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Article

Construction of intelligent sports service platform and application of physiological index evaluation under VR background

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Abstract: With the continuous progress of VR (Virtual Reality) and biomedical sensing technology, traditional sports platforms have been significantly limited in many aspects. This article combines VR technology and biomedical equipment to innovatively build an intelligent and personalized sports service platform. The platform can use the user's heart rate variability, body surface electrical muscle map, exercise trajectory, and biomechanical indicators including joint angle and muscle strength to conduct a comprehensive evaluation of the effect of sports services. OpenHMD technology is used to create a diverse and highly interactive virtual sports environment for users, while 3ds Max is used to carefully design training models to enhance the immersive experience. Through Kinect and heart rate monitors, we accurately collect users' movements and biophysiological data, and use advanced algorithms for motion recognition. The data analysis module can dig deep into the user's exercise characteristics and provide personalized exercise recommendations and physical fitness assessments. The results showed that the user's heart rate fluctuated greatly in the early stages of training, but gradually stabilized, from 128 bpm in the first cycle to 120 bpm in the third cycle, indicating improved physical fitness and increased endurance. At the same time, the range of heart rate fluctuations gradually shrank, showing that the user's adaptability improved. The comparison of the histogram shows that the cardiovascular burden is reduced and the physical fitness is significantly improved. The long-term trend chart shows that as training progresses, physical fitness gradually improves. Experiments have proved that the platform still performs well under high loads, and the analysis of biomechanical indicators verifies its rationality and practicality.

Keywords: sports science; heart rate monitoring; biomechanics; virtual reality; intelligent sports platform

1. Introduction

With the rapid development of VR and biomedical sensing technology, the problems of traditional sports service platforms have become more and more prominent, such as uneven distribution of resources, rigid service models, and lack of data analysis capabilities, which have restricted the development of the sports industry and affected the user experience. Especially the regional differences in sports resources make it impossible for many people to obtain quality services. At the same time, the lack of a personalized service model is also difficult to meet the diverse needs of users. In order to solve these problems, this research proposes to integrate VR technology and biomedical monitoring equipment to build an efficient, intelligent and personalized smart sports service platform. VR technology can create a multi-scene, highly interactive virtual environment, enhance user immersion and interactive experience, realize virtual sharing of sports resources, reduce dependence on physical facilities, and help balanced resource allocation [1]. In addition, we also apply motion capture technology to the platform to provide data support for managers, provide users with customized exercise guidance and health management solutions, and promote sports service innovation. The platform also integrates heart rate monitoring and other physiological sensors to monitor the user's health status in real time, combine AI (artificial intelligence) algorithms for data analysis, provide personalized fitness recommendations and risk warnings, and improve the effectiveness of personal health management [2]. This research not only has theoretical significance, but also enriches the theoretical system of smart sports and lays the foundation for the digital transformation of the sports industry. By building a highly integrated smart sports service platform, we are expected to break the limitations of the traditional sports model, enhance user participation and satisfaction, provide a rich and smooth virtual training environment, and promote the prosperity and development of the national fitness and sports industry. This move is in line with the interdisciplinary development trend of computer science, biology, medicine and sports, and is of great significance to the deep integration of the health industry and technology applications.

This article constructs a smart sports service platform based on VR technology, aiming to solve the problems of uneven resources, single service, and lack of data analysis in traditional sports platforms. Using OpenHMD virtual reality technology, combined with motion capture and feedback technology, a multi-scene, interactive, and smart sports platform is created, and a performance and experience evaluation is carried out in a certain university. The results show that the platform performs outstandingly in response, transmission and stability, and is still efficient under high concurrency; in the user experience test, the immersion, interactivity and operability are highly evaluated, which is superior to other technical platforms, effectively improving user participation and satisfaction, and providing a rich and smooth virtual environment for sports training. Compared with traditional platforms, the innovation of this platform is that it can break geographical and facility restrictions, realize virtual resource sharing, and improve the fairness and accessibility of sports services. Using VR technology, we have built a multi-scene, highly interactive sports platform that allows users to access the virtual environment for training or competition at any location without physical space restrictions. This solves the problem of uneven physical education resources between regions. For example, students in remote areas can also enjoy the same physical education resources as urban students. At the same time, VR technology also supports the customization of personalized exercise programs, so that every user can get a training plan that suits them. In terms of resource utilization, VR technology highly simulates physical resources, reducing the demand for actual venues and equipment, reducing operating costs, avoiding queuing, and enabling more users to participate at the same time. In addition, this model also promotes exchanges and interactions between regions, allowing high-quality sports content to be widely disseminated. In the end, the application of VR technology has optimized the allocation of resources, promoted the fitness of the whole people, and realized the popularization of sports services and the GSP (Good Supply Practice) system.

The contributions of this study are:

- The VR is used to create a multi-scene and highly interactive sports platform, and OpenHMD and Kinect are used to precisely capture user movements and enhance immersion and interactive experience.
- Through virtualization technology, the platform realizes sports resource sharing, improves resource utilization, and promotes educational balance.
- Combining personalized recommendations with real-time data analysis, customized services are provided to enhance user experience, while a scientific decision-making support is provided for managers to promote innovation and development of sports services.

2. Related work

The smart sports platform can optimize resources, improve services and the attractiveness of sports, realize personalized sports guidance and health management, and promote the health of all people [3]. It also supports the digitalization of the sports industry, promotes economic development, and promotes cooperation and innovation among all sectors of society [4,5]. To this end, many scholars and researchers have conducted in-depth research on the smart sports platform. Smart sports have become a new trend in the development of sports. Mingchan Gong, taking machine learning models as the core, created a smart learning environment and built a smart sports platform, effectively optimizing the integration and sharing of sports resources. He also stated that building a smart sports platform can provide support and guarantee for the sustainable development of sports [6]. With the popularization of public sports services and the rapid development of the digital economy, the smart service of public sports has become a major trend in the new era. Jian uses data integration and sharing, interest orientation, and functional coordination driven by sports platforms to form a chain operation mechanism to promote accurate identification of public needs, joint participation of multiple subjects, and deep integration of sports resources [7]. Internet of Things (IoT) technology supported by artificial intelligence (AI) technology can be used to analyze athletes' performance in real-time. Munish proposed a mathematical framework based on two-person game theory to build a smart sports industry decision-making system, and experimentally demonstrated that the proposed method achieved enhanced performance values in terms of time delay, classification efficiency, statistical validity, correlation analysis and reliability [8]. To further promote the healthy development of college students' physique, Zhang, from the perspective of artificial intelligence and by utilizing the advantages of Internet technology in the field of sports, built a sports health management service platform for college students, conducted multi-dimensional physical health assessment and diagnosis on students, and formed a personalized, scientific, and comprehensive exercise prescription intervention mechanism to ensure and promote the healthy development of students' physique [9]. Scholars' research on smart sports platforms helps to improve the integration, sharing, and smart service of sports resources, and provides new ideas for the sustainable development of the sports industry. However, the research focuses on technology and pays insufficient attention to user experience, privacy, and ethical issues. At the same time, the universality and data quality of smart sports platforms are also challenges. Although there are multiple service models, they need to be verified in different regions and groups. In addition, data integrity is crucial to the effectiveness of the solution.

VR applied to sports platforms can enhance user immersion and interactive experience, and innovate sports training and viewing methods. By simulating the sports environment, this technology helps athletes improve their skills and tactical drills, and also provides ordinary users with a convenient way to participate in sports [10,11]. To make up for the shortcomings in the existing research on smart sports platforms, some scholars have begun to explore the application effects of VR in sports in order to solve the existing shortcomings. The integration of virtual and augmented reality technologies has become a transformative force in reshaping the audience-sports interaction pattern. Javani et al. proposed a comprehensive paradigm model to contribute to the sports field, which integrated VR/AR (Augmented Reality) technology into the complex dynamics of sports events to enhance the potential of sports fans' experience and advocated continuous innovation and cooperation in the fields of technology and sports management [12]. VR technology can be used to improve rural sports and reduce the need for a large amount of development infrastructure. Wang proposed a new World Cup search-driven quadratic support vector machine method to improve the performance of VR in rural sports by using VR to replicate the subtleties of dragon boat movement and sensory perception, and stated that the use of VR can promote the sustainable development of rural sports [13]. The research of the above scholars demonstrates the potential of VR technology in sports development and emphasizes the importance of combining technology with sports management. However, it still faces problems such as difficulty in technical implementation and high system complexity. Therefore, this article proposes a smart sports service platform that integrates VR and big data analysis to improve interactivity, personalized recommendations, and immersive experience, and make up for the current research deficiencies.

