Design of virtual reality cycling intelligent interaction system based on VR technology

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Abstract: Aiming at the problems of small touch sensing range of user interface, low user satisfaction and long system response time existing in the current intelligent interactive system, this paper designs an intelligent interactive system of virtual reality bicycle riding based on VR technology. The user interface and image filter of the system hardware are optimised to realise 3D virtual modelling of cycling. On this basis, VR virtual technology is introduced to effectively integrate constraint factors of interactive components, so as to improve the authenticity of outdoor cycling simulation and realise intelligent interaction. The experimental results show that the touch sensing range of the studied system is between 145 nm^2 and 185 nm^2, the user satisfaction tends to 1 infinitely and the response time is less than 2.3 s, indicating that the system has good intelligent interaction.

Keywords: VR technology; virtual reality; cycling; interactive systems.

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1 Introduction

With the continuous improvement of people's living quality, outdoor cycling has become a competitive way for urban residents to do physical exercise (Skowron and Jankowski, 2019). Owing the continuous improvement of traffic safety level, the groups and purposes of cycling become more diverse and the connotation of bicycle is also richer. It has become the future development trend of the bicycle industry to dig into the cycling needs of a subdivided group and provide more professional functions and services (Zheng et al., 2019). Outdoor bicycle cycling is restricted by different degrees of environmental conditions, so it is impossible to accurately grasp the information and data of related sports. Human-machine interaction technology utilises modern wireless communication to realise the intelligent communication of single workshop data, and realises the interaction and cooperation between vehicles, which is beneficial to improving the safety level of outdoor cycling. Therefore, the design of intelligent interactive cycling system is of great research significance (Saulnier et al., 2020).

Liu et al. (2019) based on somatosensory interaction and virtual reality technology in the intelligent interactive movement system, due to the outdoor sports affected by environmental factors and safety performance is low, indoor cycling device experience is relatively single, type selection of hall sensor, through six gyroscopes and upload data gathering, combining Unity3D cycling scene virtual interactions. The physical sign information collection device is used to collect the physiological index parameters such as the heart rate of the cyclist, which is convenient to guide the cycling. However, the system has the problem that the touch sensing range of user interface is small. Liu and Zhang (2019) proposed an intelligent auxiliary system for cycling. Realise the normal cycling equipment intelligent, fully integrated into the modular system circuit design, including display, collection and communication module, cycling system including environmental awareness, heart rate and calories monitoring, change in the external environment, against riding condition, issued a warning information, and upload to the mobile terminal through a Bluetooth device. However, this system has the problem of poor user satisfaction. Zheng et al. (2019) proposed a bicycle virtual scene system based on virtual reality technology. The C# program generated interface programming software is Unity, which integrates the preferences of the cyclists, selects the cycling mileage, slope number and Angle, controls the parameters, simulates the virtual scene of the bicycle and makes the cycling process more humanised. But the intelligent interaction of the system has the problem of large response time.

In order to solve the problems of the above-mentioned intelligent interaction system, such as small touch perception range, poor user satisfaction and long system response time, a virtual reality bicycle riding intelligent interaction system based on VR technology was proposed and designed. The overall design scheme of the system is as follows:

(1) In order to improve the effect of intelligent interaction of virtual reality bicycle cycling, based on the logical framework of real scene training, the system hardware was optimised for the user interface module, image filter module and real-scene 3D modelling module respectively and the noise reduction processing of image acquisition was completed.

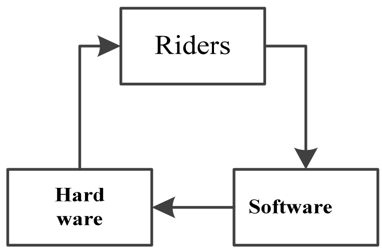
(2) Upon completion of the system hardware design, on the basis of the introduction of VR virtual technology, analyse the cycling layout principles and establish the objective function, the interface element weights, through inhibition of virtual user generated virtual figures mask model noise edge information and fully integrated with real-world user virtual character, in order to realise the goal of virtual imaging bike riding intelligent interactive improve.

(3) Performance verification: The touch sensing range of the user interface, user satisfaction and system response time were taken as the experimental comparison indexes, and the proposed system was compared and verified with the systems in Liu et al. (2019); Liu, C. and Zhang et al. (2019) and Zheng et al. (2019).

