70.1
8	0.295	372	0.048	56.5
9	0.287	363	0.056	65.1

Figure 2. Windward area of nine riding positions

2.2.2 Speed

We know that speed is a vector physical quantity, so we need to consider both the magnitude of the speed and the direction of the speed.

In terms of speed, people will be affected by wind direction and wind strength during riding. In practice, the wind speed perceived by the rider is the relative wind speed, which is the vector difference between the wind speed and the rider's speed. Based on the air drag formula, we know that drag is proportional to the square of the relative wind speed, while power is the product of drag and the inline part of the rider's speed. The time it takes for a rider to complete a race increases approximately exponentially as the wind strength increases. And when the wind strength is too high, the rider can't even finish the race due to the limitation of the rider's own power curve. Therefore, in a headwind condition, the rider tries to adopt a low-speed riding strategy[7].

For the speed direction, we used the method of controlling variables to explore the rider's speed corresponding to different wind direction angles under constant power, and the rider's power corresponding to different wind direction angles under constant speed. Among them, in order to eliminate the influence of dimensions, we standardized the rider power. It is calculated that the race time will be reduced in the tailwind state compared to the headwind state. And a tailwind doesn't make up for the time lost in a headwind at the same speed, and the wind direction actually affects the rider's drag more than the thrust. Therefore, the rider's race time is more sensitive to the wind direction angle[8].

As can be seen from the image, we can approximately think that when the wind direction angle is 0°-90°, it has a pushing effect on the rider; when the wind direction angle is 105°-180°, it has a blocking effect on the rider; and when the wind direction angle is 90°-105° In the range, the wind tends to push the rider with a stronger power curve and retard the rider with a weaker power curve.

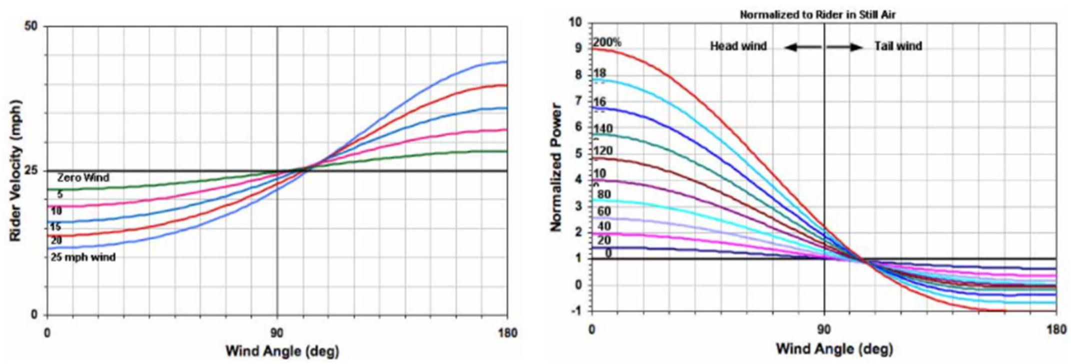

Figure 3 The effect of wind direction on cycling

2.2.3 friction

The friction force experienced by the rider is mainly divided into rolling friction force and gradient force.

Rolling Friction: $F_{roll} = c_r mg$

Slope Force: $F_{slope} = smg$

In the process of going uphill, due to the influence of the slope, the gravity of the athlete and the bicycle will also become the resistance to their forward movement, and the slope force is the synthesis of gravity and friction $F_{upslope} = c_r mgcos\theta + mgsin\theta$. In the process of downhill, gravity forms thrust, and the gradient force is the difference between gravity and friction $F_{downslope} = c_r mgcos\theta - mgsin\theta$.

2.2.4 Total resistance

The terrain of the track is complex and changeable, which can be roughly divided into straight sections, slopes and curves. Below, we analyze the force of the rider and bicycle during the riding process for each road segment.

2.2.5 Straight road section

On straight sections, the rider is primarily exposed to air resistance for high-speed bicycles $F_{\text{wind}} = rc_W A v_{\text{wind}}^2/2$ and frictional force $F_{roll} = c_r mg$.Therefore, the force experienced by the rider is:

$$F_A = F_{\text{wind}} + F_{roll} = \frac{rc_d A v_{\text{wind}}^2}{2} + c_r mg$$

The total resistance is related to the speed. When the speed increases, the air resistance gradually increases and is closer to the total resistance.