3. Construction of a platform supported by VR technology that integrates biomedical data

3.1. Smart sports service platform architecture

3.1.1. Platform functional requirements

Based on modern information technology, the rational allocation of sports resources is realized, and the information operation efficiency of sports work is improved, providing accurate and personalized services to users. The smart sports service platform can effectively integrate scattered information resources to provide users with diversified and integrated sports services.

Based on the above analysis, considering the needs of sports management, strengthening and improving sports services in sports facilities and sports feedback is emphasized. On this basis, computer virtual reality technology is fully utilized to build a smart sports service platform to achieve co-construction and co-governance. Through the functional integration and classification of 10 design elements, the content modules such as physical health testing services, daily sports comprehensive services and user interaction services are clarified. By integrating various resources in the entire platform, users' personalized sports needs and diversified functional services are realized, thereby helping to achieve sports goals. The functional services of the smart sports service platform are shown in **Figure 1**:

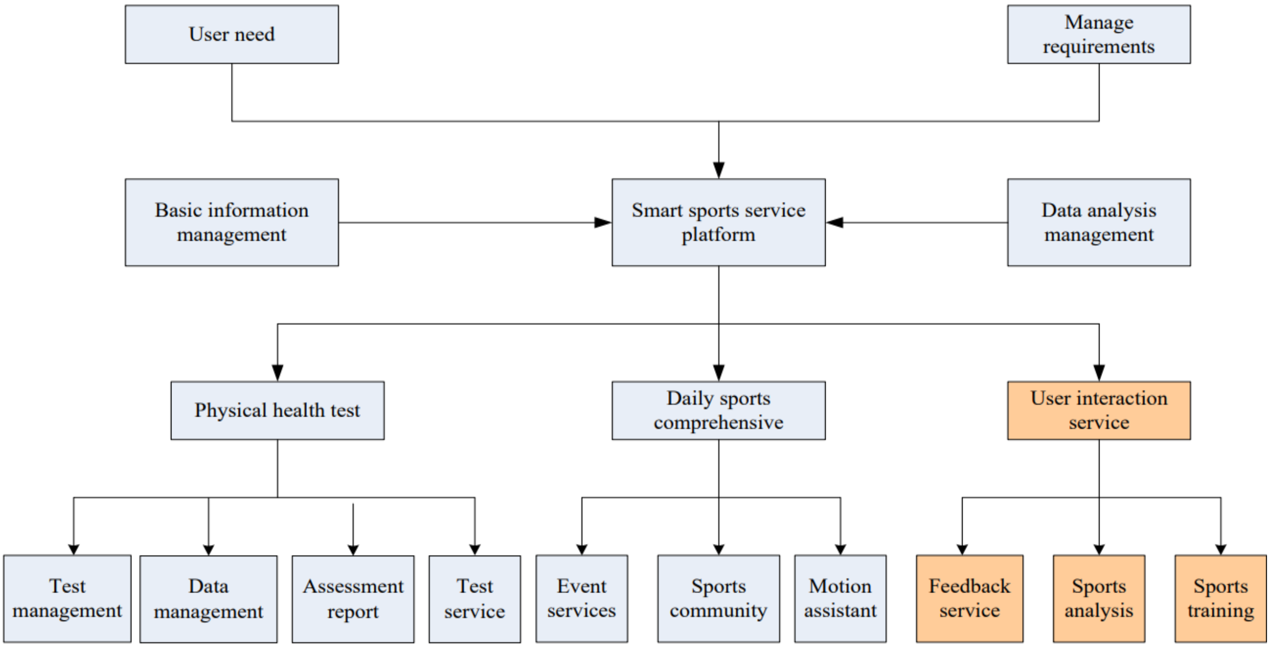

Figure 1. Functional services of the smart sports service platform.

3.1.2. Platform structure design

Based on VR technology, the smart sports service platform is established to improve the interactivity and immersion of sports services and reduce the time and location constraints in sports learning [14–16]. Based on OpenHMD, this article combines intelligent motion capture and feedback technology to build a multi-scene, interactive, and intelligent smart sports service platform. Compared with traditional sports service platforms, this platform can bring better experience to users. To take into account the flexibility and easy operation requirements of the platform, the design of the platform must take into account both scalability and the adaptability of multiple platforms, so as to facilitate subsequent functional development and support more platforms, thereby simplifying the platform construction process. From the perspective of hardware design, the overall structure of the smart sports service platform needs to support efficient and intuitive operations to ensure that users can easily enter this virtual environment. The structure of the smart sports service platform based on VR technology is shown in **Figure 2**:

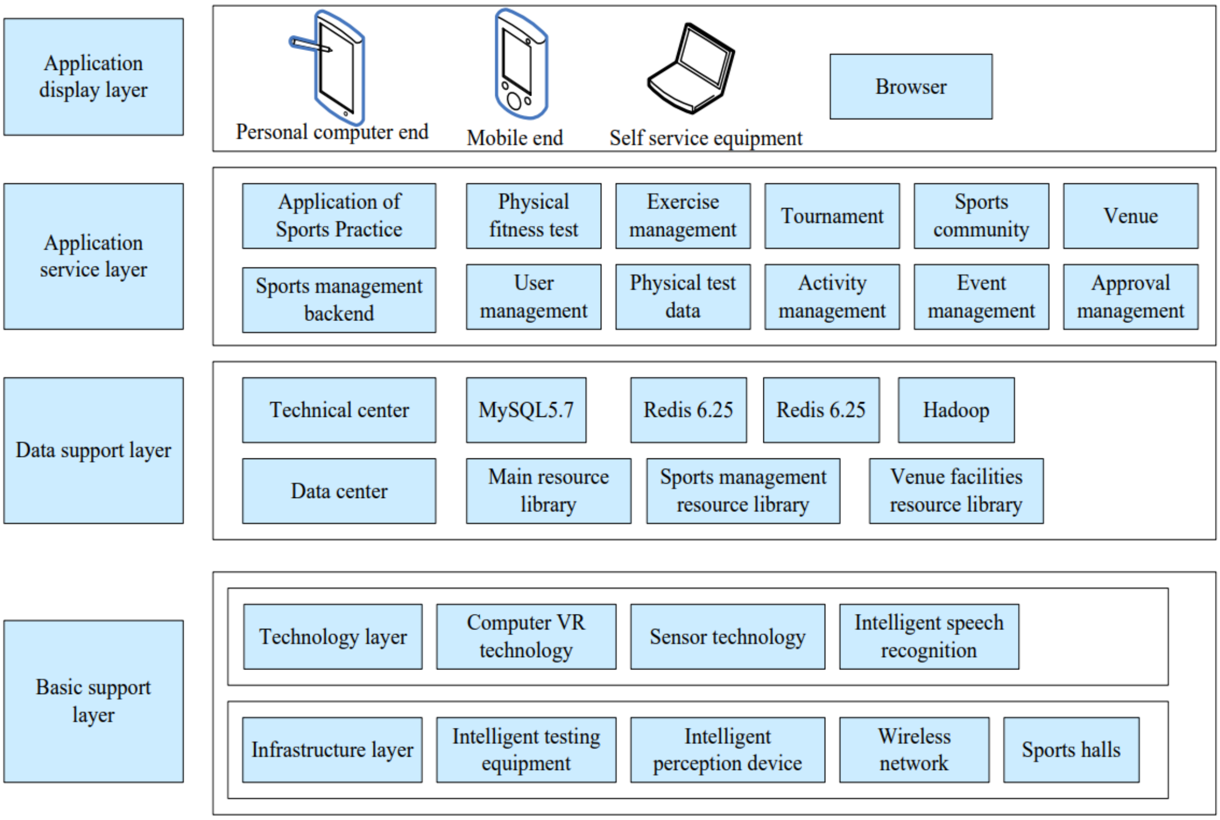

Figure 2. The structure of the smart sports service platform based on VR technology.