2 Intelligent interactive system for virtual reality cycling based on VR technology

The VR virtual technology is applied to the system software design of virtual reality bicycle riding visualisation, and the system software is developed on the Windows platform. The man-machine system is mainly formed by the cyclist (human) and the software and hardware (machine) of the system. The work flow of the human-machine interaction system is shown in Figure 1.

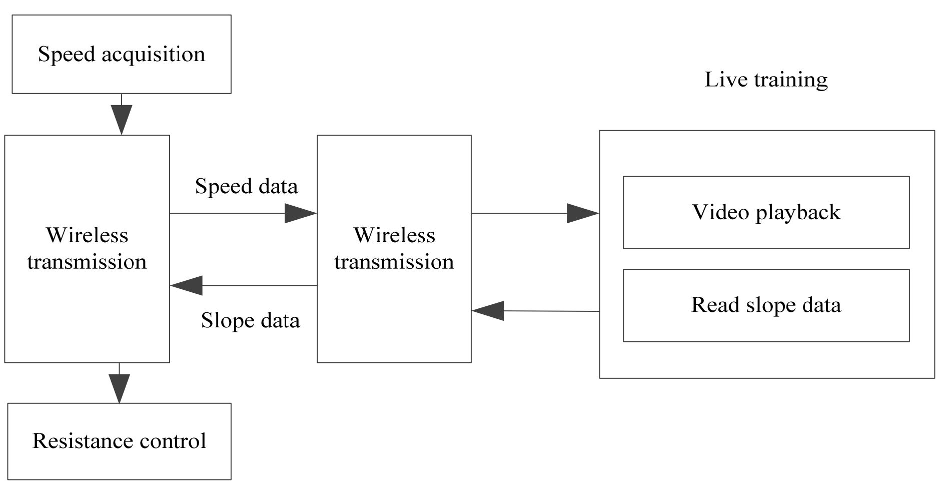
Figure 1 Man-machine system flow chart



Based on the man-machine system workflow as shown in Figure 1, the hardware of the intelligent interactive system of virtual reality bicycle riding was optimised.

In the process of cycling, the real-time training system is used to read the cycling speed data and carry out real-time tracking and control (Baker et al., 2020). First of all, the speed scene is obtained based on the driving video player, and the slope data in the road condition is collected by the system and uploaded to the cycling platform. Secondly, the slope data is processed by the resistance control module, and the cycling resistance is adjusted based on the adjustment results, so that the simulated environment is close to the real cycling environment. The logical framework of real-scene training is shown in Figure 2.

Figure 2 Logical framework of real scene training



Under the logic frame structure of live-action training, the 8-bit analogue digital signal of the camera is quantified, and the synchronous signal contained in it is output separately (Errichiello et al., 2019). The design of clock synchronisation circuit is simplified. SAA7111A decoder chip produced by PHILIPS is selected to reduce the complexity of the system circuit. External controller using the I2C bus control chip internal operation, the Chroma and luminance signal processing different input values, the Chroma, saturation and brightness, the chip support multiple output formats, can automatically detect and separate line, field synchronisation signal, so as to meet the optimisation of virtual imaging bike riding intelligent interactive system requirements.

2.1 Hardware design of virtual reality cycling intelligent interactive system

In order to improve the intelligent interaction performance of virtual reality cycling, it is necessary to optimise the design of the intelligent interaction system from two aspects of system hardware and system software. Based on the real scene training logic framework shown in Figure 2, the system hardware is optimised from three parts: user interface module, image filter module and real-scene 3D modelling module.

