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Research on the application of environment interaction perception algorithms in virtual reality for audience immersion enhancement in live sports event broadcasting

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Abstract The traditional way of watching sports events can no longer meet the modern audience's demand for interactivity and immersion. The environment interaction perception algorithm in virtual reality provides new ideas to enhance the immersion of live sports events. Using Leap Motion and other sensing devices combined with virtual reality technology, the gestures of the audience can be recognized in real time, thus improving the interaction between the user and the live broadcast environment and enhancing the audience's sense of presence and participation. This study explores the application of virtual reality technology based on environment interaction perception algorithms in live broadcasting of sports events, using Leap Motion sensors to capture the user's hand movements and interacting with the virtual reality environment through gesture recognition algorithms. In the experiment, 18 participants watched live sports events using different media and completed the corresponding interactive tasks. The experimental results show that after applying the interactive perception algorithm, the viewer's operation efficiency is improved by about 30%, and the interaction process is smoother. Through regression analysis, it was found that perceptual algorithm response, algorithm awareness and immersion experience were significantly positively correlated, while perceptual algorithm indifference and intrusiveness were significantly negatively correlated. The study shows that the live sports event broadcasting system based on this algorithm can significantly enhance the immersion of the audience and reduce the operation burden, which provides a useful reference for the development of virtual reality live broadcasting technology.

Index Terms Virtual Reality, Environmental Interaction Perception, Gesture Recognition, Immersive Experience, Leap Motion, Live Streaming of Sports Events

I. Introduction

In recent years, sports events are booming, and countries around the world are paying more and more attention to the live broadcast of sports events. Since the popularization of live television broadcasting in the 20th century, live sports events have been broadcast from professional live platforms to social media platforms, experiencing a single-camera 2D-4K/8K UHD-social media-multi-camera video, but the traditional form of live broadcasting ignores the interaction of athletes, referees, and coaches in the perception of the audience, and most of the live broadcasts have a delayed effect and lack real-time interactivity, which makes it difficult for viewers to truly perceive the atmosphere of the scene, and the immersion decreased [1]-[5]. Some studies have applied artificial intelligence technology in live broadcasting means to enhance online audience engagement [6]. However, the immersion of the audience has not been significantly improved.

Virtual reality (VR) technology with a three-dimensional perspective, in recent years, has been continuously applied to the live broadcast of sports events, which can enable it to better play its own value and real role in realizing the new development of sports live broadcast [7], [8]. In the 2016 Rio Olympics, VR technology was first applied to live sports events. Since then, there have been more and more application cases. For example, in 2018, FIFA and BBC introduced VR technology into the live broadcast of the World Cup that year for the first time [9]. Its appearance means that the live broadcast of large-scale sports events has entered the interactive three-dimensional era from the once flat video era, and viewers all over the world have the opportunity to come into closer contact with such sports events [10], [11]. The application of VR technology in the live broadcast of sports events can better enrich the dissemination form of sports programs, provide a better broadcasting effect for the audience, further change the traditional live broadcast of sports events on the image display as well as the shortcomings of the event effect, increase the interactive effect, so that the audience can enjoy the event scene more, and further have a good grasp of the event content [12], [13]. And VR technology through the environment perception, to bring the audience immersive live feeling, stimulate the audience's emotional experience, this technology revolution for live sports events injected a new vitality, bring new business opportunities, become one of the highlights of the live sports events [14], [15].

Virtual reality technology has made significant progress in recent years in a variety of fields such as entertainment, education, and healthcare, and in particular, its application in live sports events has attracted widespread attention. The traditional way of watching sports events mainly relies on TV or computer screens, which can provide real-time information and images of the game, but the audience's interactivity and immersion are more limited. With the maturity of virtual reality technology, viewers are able to watch sports events immersively through VR equipment, greatly enhancing the viewing experience. However, the existing VR live broadcast system for sports events still faces some problems, the most prominent of which is the lack of an effective interactive perception mechanism, which makes the audience's immersion unable to achieve the desired effect.

In order to overcome this problem, an environment interaction perception algorithm has emerged. The algorithm enables the audience to interact with the virtual environment through natural hand movements by utilizing gesture recognition and other technologies, thus enhancing the sense of immersion. Leap Motion, as a high-precision gesture recognition tool, is able to capture the audience's hand movements and provide real-time feedback through the virtual reality platform. By real-time sensing and analyzing viewers' hand gestures, viewers are not only able to control the rotation and zoom of the live broadcast screen, but also perform more customized operations, such as selecting key moments in the event, replaying and other functions.