The resultant force on the slope is:

$$\begin{cases} \mathrm{F}_C = \mathrm{F}_{wind} + \mathrm{F}_{\mathrm{up}slope} = \frac{1}{2} C_d \rho A v^2 + c_r mg \cos\theta + mg \sin\theta, upslope \\ \mathrm{F}_C = \mathrm{F}_{wind} + \mathrm{F}_{downslope} = \frac{1}{2} C_d \rho A v^2 + c_r mg \cos\theta - mg \sin\theta, downslope \end{cases}$$

In corners, the bike and rider also experience centripetal forces. In order to maintain stability, the rolling friction of the bicycle increases to resist centripetal force, and as the speed increases, the rolling friction increases. Therefore, the force experienced by the rider is the sum of air resistance and centripetal force.

$$\mathrm{F_B} = \mathrm{F}_{wind} + \mathrm{F}_{curve} = \frac{1}{2} C_d \rho A v^2 + \mathrm{c}_r mg$$

In addition, the inner and outer circles of the corner have different effects on the power consumption of the rider. The ideal situation is that the rider can enter and exit the corner without braking. This reduces power loss and saves more stamina for the rest of the bike phase[9].

For the convenience of calculation, we assume that the relationship between the output power of the player in the corner and the curvature of the curve is:

$$\mathrm{P_{curve}(t) = P(t) * e^{-\delta}}$$

Among them, δ represents the curvature coefficient, that is, the greater the curvature, the greater the impact on the output power.

2.3 Rider Power

From $P = Fv$, we can obtain the expression of the instantaneous output power of the rider in the three road sections as

$$\begin{cases} P_A = \mathrm{P}_{wind} + \mathrm{P}_{roll} = \frac{1}{2} C_d \rho A v^3 + c_r mgv \\ P_{\mathrm{B}} = \mathrm{P}_{wind} + \mathrm{P}_{curve} = \frac{1}{2} C_d \rho A v^3 + m \frac{v^3}{R} \\ P_C = \mathrm{P}_{wind} + \mathrm{P}_{slope} = \frac{1}{2} C_d \rho A v^3 + (c_r mg + mg \sin\theta) v \end{cases}$$

Among them, A, B, and C represent the movements of the rider on flat ground, corners, and slopes, respectively.

the weak function of the rider:

$$\mathrm{P_{weak}(t) = P(t) * e^{-wt}}$$

where w is the frailty index and t is the duration of frailty

Let the total duration be t total, divide the t total infinitely into n equal parts, $\mathrm{n} \to \infty$, so the distance at each moment can be expressed as

$$S_t = \frac{t_{all}}{n} \int_0^i v_j dj$$

After consulting, it was found that the maximum oxygen uptake decreased by about 5% for every 5,000 feet of elevation. The functional relationship between the maximum oxygen uptake and the altitude was obtained as follows:

$$n = -3.28h + n_0$$

Therefore, the power change due to the change in track altitude is:

$$P_h = \frac{n}{n_0} P_{max}$$

2.4 Rider power output optimization model

Anaerobic respiration can release less energy, which is the self-protective behavior of the body when it is overloaded. However, with the decrease of exercise intensity, after lactic acid is metabolized, it can be gradually transformed into aerobic respiration. This process takes about 30 minutes[10].

The duration of a time trial is generally 1-2 hours. What is the duration of the time trial for the 2021 Olympic Games? h, What is the duration of the 2021 UCI World Championship? h. We therefore assume that in a time trial, the athlete can perform a maximum of 2 anaerobic breaths. From this, the constraint (1) can be obtained as:

$$\int_0^t \mathrm{P}t \le W_{all}$$

In problem 1, we have obtained the maximum output power curve of the athlete, and we can know that the maximum power that the athlete can output has its upper limit, so the constraint condition (2) is

$$P_i \le \mathrm{P}_{i\max} + \int_0^{i-1} (P_{j\max} - P_j)dj$$

in the previous section , we get the expression of the power of the athlete in different terrains.Here, we define three indicative functions XA(x), XB(x), XC(x) as follows:

$$X_A = \begin{cases} 1, x \in A \\ 0, x \notin A \end{cases}, X_B = \begin{cases} 1, x \in B \\ 0, x \notin B \end{cases}, X_\mathrm{C} = \begin{cases} 1, x \in \mathrm{C} \\ 0, x \notin \mathrm{C} \end{cases},$$