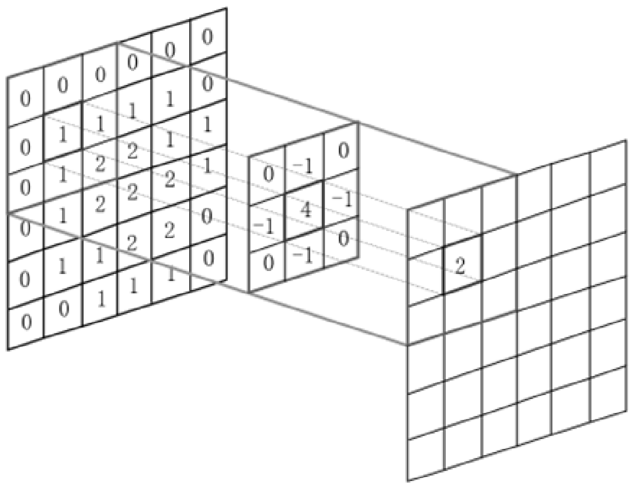
1) *User interface module*: For augmented reality technology is one of the virtual reality technology, the main differences are: virtual reality technology is to create a new virtual world; Augmented reality technology is the combination of virtual and real, that is, the fusion of the real world environment and the virtual objects formed by computer. Augmented reality represents a kind of real virtual space, which is based on computer as a carrier to simulate and integrate virtual objects into the real environment. Through the display device, users can intuitively see the virtual interface of the two and fully integrate into the virtual environment. Its basic characteristics are interactivity and conception, which belongs to the advanced human-computer interaction operation of computer. The user interface is shown in Figure 3.

Figure 3 User interface renderings

In the cycling system, the real world and virtual characters of users are fully integrated. Through optimising the user interface, the overall interaction of cycling is realised, the touch sensing range of the user interface is improved, and users' feedback is obtained in time to ensure high user satisfaction (Nitzburg and Farber).

2) *Image filter module*: Laser scanning technology is used to collect the data of virtual reality bicycle cycling point cloud. But in the process of riding point cloud data collection, the internal sensor material attribute will produce certain influence, interactive system circuit structure and the operating environment will be affected, produced in the middle of the image noise (Thakur et al., 2020), therefore, to achieve the effective to deal with the noise of the image data, using the image filter, will be collected to deal with the noise of the image data. The principle of the filter is shown in Figure 4.

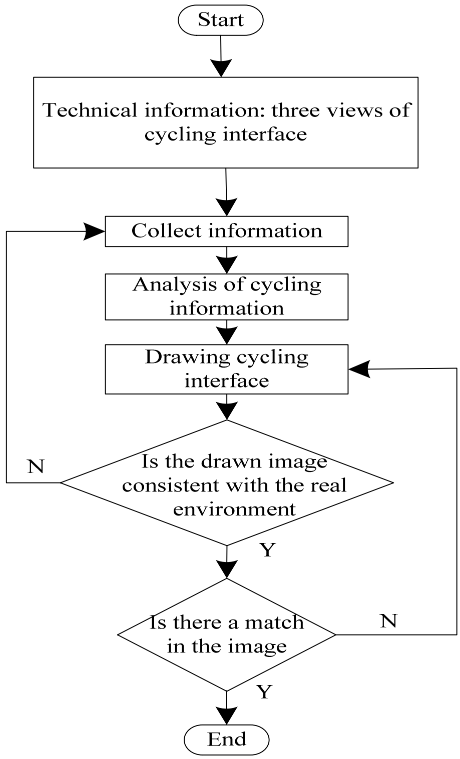
Figure 4 Schematic diagram of filter



As shown in Figure 4, the neighbourhood pixel value of the filter centre is successively calculated, which is multiplied by the corresponding coefficient value in the filter to carry out the overall summation processing, and the obtained value is represented as the pixel centre position. Based on ray projection and visual imaging, the physical visual model is constructed to generate a visual 3D image.

3) *Real-scene 3D modelling module*: In the three-dimensional virtual modelling of scene recognition, it is considered that the cycling system contains multiple operating devices and each device contains a variety of fine parts, and the connection and matching between the parts are realised through interfaces. Owing the possibility of small parts in each device, a high-precision modelling method is needed to complete three-dimensional virtual modelling of cycling (Gong et al., 2019). In the process of modelling, a large number of various types of technical data and multimedia data should be used, such as real equipment profile, three-view, assembly drawing, physical photos, videos, schematics, etc. In the process of modelling, the physical structure of parts and the details of interface matching during connection should be analysed. The three-dimensional modelling process is shown in Figure 5.

Figure 5 3D modelling process



Through the above process, the hardware design of the intelligent interactive system for virtual reality bicycle riding is completed, which improves the overall quality of the intelligent interactive system and lays the foundation for the software design of the intelligent interactive system for virtual reality bicycle riding effectively.