Based on the combination of Leap Motion sensor and virtual reality technology, this study designs a new interactive environment perception algorithm, which aims to enhance the immersive experience of viewers in live sports events by interacting with the virtual environment through gesture recognition. This paper verifies the effect of the algorithm in practical applications through experiments and analyzes its potential in live sports events in depth. The results show that the environment interaction perception algorithm can significantly enhance the immersion and operation efficiency of the audience, providing new technical support for the future development of live sports events.

II. Environment-based interactive perception algorithm for live sports event broadcasting system

II. A. Leap Motion-based interactions

II. A. 1) Leap Motion related principles

The Leap motion somatosensory controller can track up to 10 hands as well as fingers [16]. The sensory range of the Leap motion controller is about 150° and the working range is about 25 to 600 mm in front of the device, so that the spatial range forms an inverted quadrangular pyramid, similar to an inverted pyramid, with the tip of the pyramid at the center of the device. The device has a high precision and high tracking frame rate, and can track hand movement at over 200 frames per second with an accuracy of 0.01 mm. The device consists of two high frame rate HD cameras, three IR LEDs, IR filters, optical sensors, and a USB 3.0 chip.

The two cameras collect images within the field of view, analyze and calculate the parameters in different directions, get all the information of the hand in real space, and use parallax to produce a sense of spatial depth.

The device is backlit by infrared LEDs, if the hand appears in the detection range, the infrared light emitted will be blocked and reflected back through the narrow-band filter to identify the infrared, and then with the help of binocular stereoscopic ranging principle to obtain data information, the two parts of the contents of the USB transmission to the computer, after the calculation of the realization of the hand's tracking, the principle of the Leap motion gesture recognition is shown in Figure 1.

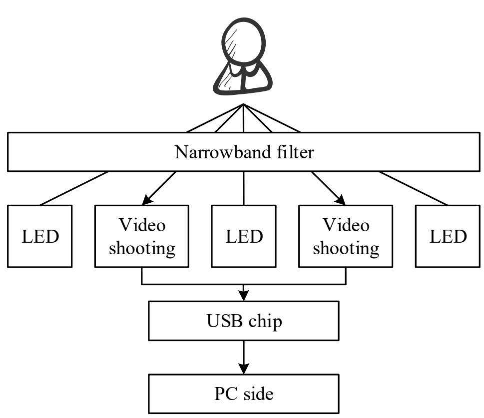


Figure 1: Computer gesture recognition processing

II. A. 2) Leap Motion Gesture Recognition Technology Study

The Leap Motion SDK allows programs to access deep data or edit it using a high-level language. From a functional point of view, the Leap Motion sensor analyzes and calculates a stream of data, which is divided by the SDK framework and is largely dependent on time, to calculate the gesture or speed at which the hand is moving over the sensor.

Leap Motion recognizes each target individually, with internal algorithms attaching a unique identifier to each finger, gesture, and hand, making it easy to track the user's hand.The Leap Motion software uses an internal model of the human hand to provide predictive tracking even when parts of the hand are not visible, but tracking works best when the hand's contours and its fingers are clearly visible. Optimal. In the case of partial invisibility, a pre-built model of the hand and the parameter data visible in the previous frame are used to calculate the most likely position and situation at this moment.

Leap Motion is used to acquire the data and match it with the relevant data from the prefabricated gestures to determine the action recognition and categorization, and to control the actions to be performed accordingly.

The acquired and processed data need to be discriminated to realize control, and the discrimination process needs to be matched with the prefabricated gestures. In this paper, the Euclidean distance determination method is chosen, and the Euclidean distance in three-dimensional space is shown in equation (1):

$$d_{ab} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2} \tag{1}$$

For this paper will be placed LeapMotion in the front of HTCVive, according to the user's use of behavioral habits analysis found that the three-dimensional coordinates in the $x-z$ plane in the range of change is much larger than the y axis of change, so in the above formula of the Euclidean distance to add weighting coefficients, through the weighting coefficients can be more accurately determined. Let λ, β, φ be the weighting coefficients of x, y, z axes respectively, and $\lambda + \beta + \varphi = 1$, the weighted Euclidean distance is shown in equation (2):

$$d_{ab} = \sqrt{\lambda(x_1 - x_2)^2 + \beta(y_1 - y_2)^2 + \varphi(z_1 - z_2)^2} \tag{2}$$

Gesture recognition requires a threshold μ, through which the gesture is determined. If the condition is met, it is determined as the corresponding prefabricated gesture, otherwise it can be determined again with other prefabricated gestures.