Figure 2 shows the architecture of the smart sports service platform based on VR technology, including four layers: basic support, data support, application services and application display. The basic support layer has infrastructure such as intelligent detection, sensing device, wireless network and technologies such as VR and sensors. The data support layer includes the data center and the technology center. The former has various resource libraries and the latter integrates a variety of data management tools. The application display layer is the user contact part, and the service can be accessed through a browser or mobile terminal. This architectural design ensures that the platform is comprehensive and flexible, while ensuring data security storage and efficient processing, providing users with intelligent and personalized sports services.

The implementation idea of the smart sports service platform based on VR technology: the 3ds max [17,18] is used to build a three-dimensional model related to sports training, and imported into OpenHMD for virtual design. With the help of Kinect device [19,20], human motion data is collected and a dynamic three-dimensional model is built. This process requires converting the camera coordinates into world coordinates, using the dynamic sampling ray projection algorithm to deeply reconstruct the model, and realizing dynamic modeling through texture mapping. A multi-feature fusion algorithm [21] is used to combine distance and angle features to match and score the motion model with the training action. As a result, the platform can precisely identify user actions, provide error evaluation and personalized guidance, and significantly improve the training experience and platform intelligence level.

The smart sports service platform integrates multiple resources to create an accurate and personalized service system. The physical fitness test module collects health data such as the user's heart rate and physical fitness, and transmits it to the data center for analysis. The data analysis system uses advanced algorithms to dig deep into users' exercise habits, preferences and needs to provide decision-making support for personalized recommendations. Daily sports services work closely with the user interaction module to provide users with customized sports programs based on data analysis results. If users want to improve a certain physical fitness index, the platform will combine their historical records and goals to intelligently recommend suitable training courses. The platform tracks the progress of users' movements in real time, adjusts recommended content, and meets their changing needs. The platform uses virtual reality technology to create realistic sports scenes, reduce dependence on physical facilities, and realize virtual sharing of sports resources. With the help of smart devices and sensors, the platform accurately captures the user's sports performance in the virtual environment and feeds it back to the data analysis system to optimize personalized services. The user interaction module encourages the sharing of sports experiences, forms a community atmosphere, and promotes personalized content generation. This closed-loop collaborative mechanism ensures that the smart sports service platform continues to provide high-quality and personalized sports experiences. From data collection to analysis, to service recommendation and interaction, the various modules of the platform support each other to jointly create an excellent sports life for users.

3.2. User interaction module implementation

3.2.1. Virtual environment design

Using 3ds max technology, objects such as stadiums and sports facilities are finely modeled and exported in FBX (FilmBox) format [22–24]. The modeling strictly follows the design of the drawings, and diffuse reflection and normal mapping are used for mapping. The normal map can be used to make the model have a concave and convex feeling and the low-poly model can present the effect of high-poly model, and reduce the storage space. The modeling effect of the stadium and sports facilities is shown in **Figure 3**:

Figure 3. Modeling rendering of sports stadium and sports facilities.

3.2.2. User interaction design

The design of the user interface uses several basic UI (User Interface) controls provided by OpenHMD. A new Canvas is created in OpenHMD, and an image is added to it as the background of the interface. Basic text and buttons are added, and then a script is created. In this script, the corresponding operation can be completed by clicking the button. Error information is set in the system to ensure the correctness of system operation and management. When executing each functional module, there is an error message when facing certain operations. This article counts the system error prompts and error handling table, and the specific content is shown in **Table 1**:

Table 1. System error prompts and error handling table.

Serial number	Error type	Specific description of the error	Solution
1	System error	Network connection failed	Check the network connection and reconnect
2		Weak signal and unstable connection	Enhance the signal and move to a place with a stronger signal
3		Data loading error	Refresh the data and reload the page
4	System customization error	Image rendering is not clear	Adjust image rendering settings to improve clarity
5		Audio playback failed	Check the audio device and replay
6		System stuck or crashed	Restart the application or device
7		Sensor not responding	Check the sensor connection to ensure normal operation
8		Tips for illegal operations	Prompt the user to operate correctly to avoid violations
9	Operation error	Incomplete user information	Improve user information to ensure accurate data
10		Account is locked	Contact customer service to unlock your account

In terms of user interface design, we chose the basic UI controls of OpenHMD to better adapt to the VR environment and enhance user ease of use. These controls are designed for three-dimensional space rendering and can respond to input from VR headsets and handles. Controls such as buttons and sliders not only support two-dimensional clicking or dragging, but also can be operated through gesture recognition to achieve virtual interaction similar to the real world. Elements such as images and text are placed on the new canvas to ensure visual coherence. When performing specific functions, the system will display error messages to guide users to avoid misoperation. Taking into account the changeable user perspective in VR, we optimized the position and size of the UI controls so that they are always in the user's field of vision and easy to access quickly. This design improves operational efficiency and reduces the time for users to find controls.

The interaction design of the user interaction module uses C# language as the development core. Combined with VR headsets, handles and other devices, the hardware operation is fed back to the back-end service program, which is then processed by the corresponding module of the service program [25,26]. The interactive function is to complete the movement of the character, the dialogue between the characters, etc. When the user wears the helmet, the movement and orientation of the user's head can be captured, and the corresponding three-dimensional image can be presented in the helmet.

The main function of the user interaction module is to realize human-computer interaction. To ensure the interaction effect, it is necessary to generate an interactive interface. The multiple perceptual information generated during the generation process directly affects the realism and immersion of the interaction. Based on this, this article applies a multi-sensory experience method of VR technology to ensure the generation effect of the human-computer interaction interface. The specific design of the interactive interface is shown in **Figure 4**:

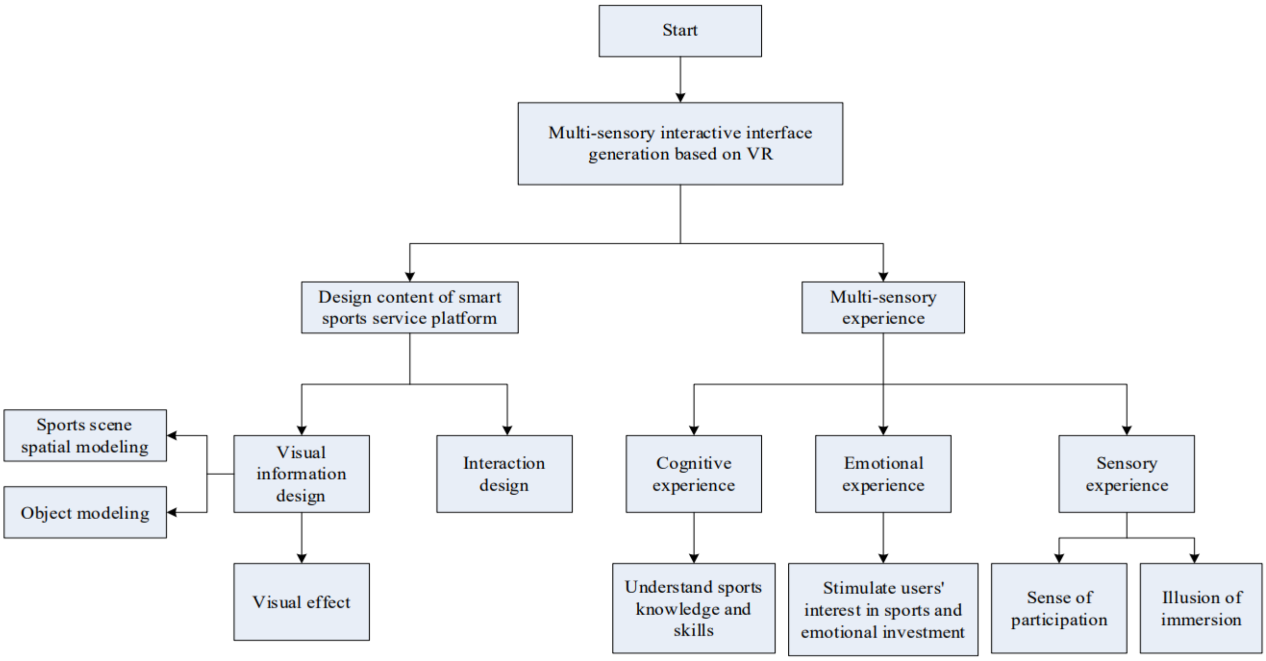

Figure 4. Interaction interface design.