2.2 Software design of virtual reality cycling intelligent interactive system

Firstly, VR virtual technology is used to analyse the principles of cycling layout, and colour, spacing and visual attention constraints in the attention mechanism of human eyes are combined to obtain the corresponding objective function. The specific scheme flow is given as follows:

Assume that there are a series of interface elements in the model, and order them according to the importance of the elements in the model. Set m to represent the total number of components, then the relative importance of components between two adjacent sections can be calculated by the following formula:

$$A_k = \frac{\omega_i}{\omega_{i-1}} \tag{1}$$

In the above formula, ω_i represents the weight value corresponding to the i indicator; ω_{i-1} represents the weight value corresponding to the $i-1$ indicator. In the early stage of calculating the importance of components in multi scene interactive interface, the weight of components corresponding to the interface ω_i is unknown. Each expert scores the component degree of different interfaces to obtain the corresponding value of A_k.

Further calculate the weight value of element i by formula (2), namely:

$$\omega_i = \left[1 + \sum_{k=2}^{m}\left(\prod_{i=k}^{m} A_i\right)\right]^{-1} \tag{2}$$

In the above formula, A_i represents the collection of weight attributes, k represents the edge nodes of intelligent interaction and the weight of the remaining interface elements, calculated by formula (3):

$$\omega_{i-1} = A_k \cdot \omega_i \tag{3}$$

In the real cycling environment, cyclists' colour perception is divided into three main ways, respectively by brightness; Divided by saturation; Divided by colour. Colour classification can be effectively realised through the above three ways (Cheng and Zhang, 2020). In the process of colour perception fusion, the noise of source image will affect the output result. In order to ensure a good state of the user's virtual role integrating into the video scene, a mask model (Sun et al., 2021) was built to suppress the interference factors of the virtual user's edge information and the mask model of the virtual character was generated, as shown in Figure 6.

Figure 6 Generating virtual persona mask. (a) The source image of virtual character (b) the result of edge detection (c) the mask of virtual character

(a) (b) (c)

The edge detection of riding virtual user is carried out by Canny operator, and the mask model is constructed to realise the creation of multi scene interactive interface. Therefore, each component is regarded as an object with a single colour (Shao et al., 2019; Zhang et al., 2019; Sun and Wang, 2019). It is set that the multi-scene interactive interface contains m interface components, c_i and c_j represent the i and j interfaces respectively, and the colour contrast calculation formula between the two components is:

$$C_{ij} = \sqrt{\left(L_i^* - L_j^*\right)^2 + \left(a_i^* - a_j^*\right)^2 + \left(b_i^* - b_j^*\right)^2} \tag{4}$$

In the above formula, L_i^* represents the brightness value of element c_i in the colour model; L_j^* represents the brightness value of element c_j in the colour model; a_i^* represents the colour channel value of element c_i in the colour model; a_j^* represents the colour channel value of element c_j in the colour model; b_i^* represents the colour difference of element c_i; b_j^* represents the colour difference of element c_j.

The colour contrast matrix between element i and element j can be expressed by the following formula:

$$C = \left[c_{ij} \right] = \begin{bmatrix} c_{11}, c_{12}, \ldots, c_{1m} \\ c_{21}, c_{22}, \ldots, c_{2m} \\ \vdots \quad \vdots \quad \cdots \quad \vdots \\ c_{m1}, c_{m2}, \ldots, c_{mn} \end{bmatrix} \tag{5}$$

The correlation length matrix between element i and element j can be expressed as:

$$O = \left[o_{ij} \right] = \begin{bmatrix} o_{11}, o_{12}, \ldots, o_{1m} \\ o_{21}, o_{22}, \ldots, o_{2m} \\ \vdots \quad \vdots \quad \cdots \quad \vdots \\ o_{m1}, o_{m2}, \ldots, o_{mn} \end{bmatrix} \tag{6}$$

where o_{ij} represents the degree of correlation between two elements.

If there is a strong correlation between various components in the multi-scene interactive interface, the components with small colour contrast need to be placed in the nearest position, so that the colours of the entire interactive interface will not overlap, nor will it increase the cognitive burden of users. If the correlation between various components in the multi-scene interaction interface is weak, the components with large colour contrast need to be placed in the nearest position to ensure the overall search efficiency and visual attention of the interface are improved.