II. A. 3) LeapMotion Gesture Sensor

Leap Motion is not only capable of real-time tracking and recognizing the information of hands and fingers during the process of use, but also transmits the tracking data by means of data frames [17]. In each data frame, the key point information of the tracked object is included and encapsulated in the form of a list. All detected hand models are given an ID until the model is out of detection range.

In the data frame, the information and list of detected hands, the information and list of fingers, and also the information of various handheld tools, finger pointing objects, and the list are encapsulated. According to the information of the list encapsulated in the data frame, its corresponding information is queried through Frame::hand, or Frame::finger functions. Depending on the hand model ID, the independent skeletal node to be tracked can be found in the next data frame. At the same time, it is also able to further determine all the objects in the tracking list based on the ID, and then return a reference if the ID exists, or an invisible object if it does not exist, as a basis for determining the existence of the hand model. The changes before and after the data frames are acquired through Leap Motion, and the gestures are further interpreted to form various movement factors.

The hand model acquired through LeapMotion yields 3D information such as hand key point pose and position. However, not all of these data can be detected in all hand model data frames; if the hand is out of the Leap-Motion field of view, then the corresponding data frame is empty.

II. B.Application of Gesture Recognition in Panoramic Stereoscopic Video Live Streaming System

II. B. 1) Definition of gesture semantics

Based on the hand information available to Leap Motion, the defined gestures and semantics are shown in Table 1.

Table 1: Interaction gestures and semantic definitions

Gesture description	Word of hand
Left hand	Rotary picture
kneading	Zoom screen
Right hand grip	Mobile image

II. B. 2) Experimental Principles of Gesture Interaction

Leap Motion controller service runs on the daemon of the operating system, when using Leap Motion you need to open the controller software, detect the Leap Motion connected through the USB interface to obtain the hand model.

Leap Motion controller service can be used for subsequent development of gesture interaction experiments after scanning the Leap Motion accessed through the USB interface, this chapter gesture interaction based on the panoramic stereoscopic video live broadcasting system on the receiving end of the hardware and software platform, in the Unity2018.1.0 import Leap Motion Unity SDK can be completed gesture interaction related to the development. The interaction logic is written through the Unity project C# language script, through the recognition of predefined gestures, operating the live screen spherical curtain, to complete the gesture interaction.

When the Unity scene is running, the Mono Behavior class inherited from the script is called, and in this class, according to the function of each function, the first functions to be called are Awake and Start, which are used to initialize the variables and assign values, and then to the Updates module.

Update is related to the number of frames that the platform is running, Fixed Update is executed based on a fixed time. the refresh frame rate is not the same every time Unity runs the scene, if Fixed Update is used, the number of times per second that the function is called is the same, which may result in the sequence of gesture data obtained from Leap Motion is not the same as the refresh frame rate, which affects the gesture interactions in real-time, so Update is chosen as the update function.

II. B. 3) Gestures to control the live screen

The receiving end of the live streaming system receives and displays the panoramic video in real time in Unity, and when the user puts on the VR headset the screen they watch is the screen displayed in real time by the Game panel in Unity. Place Leap Motion on the desktop, when the hand appears in the Leap Motion field of view, the live screen will display the hand model recognized by Leap Motion. During the gesture interaction, observe whether the screen in the Unity Game panel can achieve the predefined effect of rotating, scaling, and moving the live screen. In addition, in order to avoid the influence of the VR headset movement on the switching of the panoramic video screen, there is no need to connect the VR headset during the gesture interaction.

II. C.Interactive Perception Experimental Program Design and Research Methodology

II. C. 1) Experimental conditions

Hardware environment: host CPU for, main frequency, memory, video image acquisition for ordinary camera.

Software configuration: the operating environment of the experimental platform vc6.0, based on the MFC single-document application, the virtual scene using OpenGL modeling.

Experimental distance: this experiment was carried out under the ordinary camera, in order to make it easier for the experimenter to complete the experiment independently as well as to match the parameters of the virtual human hand and the human hand, the experimenter was required to stand at a position 1 meter away from the camera.

Experimenters: 18 graduate students, 7 of them are from our lab with research direction of human-computer interaction, and the other 11 are graduate students from our college with different research directions. Among all the experimenters, the ratio of male to female is 3:2. Before starting the experiment formally, the experimenters were fully explained the steps and methods of the experiment, as well as the precautions to be taken when doing the experiment, such as the speed of hand movement is not easy to be too fast, and the human face should not appear in the range of the camera image, and so on.