The total power P of the athlete,

$$\mathrm{P} \ge X_A P_A + X_\mathrm{B} P_\mathrm{B} + X_\mathrm{C} P_\mathrm{C}$$

In addition, the rolling friction force should be greater than the centripetal force at the curve

$$f \ge X_\mathrm{B} \frac{mv^2}{R}$$

All in all,

$$\min t$$

$$s.t. \begin{cases} \int_0^t \mathrm{P}t \le W_{all} \\ P_i \le \mathrm{P}_{i\max} + \int_0^{i-1} (P_{j\max} - P_j)dj \\ \mathrm{P} \ge X_A(x) P_A + X_\mathrm{B}(x) P_\mathrm{B} + X_\mathrm{C}(x) P_\mathrm{C} \\ f \ge X_\mathrm{B} \frac{mv^2}{R} \end{cases}$$

3. Design and development of networked real-life cycling training system

3.1 Piecewise polynomial fitting power algorithm

The riding controller receives the slope data of the real track and matches the corresponding gear to adjust the resistance. Therefore, the riding power is affected by two factors, the riding speed and the corresponding gear, and the relationship between the three is not a simple linear relationship. Since the surface fitting is greatly affected by the error interference, and based on the characteristic that the power data corresponds to the gear position, a piecewise polynomial fitting method is used to obtain the power algorithm. The corresponding power-speed curve is measured in different gears, and then polynomial curve fitting is performed to obtain the final power algorithm.

$$\begin{cases} na_0+\left(\sum_{i=1}^{n} v_i\right)a_1+\cdots+\left(\sum_{i=1}^{n} v_i^m\right)a_m=\sum_{i=1}^{n} p_i \\ \left(\sum_{i=1}^{n} v_i\right)a_0+\left(\sum_{i=1}^{n} v_i^2\right)a_1+\cdots+\left(\sum_{i=1}^{n} v_i^{m+1}\right)a_m=\sum_{i=1}^{n} v_i p_i \\ \cdots\cdots \\ \left(\sum_{i=1}^{n} v_i^m\right)a_0+\left(\sum_{i=1}^{n} v_i^{m+1}\right)a_1+\cdots+\left(\sum_{i=1}^{n} v_i^{2m}\right)a_m=\sum_{i=1}^{n} v_i^m p_i \end{cases}$$

Then convert these equations into matrix form, you can get the following matrix:

$$\begin{bmatrix} n & \sum_{i=1}^{n} v_i & \dots & \sum_{i=1}^{n} v_i^m \\ \sum_{i=1}^{n} v_i & \sum_{i=1}^{n} v_i^2 & \dots & \sum_{i=1}^{n} v_i^{m+1} \\ \vdots & \vdots & \ddots & \vdots \\ \sum_{i=1}^{n} v_i^m & \sum_{i=1}^{n} v_i^{m+1} & \dots & \sum_{i=1}^{n} v_i^{2m} \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ \vdots \\ a_m \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^{n} p_i \\ \sum_{i=1}^{n} v_i p_i \\ \vdots \\ \sum_{i=1}^{n} v_i^m p_i \end{bmatrix}$$

Then simplify this Vandermonde determinant to get

$$\begin{bmatrix} 1 & v_1 & \dots & v_1^m \\ 1 & v_2 & \dots & v_2^m \\ \vdots & \vdots & \ddots & \vdots \\ 1 & v_\mathrm{n} & \dots & v_n^m \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ \vdots \\ a_m \end{bmatrix} = \begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_i \end{bmatrix}$$

Could be written as vA=p, the coefficient matrix A can be solved, and the fitted power algorithm P(v)

3.2 Real scene motion control algorithm test

3.2.1 Real scene motion control algorithm test

The real scene motion control algorithm is mainly to innovate the key steps of the early data processing and riding algorithm of the real scene riding training system. Aiming at the real-time nature of the real-life riding system, an algorithm for dynamically fitting slope data is proposed. The processed slope data is shown in Figure 4.