The distance and colour model between element i and element j can be expressed as:

$$C_i = \begin{cases} \sum_{j=i+1}^{m} \left(c_{ii} / d_{ij} \right), o_{ij} \geq \varphi \\ \sum_{j=i+1}^{m} \left(c_{ii} d_{ij} \right), o_{ij} < \varphi \end{cases} \tag{7}$$

In the above formula, c_{ii} represents the parametric model of intelligent interaction, d_{ij} represents the fusion parameters of intelligent interaction and φ represents the structure coefficient of intelligent interaction. The closeness between each interface element is mainly expressed by distance correlations, and the shorter the distance between the two elements, the closer the relationship between the two shows. The distance matrix between the element i and the remaining elements can be expressed as:

$$D = \left[d_{ij}\right] = \begin{bmatrix} d_{11}, d_{12}, \dots, d_{1m} \\ d_{21}, d_{22}, \dots, d_{2m} \\ \vdots \ \vdots \ \cdots \ \vdots \\ d_{m1}, d_{m2}, \dots, d_{mn} \end{bmatrix} \tag{9}$$

The mathematical model of visual attention level is as follows:

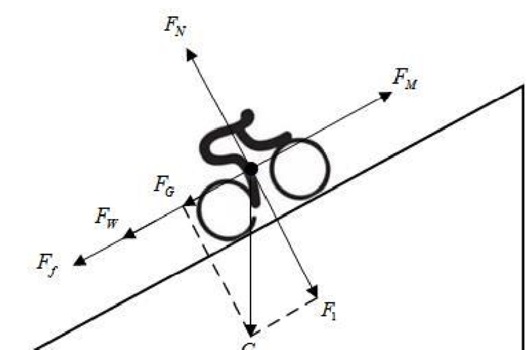
$$u_{ig} = \begin{cases} 1, \dfrac{x_i^2}{aB^2} + \dfrac{y_i^2}{aB^2} > 1, \dfrac{x_i^2}{ac^2} + \dfrac{y_i^2}{ac^2} \leq 1 \end{cases} \tag{9}$$

In the above formula, x_i^2 represents the structural parameters of intelligent interaction, y_i^2 represents the dimension parameter of intelligent interaction, aB^2 represents the effective value of intelligent interaction and ac^2 represents the set of characteristic distribution of intelligent interaction. Based on the basis of the above analysis, under the influence of the above constraints, select the maximum of the optimisation target function, the target function is expressed as follows:

$$f(i) = \max\left[\sum_{i=1}^{n}\left(\lambda_1 \cdot Z_i + \lambda_2 \cdot O_i\right)\right] \tag{10}$$

In the above formula, λ represents the structural information of the intelligent interaction, Z_i represents the filtering analysis of the intelligent interaction and O_i represents the edge information points of the intelligent interaction system. In the process of outdoor cycling, due to the slope resistance and rolling drag will have an impact on the cycling process, in the process of relatively flat road cycling, the human weight and the gravity component of the car will have a certain impact on the resistance. Resistance F mainly includes three parts, respectively, rolling drag F_f, air drag F_W, gravity split F_G. Fully combined with the three obstacles, combined with the corresponding power of cycling speed, the virtual real picture of cycling is simulated to obtain the real outdoor cycling effect. The cycling stress analysis is shown in Figure 7.

Figure 7 Analysis of riding force



In Figure 7, the resistance F_f includes tire and ground friction and body friction. The size of the rolling resistance is affected by external factors, mainly including the human weight, car weight and the size of the road slope. Among them, the greater the road slope, the greater the friction, the friction between people and bicycles will also increase. During the virtual simulation, the body and bike push the surrounding air away to increase air resistance. F_W is calculated as follows:

$$F_W = 0.5 * Cd * A * Rho * \left(v\left(m/s\right)\right)^2 \tag{11}$$

where v represents the riding speed, *Rho* represents the air density, and half of the value is 1.226 kg/m3, *Cd* is the coefficient of friction.

To sum up, the introduction of VR virtual technology simulates the sense of outdoor riding. By optimising the system hardware, fully integrate the relationship between the real cycling environment and the user virtual role, so as to obtain the good interaction effect; optimise the system software, obtain the objective functions under different constraints, create a mask model to suppress the external interference and retain the edge information of the cycling interface and simulate the real-outdoor cycling effect. So far, the design of the virtual intelligent interactive system of real-action bicycle cycling has been completed, and the practical application effect of the system needs to be further verified through experiments.