Purpose of the experiment: the purpose of the experiment in this chapter is to verify the perception and sports events live phase interaction algorithm, in the virtual scene of the interaction process can reduce the user's operational burden, so that human-computer interaction is more natural and efficient.

II. C. 2) Experimental design

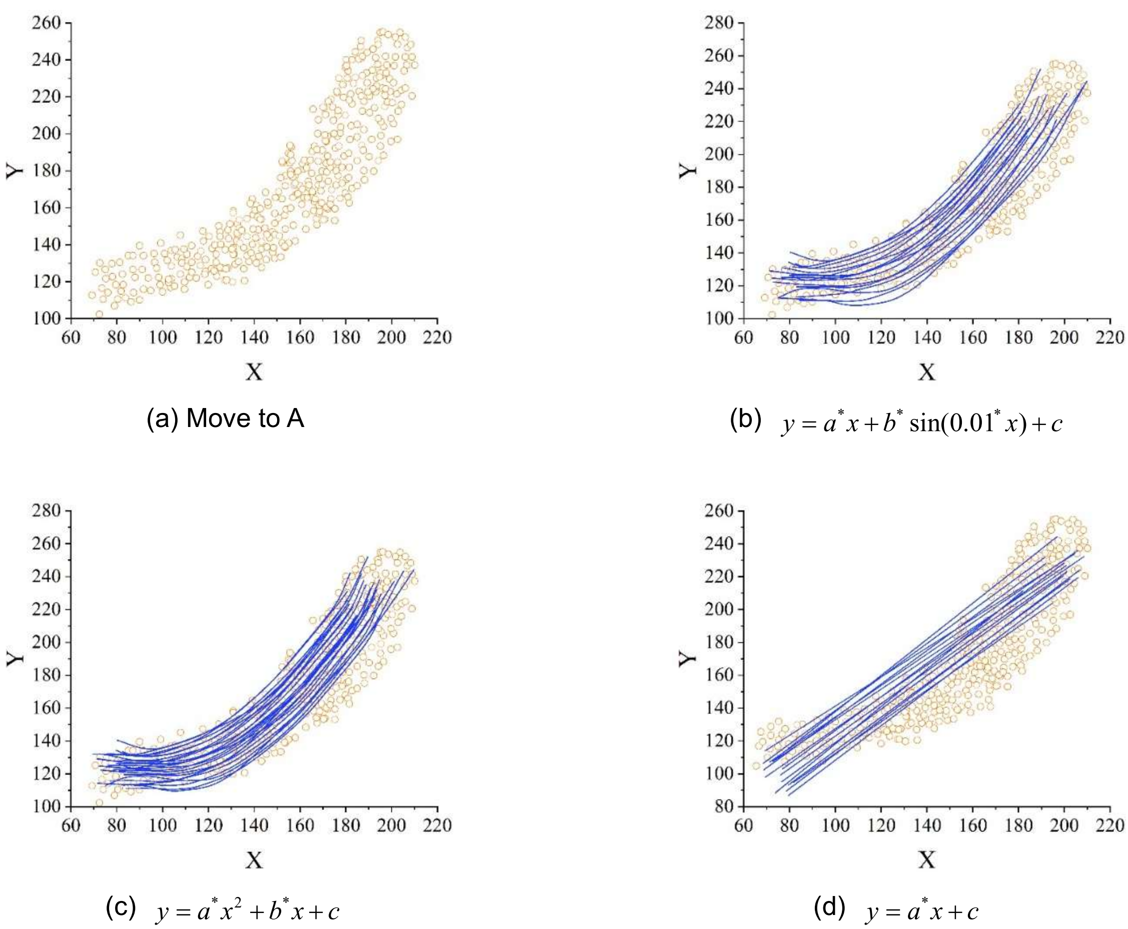
The experimenter uses the human hand to control the virtual human hand to move towards the virtual object, the system senses the direction of the human hand movement, predicts the object that the user wants to operate, and then moves the prediction result towards the virtual human hand until the distance between the two is less than the threshold and then carries out the collision detection, and the indicator light for this process is green for the selection of the object stage; 2s after the end of the collision detection, it is the waiting stage, and the indicator light is orange; and the indicator light is orange for the waiting stage; and the dynamic gesture recognition is carried out after the end of the waiting stage. Dynamic gesture recognition, and then according to the recognition results to make the corresponding operation, this process is the interactive stage, the indicator light is yellow.