To ensure the generation effect of the interactive function interface, the interactive interface layout optimization model is used to achieve it. This article divides the model based on interface visual attention [27]. In the interface generation process, the optimal visual attention partition is used as the objective function to establish a generation model for interactive interface optimization.

In simple terms, suppose a mobile phone screen contains multiple application icons and shortcuts. In the VR environment, these elements are arranged according to the frequency and importance of the user's use, so that users can quickly find the required functions. The visual attention segmentation method used in this article adjusts the position of interface elements according to the user's focus in different scenes. The functional modules that are critical to completing the task will be placed in the central area where the user is most likely to pay attention. Auxiliary or less commonly used functions are moved to the edge. For example, during exercise training, the start training button is located in a prominent place in the center, and the setting options are slightly biased. This aims to make key operations more intuitive and convenient, reduce unnecessary visual interference, and improve the user experience. This method allows readers to understand how the interface layout adapts to the VR environment even if they have no programming background.

In the process of interface generation, if any functional module is expressed by h_l, then any h_l is within the visual expectation of level difference and grade difference, and the unit visual attention and unit number they occupy are expressed by $X = \{x_{ji}\}$ and $N = \{n_{ji}\}$.

In visual area i, the attention level and unit number of the j-th h_l are represented by x_{ji} and n_{ji}. The attention level of the center coordinate of h_l within its visual expectation is $Z = \{z_{ji}\}$, and then the attention level of this h_l is z_{ji}. The criticality of the interface function is determined by the subjective weighting method, and its relative criticality λ_l is calculated by the formula after pairwise comparison.

$$\lambda_l = \frac{v_{l-1}}{v_l} \tag{1}$$

Among them: v_l—the criticality.

The criticality of the j-th functional module h_j is calculated by the following formula:

$$v_j = \left(1 + \sum_{l=2}^{m}\sum_{j=l}^{m}\lambda_j\right)^{-1} \tag{2}$$

Among them: λ_j—the relative criticality of the jth functional module.

When designing the interactive function interface, the visual attention segmentation strength p_l is calculated according to the calculation result of Equation (2), and the calculation formula is:

$$p_l = \sum_{j=1}^{m}\sum_{i=1}^{3} v_j\, x_{ji} z_{ji} c_{ji} \tag{3}$$

If $p_{\max}$ is used to divide the upper limit of the visual attention strength of the interactive interface, the formula is:

$$\max \hat{p} = \sum_{j=1}^{m}\sum_{i=1}^{3} v_j\, x_{ji} z_{ji} c_{ji} \tag{4}$$

The increase in $\hat{p}$ value means that the interactive interface is divided more into key functional modules in terms of visual attention. By optimizing the firefly algorithm [28–30] and solving Equation (4), the functional interface layout is obtained, and then the interactive interface of smart sports digital services is constructed. In the generated interactive functional interface, users can interact with digital services through VR devices and immersive projection.

3.3. Biomedical data collection and analysis module

3.3.1. Biomedical data collection

In the smart sports platform, data collection is crucial for personalized services and intelligent feedback. This article uses a variety of sensors and VR devices to collect user motion data in a virtual environment. VR headsets and handles not only provide an immersive visual experience, but also capture head and hand data for analyzing line of sight and gestures. The headset collects head data through built-in sensors and tracking systems, while the handles collect operation data through buttons.

At the same time, a heart rate monitor is used to monitor the user's heart rate in real-time to reflect their physiological state and exercise intensity [31]. These heart rate data are transmitted to the main control computer via Bluetooth for real-time processing, providing a key reference for subsequent analysis.

When the human body is exercising, the Kinect somatosensory device is utilized to obtain the depth information of the human body in a single direction, and the origin coordinates of the camera are converted into the world coordinate system to obtain the initial reconstruction model [32,33].

The collected depth data is processed to convert its two-dimensional vertices into three-dimensional form. This process uses floating-point data to replace the original depth frame data, and combines the camera coordinates to convert the floating-point data into point cloud data consistent with the orientation of the Kinect camera. The method can be expressed as:

$$N_j(o) = Y_j(o)G - 1[o, 1] \tag{5}$$

$$N_j^{\mathrm{f}}(o) = R_j N_j(o) \tag{6}$$

$$m_j^{\mathrm{f}}(o) = O_j m_j(o) \tag{7}$$

Among them: G—the internal calibration matrix of the camera of the Kinect somatosensory acquisition device;

o-a certain point in the image. The depth value and the normal vector are represented by $Y_j(o)$ and $m_j(o)$ respectively;

R_j and O_j—the translation and rotation matrices of the camera, describing its posture transformation.

The basic principle of the ray projection algorithm is to start from each pixel of the sample image and emit a beam of rays along the observation point, which passes through the 3D data field [34,35]. In the traditional ray projection algorithm, each ray passing through the 3D data field has the same sampling frequency and equal spacing, resulting in a large amount of calculation and a slow rendering speed.

On the sight line X, there is a partial derivative $s = k'a(a_0, b_0)$ at the point $N_0(a_0, b_0, s_0)$ where the curve intersects the cross section normal, which can be expressed as:

$$k'a(a_0, b_0) = \left.\frac{\partial \mathrm{k}}{\partial \mathrm{a}}\right|_{\substack{a=a_0 \\ b=b_0}} \tag{8}$$

Equation (8) refers to the slope l_0 between the sight line X and the A axis. Similarly, it can be seen that the tangent plane at point Q is parallel to the S axis, and its slope l_0 is also the largest. When the surface is convex, its slope l_0 is positive, and when the surface is concave, its slope l_0 is usually negative. Therefore, the slope l_0 at the tangent point N_0 is defined as:

$$l_0 = |k'\mathrm{a}(a_0, b_0)| \leq 1 \tag{9}$$

The distance between viewpoint Z and N_0 is as follows:

$$|ZN_0| = \sqrt{(a_0 - a)^2 + (b_0 - b)^2 + (s_0 - s)^2} \tag{10}$$

The sampling frequency rate at point N_0 is expressed by the formula:

$$\text{rate} = \frac{l_0}{|ZN_0|} = \frac{|k'a(a_0, b_0)|}{\sqrt{(a_0 - a)^2 + (b_0 - b)^2 + (s_0 - s)^2}} \tag{11}$$

The dynamic sampling ray projection algorithm is utilized to increase the slope of the tangent point and reduce the distance between the viewpoint and the tangent point to increase the sampling rate, so that more pixels are projected onto the screen, thereby improving the image's clarity. As the viewpoint of the human eye changes, the acquisition frequency is constantly changing, which can greatly reduce the amount of calculation and improve the rendering speed of the image.

Motion capture technology [36–38] is used to collect standard motion data of sports, and the three-dimensional human motion model is matched with the sports action through a multi-feature fusion algorithm to construct a virtual reality dynamic motion system. At the same time, the distance and angle features of the action are scored and identified through Equations (12)—(14). The formulas are:

$$P = \begin{cases} k(x_{\max})\left[(D_\alpha - D)\dfrac{100 - P_\alpha}{P_\alpha} + P_\alpha\right] & 0 \le D \le D_\alpha \\ 0 & D \ge D_\alpha \end{cases} \tag{12}$$

$$k(x_{\max}) = \begin{cases} 1 - \dfrac{0.3}{F_2} x_{\max}^2 & 0 \le x_{\max} \le \sqrt{\dfrac{10}{3}F} \\ 0 & x_{\max} \ge \sqrt{\dfrac{10}{3}F} \end{cases} \tag{13}$$

$$P = P_1\gamma_1 + P_2\gamma_2 + P_3\gamma_3 \tag{14}$$

Among them: D_α and P_α—the predefined standard angle difference threshold and benchmark matching degree parameter;

$k(x_{\max})$—the penalty coefficient of posture matching accuracy;

γ_1, γ_2, and γ_3—the feature weights of each action in sports.