3 Experimental research

In order to verify the comprehensive effectiveness of the proposed intelligent cycling interaction system, the relevant experimental research was conducted.

3.1 Experimental scheme design

3DMAX was selected as the virtual simulation model to generate the virtual results of cycling. The computer hardware environment was CPU Core I5-4590, 3.30 GHz and the graphics card was GTX960-4 GB. Cycling interactive system includes two wireless communication protocols, Bluetooth 4.0 and Ant +, respectively. The lower computer devices include cycling console, heart rate band, power crank and speed sensor, which are connected to the lower computer devices to transmit cycling data. The virtual cycling lane line detection system is shown in Figure 8.

Figure 8 Virtual interactive lane detection experimental system

Based on the above parameter setting, the Bluetooth communication protocol data message is obtained as shown in Table 1.

Table 1 Bluetooth communication protocol data message

Data type	*Bluetooth communication protocol 10 bit data message*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
heart rate	1	2	3	0	0	0	7	2	2	1
power	1	2	3	1	0	0	9	8	2	1
speed	1	2	3	2	0	0	2	0	2	1

According to the Bluetooth communication protocol data shown in Table 1, the proposed system in this paper is taken as the experimental group, with the Liu et al. (2019); Liu and Zhang (2019) and Zheng et al. (2019) system as the reference systems to verify the application performance of the proposed system.

3.2 Performance index design

(1) *Touch perception range of the user interface*: Testing the interface touch perception range of the virtual interaction system can effectively master whether the human-computer interaction performance of the system is excellent, and the greater the touch perception range of the user interface, the better the human-computer interaction performance of the system is. The judgment formula for the touch sensing range is as follows:

$$\begin{cases} K_{\min} = \sum_{i=1}^{c} \mu_{ik} + \partial \\ K_{\max} = \sum_{i=1}^{c} \mu_{ik} - \partial \end{cases} \tag{12}$$

In the above formula, $K_{\max}$ represents the maximum interface touch sensing range; $K_{\min}$ represents the minimum interface touch sensing range; μ_{ik} represents the node data of the intelligent interaction information and ∂ represents the perceived sensing interaction coefficient.

(2) *User satisfaction*: As an intelligent means of communication between 'human' and 'machine', the user satisfaction can directly indicate the application performance of the interactive system. The more the user satisfaction tends to 1, the higher the application value of the system in the actual process.

(3) *System response time*: The response time of the system can reflect the operating efficiency of a system. The shorter the response time, the higher the intelligent interaction efficiency of the virtual reality bicycle riding in the system.

3.3 Experimental results analysis

(1) *Comparison of the system touch perception range*: Based on the above experimental environment and parameter information, compare and analyse the virtual interaction

sensing touch range under different systems, and obtain the touch sensing range comparison result as shown in Table 2.

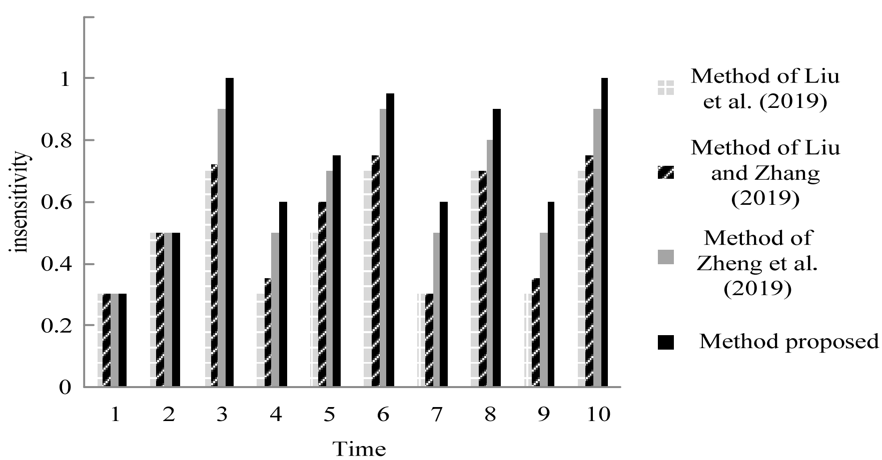
Table 2 Comparison results of touch perception range of different methods