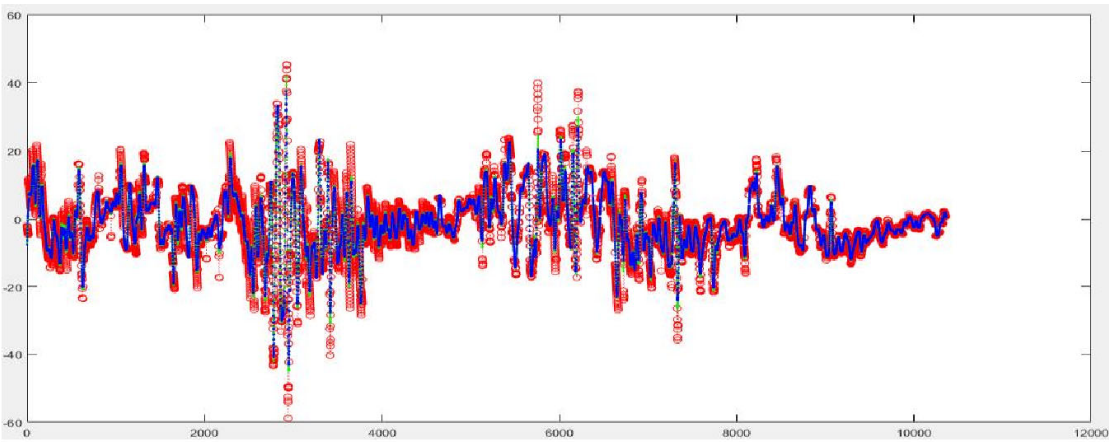

Figure 4. The rendering of the slope data after fitting

As can be seen from the above figure, the data is less disturbed by local noise, and the gradient data changes smoothly and stably, which can bring cyclists a smooth riding experience.

3.2.2 Dynamic Path Planning Test

In this paper, the movement path of the virtual character is planned by identifying and processing the lane lines of the scene. On straight roads with good road conditions, this algorithm can complete accurate lane line detection. On a curved road, the lane lines within a certain range can still be identified as straight lines, and the lane lines can be correctly detected for path planning. The test results are shown in Figure 5.

Figure 5. Test Results

4. Conclusion

This paper analyzes the force of the cyclist during the riding process, and finally obtains the optimal model of the cyclist's strength. With the development of technology and the improvement of user needs, the cycling training system is also constantly being upgraded, and its functions have also been greatly improved. The driver's goal is always to get to the finish line in the shortest time possible. If the rider adopts a better riding mode, his performance will be improved even more. With the progress of the times, riders in the new era hope to have more professional data analysis and technical guidance to further improve their performance. This article not only considers air resistance, friction, etc., but also the power generated by the rider himself due to altitude. There will be more parameters later to make the overall data more intuitive and clear. It is best to close it in the best posture model.

References

[1] Ba Hongbing. A brief analysis of the research status of cycling sports [J]. Modern Health, 2013(14): 72-73.

[2] China Net. The average number of days of fog and haze in nearly half of China's territory is the highest in 52 years [EB/OL]. http://news.china.com.cn/txt/2013-12/09/content_30836584.htm, 2013-12-09/2018-10-05.

[3] Zhu Shiqi. Qualitative research on the use of smart wearable devices by fitness people [J]. Bulletin of Sports Science and Technology Literature, 2017, 25(11): 127-128.

[4] Tacx J H J. Bicycle trainer[P]. U.S. Patent: 6,659,917, 2003-12-9.

[5] Tacx. Tacx T1000[EB/OL]. https://www.tacx.com/product/antares, 2018-09-20/2018-10-05.

[6] Tacx. Tacx trainer software 4 advanced [EB/OL]. https://www.tacx.com/en/products/software/tacx-trainer-software-4-advanced.

[7] Maijin Technology. Onelap [EB/OL], the first free smart cycling platform software in China. https://www.sohu.com/a/128355685_501219, 2018-09-20/2018-10-05.

[8] Qiu Huaiyu. Design and development of intelligent cycling platform software training system [D]. Hangzhou: Zhejiang University of Technology, 2016.

[9] Zhou Kun, Tong Yiying, Pan Zhigeng, et al. VECW: Construction and Roaming System of a Virtual Environment [J]. Journal of Computer Aided Design and Graphics, 2000, 12(5): 355-359.

[10] Qiu Zhengguang. Design and Implementation of IoT Monitoring Platform Based on Virtual Reality [D]. Guangxi: Guilin University of Electronic Science and Technology, 2017.