On the basis of obtaining the 3D model of human motion and completing the matching of motion postures, combined with sports norms and actual needs, the constructed visual virtual model and human motion postures are connected to the server to establish a smart sports service platform based on VR.

In the data collection process, the smart sports service platform attaches great importance to the accuracy and synchronization of data. To achieve this goal, the platform has adopted a number of strategies. First, calibrate sensors such as VR devices, handles, and Kinect to ensure accurate spatial positioning and motion capture. The equipment is calibrated regularly to reduce errors. Optimize the Bluetooth connection between the heart rate monitor and the computer to ensure real-time transmission and data integrity. At the same time, the sensor timestamp is unified to facilitate the alignment of data processing. The central control system coordinates the various modules to ensure the fluency of data collection, transmission, storage and analysis. Distributed database technology ensures real-time data security, and the message queuing system reduces latency. In view of data interference problems, such as wireless signal interference, the platform adopts anti-interference communication protocols to enhance the shielding effect of equipment, while optical sensors use filters to reduce the impact of ambient light. The adaptive algorithm can automatically adjust the parameters when an abnormality is detected to improve the reliability of the system. These measures not only improve the quality of data, but also lay a solid foundation for subsequent analysis.

3.3.2. Data analysis management system

The data analysis management system is mainly responsible for collecting business data from multiple external systems and saving them in the system database. The data source is mainly related information such as users, venues and facilities, and sports activities. The workflow of the system includes data collection, storage, calculation, analysis and display. The system first processes and saves school sports-related data to the basic database, and then converts these data according to the needs of management decisions for specialized analysis and visualization.

The administrator can fully query the data of multiple service modules through the platform background, which covers physical health monitoring, daily sports comprehensive services, and venue facilities services. The background also supports querying and exporting data from previous years, and can edit and update relevant information of announcements and venues.

The background has the function of managing the appointment of users' physical fitness tests. It can automatically generate peak warnings for physical tests based on the appointment situation, helping administrators to reasonably allocate test personnel and devices, thereby optimizing resource utilization, improving test efficiency, and reducing the burden on staff. Administrators can understand the current number of exercisers and their distribution locations in real-time through the background, and push this information to the visual large screen as needed, fully displaying the school's exercise situation, including daily, monthly, and annual summary exercise data and sports performance statistics. At the same time, it can also display real-time exercise flow and rankings to provide users with more reasonable exercise suggestions. The background also integrates management functions for sports clubs and events, which can set activity details and participation conditions, realize online registration, and conduct a comprehensive analysis of registration data. This article presents a trend chart of user sports performance through visualization. The results are shown in **Figure 5**:

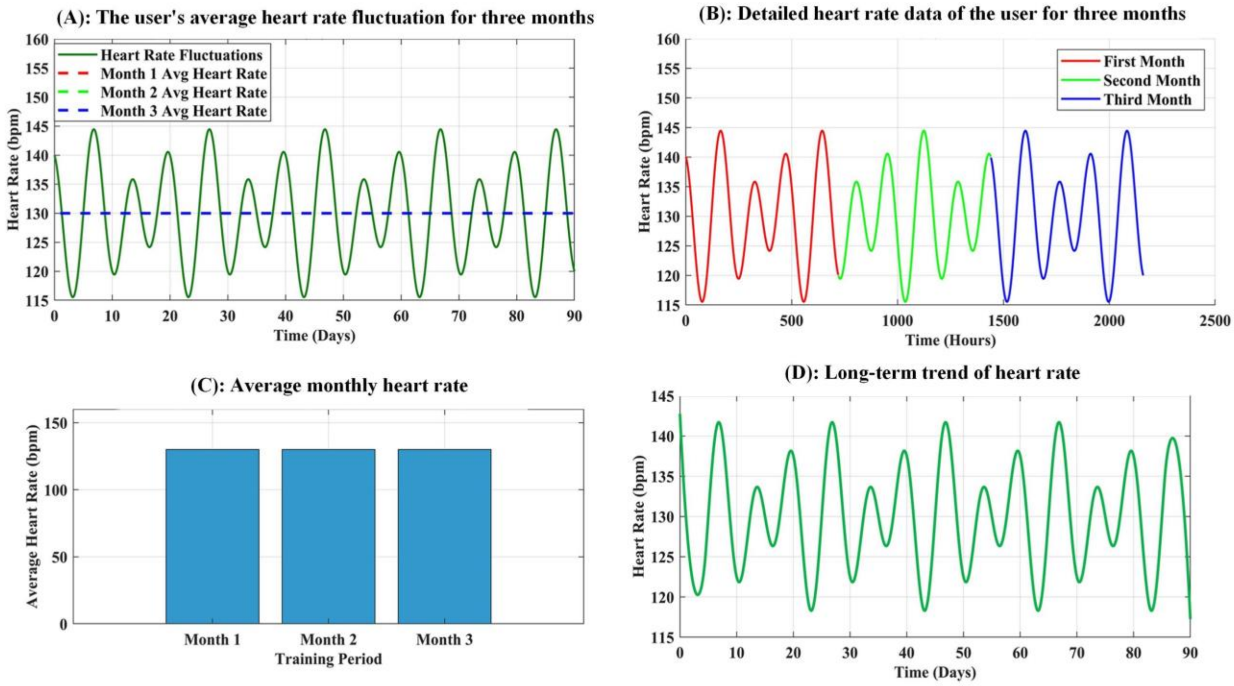

Figure 5. Trend chart of user movement performance.

As shown in **Figure 5A**, the heart rate fluctuates greatly in the early stages of training, but gradually stabilizes over time. The average monthly heart rate (dotted line) shows a downward trend, such as 128 bpm in the first cycle, 124 bpm in the second cycle, and then 120 bpm in the third cycle. This shows that the user's physical fitness has improved, his heart rate has stabilized, and his endurance has increased. **Figure 5B** shows detailed heart rate data for each month. The first month fluctuates violently, the range of fluctuations in the second month is reduced, and the third month fluctuates the least, and the heart rate is more stable. This shows that as the training progresses, the user's response to the same exercise intensity decreases and the adaptability increases. **Figure 5C** compares the average monthly heart rate, which is the highest in the first month, and gradually decreases in subsequent cycles, showing that the cardiovascular burden is reduced after training and the physical fitness is significantly improved. **Figure 5D** uses a smoothing method to show the long-term trend of heart rate. It is clearly visible that as the training progresses, the user's physical fitness gradually improves and the heart rate changes tend to calm down.

Sports combined with biomechanics can scientifically improve the effect of sports, prevent injuries and enhance health. Biomechanics mainly studies the role of force on biological systems, especially in sports. It reveals in depth the ways in which the human body produces, transmits, and bears force, as well as the effects of these forces on muscle, bone, and joint functions [39–41]. When running, jumping, or lifting weights, biomechanics helps us analyze the physical principles behind movements, such as torque, power, speed, and acceleration. The sensor can accurately record data, showing exercise posture, energy consumption and physiological response in detail. When building an intelligent sports service platform, VR technology is used to create a real sports environment and enhance the user interaction experience. The platform combines tools such as Kinect and heart rate monitors to capture users' exercise and physiological data, such as heart rate and breathing rate, in real time. Through advanced algorithms, we analyze user actions to ensure training effectiveness and safety. At the same time, the platform provides personalized recommendations and risk warnings based on data to improve personal health management. This combination not only accurately evaluates the training plan, but also optimizes the allocation of resources to help the fitness of the whole people and realize the popularization and benefit of sports services to the public.