Experiment time/ s	*Touch perception range/(nm^2)*			
	Proposed methodology	*Liu et al. (2019) methods*	*Liu and Zhang (2019) methods*	*Zheng et al. (2019) methods*
1.0	145	124	135	136
2.0	164	127	154	145
3.0	169	131	165	154
4.0	185	154	181	169

As can be seen from Table 2, compared with the literature system, the virtual touch sensing range of the proposed system is between 145 nm^2 and 185 nm^2 and the sensing range is larger. The reason for this situation is that the proposed system introduces virtual reality technology to create a mask model to suppress external interference and retain the edge information of the cycling interface. By fully integrating the real bike with the virtual environment, the touch sensing range of the intelligent interactive system is effectively improved, thus enhancing the interactive performance of the system.

(2) *User satisfaction*: Based on the basis of the above experiment, the user satisfaction comparison of the intelligent system is conducted and the user satisfaction comparison result is shown in Figure 9.

Figure 9 Analysis of system stability results



As can be seen from Figure 9, the average user satisfaction of the systems in Liu et al. (2019); Liu and Zhang (2019) and Zheng et al. (2019) is around 0.8, while the user satisfaction of the systems mentioned in this paper is close to 1. The reason for this result is that influencing factors such as people, cars, roads and surrounding environment are taken into account in the process of constructing the mask model of virtual characters.

Various factors were integrated into the cycling system. Through the mask model created to suppress the interference and retain the edge information of the cycling interface, the components of roll resistance, air resistance and gravity were calculated, so as to simulate the real-outdoor cycling effect.

(3) *System response time comparison*: In order to further verify the system response time studied, the intelligent interactive system data comparison using four methods and the system response time comparison results are shown in Table 3.

Table 3 System response time comparison results (s)

The experimental time	*Method of vector control*	*Liu et al. (2019) method*	*Liu and Zhang (2019) method*	*Zheng et al. (2019) method*
10	2.29	5.46	6.45	6.66
20	1.99	5.12	5.15	7.00
30	1.84	5.49	7.00	7.05
40	1.70	5.78	7.06	7.09
50	2.00	5.55	7.77	7.16
60	2.03	6.00	8.00	7.28
70	2.01	6.45	6.49	8.56
80	1.51	5.10	7.25	9.45
90	1.20	6.89	7.55	10.03
100	1.00	6.45	7.57	10.89
110	1.23	5.22	5.32	6.89
120	1.26	5.45	5.69	6.99
130	1.11	6.60	6.48	7.25
140	2.00	6.01	6.52	9.45
150	2.01	5.78	7.89	8.48

As shown in the above table, the response time of the system in this paper ranges from 1.00 to 2.29; The response time of the system in Liu et al. (2019) ranges from 5.10 to 6.89; The response time of the system Liu and Zhang (2019) ranged from 5.15 to 8.00. The response time of the system in Zheng et al. (2019) ranges from 6.66 to 10.89, which shows that the response time of the system in this paper is significantly lower than that of the traditional system. The reason for this result is that the system in this paper introduces VR virtual technology, uploads the information of the cycling environment ramp to the cycling platform, adjusts the resistance to simulate the real cycling environment, narrates the difference between the real- and virtual-observation values and improves the operating efficiency of the intelligent interactive system of virtual reality bicycle riding.

4 Conclusions

Aiming at the problems of poor interaction performance, poor system stability and long system response time of intelligent interactive system, this paper proposes and designs a virtual reality bike riding intelligent interactive system based on VR technology.

(1) Its innovation lies in the introduction of Virtual Technology (VR), which uploads the riding environment ramp information to the riding platform, and adjusts the external resistance through the resistance control module to simulate the real riding road feeling. The mask model is created to suppress the interference and retain the edge information of the riding interface, so as to simulate the real outdoor riding effect.

(2) The experimental results show that the touch perception range of the user interface of the system in this paper is between 145 nm^2 and 185 nm^2, the user satisfaction is close to 1 and the corresponding time of the system is all less than 2.3 s. It shows that this system has higher feasibility and can be further popularised in practice.

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