3.4. System integration and optimization

The central control system is the core of the integration of the three modules of virtual environment design, user interaction and data collection and analysis. The system is based on the microservice architecture. Each module operates independently as a service and is connected through an API (Application Programming Interface). The virtual environment design module focuses on building and rendering three-dimensional sports scenes such as track and field stadiums and basketball courts, which are uniformly scheduled by the resource manager. The user interaction module uses VR and sensor technology to capture user movements and achieve real-time interaction with the virtual environment. The data collection and analysis system precisely collect user motion data, such as heart rate, stride, etc., through sensors and biometric technology in VR devices, and then processes it by the data analysis engine of the central control system. During integration, distributed database technology is used to ensure the real-time and security of user data. At the same time, efficient communication between modules is achieved through the message queue system to reduce system latency. In addition, a flexible plug-in mechanism is created to quickly adapt to changes in technology or business needs in the future, and functional modules can be added or replaced without changing the core code.

After system integration, to improve the rendering efficiency of the virtual environment, dynamic loading and unloading technology is used to adjust the loading of scene elements in real-time according to changes in user perspective, thereby stabilizing the frame rate and reducing rendering pressure. At the same time, the lighting model and texture compression are optimized to reduce GPU (Graphics Processing Unit) resource consumption and improve image quality. In solving the problem of VR device latency, the sensor data processing algorithm is improved to ensure that user actions can be quickly fed back to the virtual environment. In addition, the design of adaptive interaction logic can adjust the interaction settings according to the user’s movement characteristics and physical characteristics to improve the smoothness and accuracy of interaction. At the data processing level, distributed computing and parallel technology are used to decompose and assign tasks to multiple servers, which improves analysis efficiency and accuracy.

After system integration and optimization, in virtual environment rendering, dynamic loading and unloading technology effectively reduces the rendering burden and ensures smooth images and rich details in complex sports scenes. In terms of user interaction, optimizing sensor data processing and adaptive interaction logic significantly reduces VR device latency and enhances the immediacy, accuracy, and immersion of user interaction. At the data processing and analysis level, contributing to distributed computing and parallel technology, data analysis is faster and more accurate, thus providing users with more personalized suggestions and health warnings, and improving the intelligence level of the platform.

4. Evaluation of the effectiveness of a smart sports service platform that integrates biomedical data

4.1. Experimental design

To evaluate the actual effect of the smart sports service platform built based on OpenHMD in this article, a university in a certain place is used as the experimental object, and the constructed smart sports service platform is applied to the university. The actual effect of the platform is evaluated from the two perspectives of platform performance and user experience. The platform built by big data (BD) technology, artificial intelligence (AI) technology and cloud computing technology is selected as a comparison to compare the performance and user experience of the platforms built by four different methods. In the platform performance test, this article takes the number of logged-in users as the comparison benchmark, compares the response time, data transmission rate, and platform stability of four different platforms, and evaluates the technical implementation effect of the platform. In the user experience evaluation, this article mainly tests the immersion, interactivity and operability of the platform. To this end, this article selects 10 students from each of the first-year classes 1 and 2 of the physical education majors of the college of physical education to conduct immersion, interactivity and operability tests, and measures their user experience effects in the form of scores.

4.2. Platform performance test

4.2.1. Response time

Response time is crucial to platform performance and directly affects user immersion and interactive experience. Optimizing response time can improve system performance, ensure efficient operation under high concurrency, and improve user satisfaction. To this end, this article compares the same response time of the platform under 4 methods, and the results are shown in **Figure 6**:

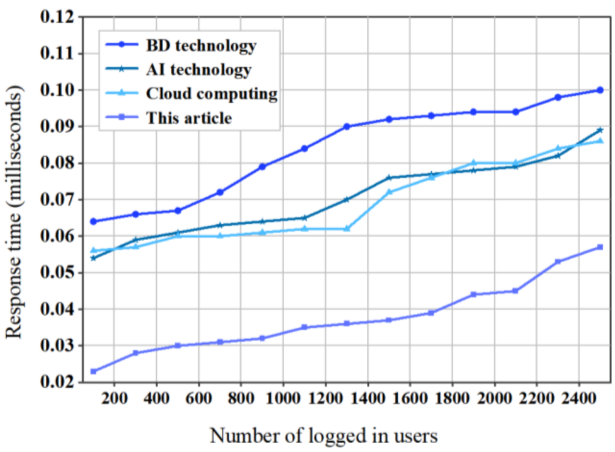

Figure 6. Comparison of platform response time under four methods.

Figure 6 shows that when the number of logged-in users is 100, the response time of this method is only 0.023 milliseconds, which is much lower than 0.064 milliseconds of BD technology, 0.054 milliseconds of AI technology, and 0.056 milliseconds of cloud computing. When the number of logged-in users increases to 300, the response time of this method is 0.028 milliseconds, which is still better than 0.066 milliseconds of BD technology, 0.059 milliseconds of AI technology, and 0.057 milliseconds of cloud computing. When the number of logged-in users is 1500, the response time of this method is 0.037 milliseconds, with 0.092 milliseconds of BD technology, 0.076 milliseconds of AI technology, and 0.072 milliseconds of cloud computing technology. It can be learned that the response time of other technologies has increased significantly. When the number of logged-in users is 2500, the response time of this method is also only 0.057 milliseconds, with 0.100 milliseconds of BD technology, 0.089 milliseconds of AI technology, and 0.086 milliseconds of cloud computing technology. The response time of this method is 0.043 milliseconds less than that of BD technology, 0.032 milliseconds less than that of AI technology, and 0.029 milliseconds less than that of cloud computing technology. These data fully show that this method has significant advantages in response time optimization, and can maintain high performance under different user loads, providing users with a smooth and natural interactive experience, improving user immersion and satisfaction, and ensuring efficient operation of the system.

4.2.2. Data transmission rate

The data transmission rate is crucial to platform performance. A high rate can ensure real-time interaction and data synchronization in the virtual environment, improve user experience, reduce latency, and ensure system smoothness, which is critical for stable and reliable sports services. To this end, this article compares the data transmission rate of the platform under four methods with different numbers of logged-in users. The results are shown in **Figure 7**:

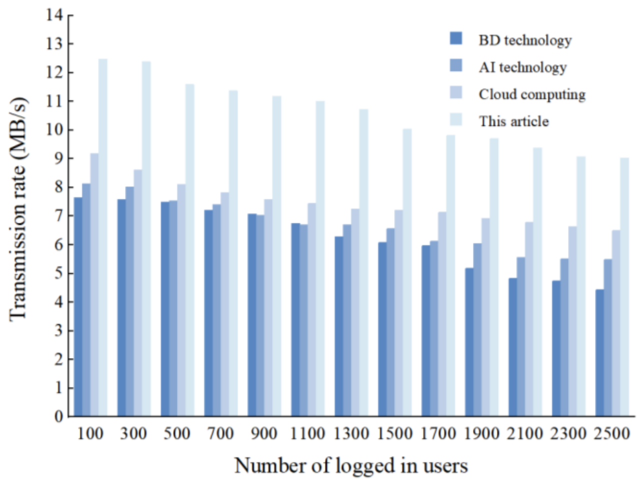

Figure 7. Comparison of platform data transmission rates under four methods.

Figure 7 shows that when the number of logged-in users is 100, the data transmission rate of this method is as high as 12.48 MB/s, far exceeding the 7.64 MB/s of BD technology, 8.13 MB/s of AI technology, and 9.19 MB/s of cloud computing. As the number of users increases, the advantage becomes more obvious. When the number of logged-in users is 300, the rate of this method is 12.38 MB/s, while the other technologies are 7.57 MB/s, 8.02 MB/s, and 8.61 MB/s, respectively. Even in the case of high concurrency of 1500 users, this method still maintains a rate of 10.03 MB/s, while the transmission rates of BD, AI, and cloud computing technologies are 6.08 MB/s, 6.56 MB/s, and 7.20 MB/s, respectively. When the number of logged-in users increases to 2500, the transmission rate of this method is 9.04 MB/s, and the transmission rates of other technologies are 4.44 MB/s, 5.49 MB/s, and 6.50 MB/s, respectively. The transmission rates of this method are 4.6 MB/s, 3.55 MB/s, and 2.54 MB/s higher than those of BD, AI, and cloud computing technologies. This shows that this method has a significant advantage in data transmission rate, can maintain high performance under different user loads, and provide users with a smooth and natural interactive experience. In scenes with high concurrent access and large amounts of data exchange, this advantage is crucial to providing stable and reliable sports services.

4.2.3. Platform stability

In addition to response time and data transmission rate, this article also conducts stability tests. This test can ensure the reliability of the platform under high load and long-term operation and prevent system crashes. Generally speaking, platform stability can be evaluated by failure rate. This article tests the failure rate of the platform under 4 methods. The results are shown in **Table 2**:

Table 2. Failure rates of the platform under 4 methods.

Number of logged in users	BD technology (%)	AI technology (%)	Cloud computing (%)	This article (%)
100	4.53	4.03	3.38	1.21
300	5.74	4.72	3.56	1.24
500	6.55	4.97	4.13	1.36
700	7.90	5.85	4.39	1.38
900	9.52	6.19	5.06	1.62
1100	9.53	7.20	5.70	1.63
1300	9.76	7.49	5.94	1.68
1500	10.32	7.93	6.88	1.84
1700	11.17	7.96	7.11	1.93
1900	12.18	8.34	8.03	2.30
2100	12.30	8.77	8.16	2.98
2300	12.33	9.62	8.22	2.99
2500	12.38	9.65	8.89	3.03

As shown in **Table 2**, as the number of logged-in users increases, the failure rate of the proposed method remains low and grows slowly. When the number of logged-in users is 100, the failure rate of the proposed method is only 1.21%, which is much lower than 4.53% of BD technology, 4.03% of AI technology, and 3.38% of cloud computing. When the number of logged-in users increases to 300, the failure rate of the proposed method rises slightly to 1.24%, while the failure rates of other technologies rise to 5.74%, 4.72%, and 3.56%, respectively. When the number of logged-in users increases to 1500, the failure rate of the proposed method is only

1.84%, which is much lower than 10.32%, 7.93%, and 6.88% of BD, AI, and cloud computing technologies. When the number of logged-in users increases to 2500, the failure rate of the proposed method is 3.03%, which is still lower than 12.38% of BD technology, 9.65% of AI technology, and 8.89% of cloud computing. The failure rate of the proposed method is 9.35%, 6.62%, and 5.86% lower than that of BD technology, AI technology, and cloud computing technology, respectively. It can be seen that the proposed method has significant advantages in terms of platform stability, can maintain high performance under different user loads, and provide users with continuous and high-quality services, thereby enhancing user trust and promoting platform development.

4.3. User experience test

4.3.1. Immersion test results

Immersion improves user experience and ensures that users truly participate in sports activities. Good immersion can encourage users to participate in sports activities and improve their health. This article uses scoring to evaluate the immersion of the platform under different methods, with a total score of 10 points. Through the scoring form of participants, the immersion of students in two classes using different methods is compared. The results are shown in **Figure 8**:

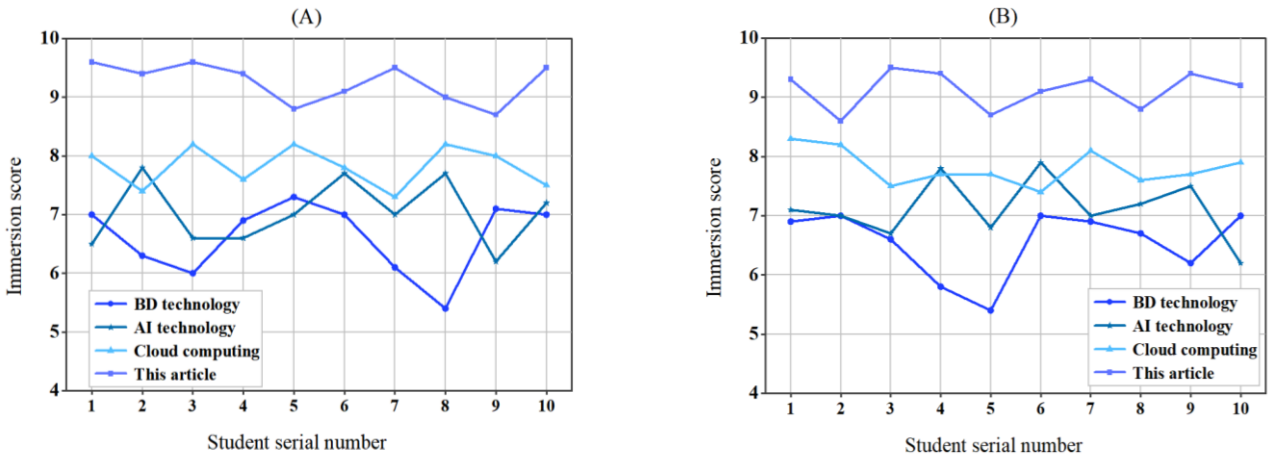

Figure 8. Immersion score **(A)** Comparison of immersion scores of students in class 1; **(B)** Comparison of immersion scores of students in class 2.

As shown in **Figure 8A,B**, the average immersion scores of students in Class 1 for BD technology, AI technology, cloud computing, and the proposed method are 6.60, 7.03, 7.83, and 9.26, respectively. Among them, the immersion scores under BD technology by students in Class 1 range from 5.4 to 7.3 points; the immersion scores under AI technology range from 6.2 to 7.8 points; the immersion scores under cloud computing range from 7.3 to 8.2 points; the immersion scores under the method of this article range from 8.7 to 9.6 points. The average immersion scores under BD technology, AI technology, cloud computing, and the method of this article by students in Class 2 are 6.54, 7.13, 7.80, and 9.12, respectively. Among them, the immersion scores under BD technology by students in Class 2 range from 5.4 to 7.0 points; the immersion scores under AI technology range from 6.2 to 7.9 points; the immersion scores under cloud computing range from 7.4 to 8.3 points; the immersion scores under the method of this article range from 8.6 to 9.5 points. It can be seen that the immersion score of the proposed method is higher than that of other methods, whether it is students in Class 1 or Class 2. This means that the proposed method is effective and has obvious advantages. It not only improves the user's immersion experience, but also improves the user's participation and satisfaction in sports activities, providing strong support for the smart sports platform.

4.3.2. Interactivity and operability

Interactivity testing is critical to improving user satisfaction and interest, and can ensure smooth interaction in the virtual environment. To this end, this article compares the interactivity scores of the four platforms in the form of student scores. The results are shown in **Figure 9**:

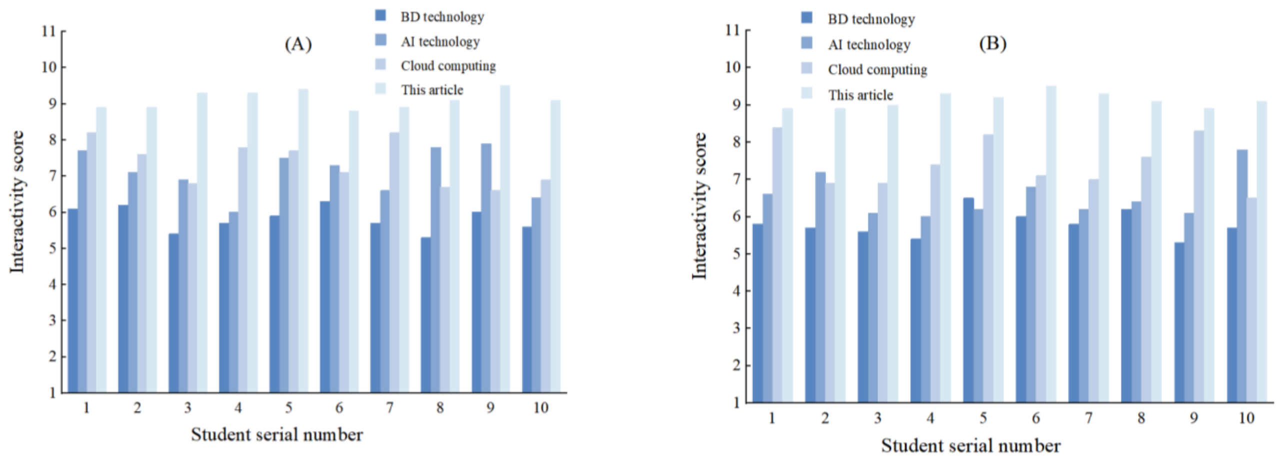

Figure 9: Interactivity scores **(A)** Comparison of interactivity scores of students in class 1; **(B)**: Comparison of interactivity scores of students in class 2.

It can be clearly seen from **Figure 9A,B** that the average interactivity scores of the students in Class 1 of the platform under BD technology, AI technology, cloud computing, and this method are 5.82, 7.14, 7.37, and 9.14, respectively; the average interactivity scores of the students in Class 2 of these four technologies are 5.80, 6.52, 7.43, and 9.13, respectively. Among them, the students in Class 1 and Class 2 score 5.3–6.3 and 5.3–6.5 points respectively for the interactivity of the platform under BD technology, 6.0–7.9 points and 6.0–7.8 points respectively for the interactivity of the platform under AI technology, 6.6–8.2 points and 6.5–8.4 points respectively for the interactivity of the platform under cloud computing technology, and 8.8–9.5 points and 8.9–9.5 points respectively for the interactivity of the platform under the method of this article. It can be seen that the cloud computing technology scores higher than AI and BD technologies, reflecting its strength in data processing and complex interactions. The overall scores of AI and BD technologies are relatively low. The interactivity score of this method is the highest, which means that it cannot only solve technical problems such as delay and response speed, but also provide a smoother and more natural user interaction experience. It not only enhances the interactivity of the system, but also brings more personalized and precise services to users, promoting the progress of smart sports services.

Finally, this article also tests its operability in the form of 2 scoring. The results are shown in **Table 3**:

Table 3. Comparison of operability scores (Score).

Class 1 students (Student serial number)	BD technology (score)	AI technology (score)	Cloud computing (score)	This article (score)
1	7.2	7.4	7.6	8.9
2	7.6	7.2	8.1	8.7
3	7.6	7.4	7.6	9.4
4	7.2	7.3	8.2	9.5
5	7.6	6.9	7.8	9.5
6	7.8	7.6	7.7	8.8
7	7.3	7.8	7.9	8.9
8	7.7	6.9	8.5	9.4
9	7.4	6.9	8.4	9.7
10	7.7	7.5	8.0	9.1
Class 2 students (Student serial number)	**BD technology (score)**	**AI technology (score)**	**Cloud computing (score)**	**This article (score)**
1	7.7	7.6	7.5	9.1
2	7.3	7.4	7.7	8.9
3	7.2	7.7	8.1	8.8
4	7.5	7.6	8.4	9.8
5	7.3	7.1	7.8	9.4
6	7.4	7.3	8.4	8.9
7	7.3	7.7	8.1	9.0
8	7.1	7.3	7.7	8.9
9	7.3	7.2	7.5	9.6
10	7.4	6.9	7.8	9.7

As shown in **Table 3**, for the proposed method, the average operability scores of students in Class 1 and Class 2 are 9.19 and 9.21 respectively; for BD technology, the average operability scores of students in Class 1 and Class 2 are 7.51 and 7.35 respectively; for AI technology, the average operability scores of students in Class 1 and Class 2 are 7.29 and 7.38 respectively; for cloud computing technology, the average operability scores of students in Class 1 and Class 2 are 7.98 and 7.9 respectively. It can be seen that the proposed method has significant advantages, and its operability score is significantly higher than other methods, which shows that the proposed method is more intuitive and simpler to operate, can effectively meet user needs, and improve the user experience, providing users with more convenient and efficient services.

In order to gain an in-depth understanding of the true feelings and needs of users when using this smart sports service platform, a questionnaire survey on user experience was designed and executed. The core goal of this questionnaire is to explore the various elements that can affect the user's immersion, such as the authenticity of the virtual environment, the harmony of sound effects, and the fluency of user interaction with the system, so as to analyze the key factors that have a significant impact on the overall user experience. Factors. The results are shown in **Table 4**:

Table 4. Survey results of user questionnaire.

Evaluation index	Very satisfied (%)	Satisfied (%)	General (%)	Dissatisfied (%)	Very dissatisfied (%)
Fidelity of virtual scenes	25	40	25	8	2
Coordination of sound effects	30	35	20	10	5
Naturalness of interaction	20	45	25	8	2
System response speed	35	30	20	10	5
Clarity of error prompts and handling	40	35	15	7	3
Overall satisfaction	30	40	20	8	2

As can be seen from the data in the table, regarding the fidelity of virtual scenes, although 75% of users expressed satisfaction or very satisfaction, 25% of users still rated generally or dissatisfied. This shows that the visual presentation of the platform has been recognized by most users, but more than one-third of users believe that there is room for improvement. Among them, high-resolution images and realistic light and shadow effects are important links to enhance the sense of immersion. User feedback specifically mentioned environmental details, such as grass textures and the true reproduction of sports equipment, which are essential to its immersive experience.

In terms of the coordination of sound effects, 65% of users have a positive evaluation, but 35% of users still express general or dissatisfied. Appropriate background music, ambient sound effects, and clear motion feedback can significantly enhance the user's sense of immersion. However, 15% of users reported that the sound effect was delayed or uncoordinated, which had an adverse impact on the immersion, indicating that the accuracy and real-time of the sound effect needed to be further optimized.

Regarding the naturalness of interaction, 65% of users expressed satisfaction, but some users still pointed out problems such as inaccurate gesture recognition and slow response to control commands. Smooth and intuitive interaction design is essential to maintain user immersion. Users expect that when performing sports activities in a virtual environment, actions can be quickly and accurately captured and reflected on the screen. If the interaction is not natural enough, it may reduce the frequency and satisfaction of users.

The fidelity of the virtual scene, the coordination of sound effects, and the naturalness of interaction are the key factors that affect the sense of immersion and the overall user experience. The data show that the satisfaction scores of these three aspects are similar, but each faces different challenges. In addition, the system response speed and the clarity of error prompt processing are also the focus of users' attention. In order to further optimize the smart sports service platform, we need to continuously improve the realism of virtual scenes, ensure a high degree of synchronization of sound effects, and improve the naturalness of interaction. These improvements will help improve the immersive experience of users, enhance their trust and dependence on the platform, and promote the digital transformation and sustainable development of sports services.

5. Conclusions

This article constructs a smart sports service platform based on VR technology, and comprehensively evaluates the performance and user experience of the platform. The research results show that the proposed method has significant advantages in response speed, data transmission rate and stability, especially in high concurrency scenes, with rapid response, efficient data transmission, and a continuously low failure rate. In terms of user experience, this method also performs well, and its immersion, interactivity and operability are highly praised by users, which is significantly better than other technologies. The smart sports service platform proposed in this study not only has outstanding technical performance, but also has achieved a qualitative leap in user experience, effectively improving users' enthusiasm and satisfaction. The successful construction of this platform provides a richer and smoother virtual environment for sports training and activities, promotes the rational allocation and efficient use of sports resources, and injects strong impetus into the innovative development of smart sports.

The research has made significant contributions to the theory of intelligent sports service platform, innovatively introduced VR technology, enriched the theories of platform architecture design, user interaction, and data-driven service optimization, filled the existing gaps, and improved the existing framework. First of all, a multi-layer architecture model based on VR is proposed, including four layers of basic support, data support, application services and display, emphasizing efficient data processing, secure storage, intelligent and personalized service design, providing a new paradigm for future platform design, supporting high-concurrency access, ensuring smooth images of sports scenes, rich details, and enhancing the user experience. Secondly, in-depth discussion on the use of VR technology and sensors to realize natural human-computer interaction, provide an immersive motion environment through precise motion capture and real-time feedback, enhance user participation and satisfaction, innovate traditional two-dimensional interface interaction, and provide a new perspective on understanding user behavior and psychological needs. At the same time, an optimization model for the layout of the interactive interface is developed to maximize the distribution of visual attention, improve operational efficiency, and inject new vitality into user interaction design. Finally, emphasize the key role of the data analysis and management system, dig deep into user data, identify individual differences and adjust service content to achieve precise transformation. Based on technologies such as dynamic sampling and light projection algorithms, it accurately collects and analyzes user action data, provides managers with scientific decision-making support, and promotes the innovation and development of sports services. These advances have solved problems such as uneven resources and single services, and laid a solid foundation for the digital transformation of the industry.

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