Let 18 experimenters who are familiar with the operation process complete the same two groups of experiments, each group of experiments 5 times, respectively, to complete the following: assembly and disassembly of the screw nut, browse and observe the surface of the teapot, move other objects, etc.. The user was told to operate according to the indicator light, and the system would decide whether the virtual hand and the object would move in one piece or not according to the user's action in the waiting phase (orange), and the gesture was stationary for 2 seconds to end the phase of selecting the object. After the operation, the user's gesture is stationary for a certain period of time after which this operation ends. In order to get better experimental data, the program is reopened after each experiment and a new file is created to store the experimental data. Each experiment consists of selecting an object, as well as operating on the object, and the system responds accordingly to the operation to complete the interaction task.

II. C. 3) Gesture Prediction

The study used two methods for gesture prediction, namely the method with perceptual interaction and the method without perceptual interaction. First, the experimenter was allowed to control the virtual human hand to move up and down, left and right in the virtual environment. When the experimenter is able to control the movement of the virtual hand more skillfully, the experimenter is allowed to grasp the specified object, record the coordinates of the center of gravity points during the gesture movement, and store the data in different folders. The obtained center of mass coordinates were then imported into MATLAB and fitted using the following code.

In this paper, by using three kinds of curves to fit the trajectory of human hand movement as shown in Fig. 2, it can be seen that the movement of human hand is regular and purposeful. And the fitting effect of the three curves is different, the straight line has the worst fitting effect, and the quadratic and sinusoidal tuning curves are fitted with almost the same effect. From the image, it can be seen that the data points in the upper right corner of the image are very dense, which is due to the fact that the fitted data contains the data obtained in the collision detection stage, which is obviously unreasonable.



(a) Move to A

(b) $y = a^* x + b^* \sin(0.01^* x) + c$

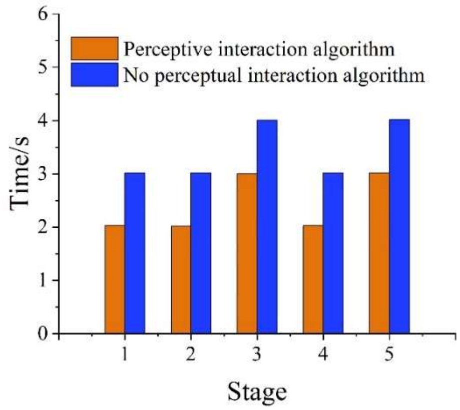
(c) $y = a^* x^2 + b^* x + c$

(d) $y = a^* x + c$

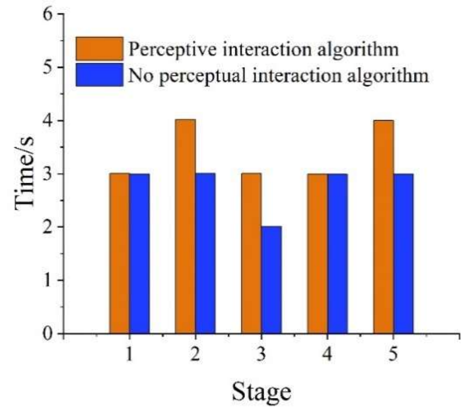
Figure 2: The three curves are fitting

II. C. 4) Experimental results and analysis

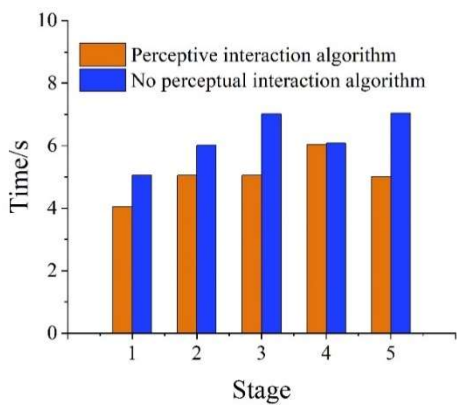
The experiment achieved good interaction results overall, and the experimenters were able to complete the interaction task relatively smoothly. The time used by the two methods to complete the interaction task is shown in Figure 3. It can be seen that: the average time for the two methods to complete the same experimental task without including the same interaction process is 12-14S, while the average time of this algorithm is 9S-11S, which saves 3S of time, and at the same time, the experimenter operates the whole experimental process more smoothly, and the interaction effect is also better.



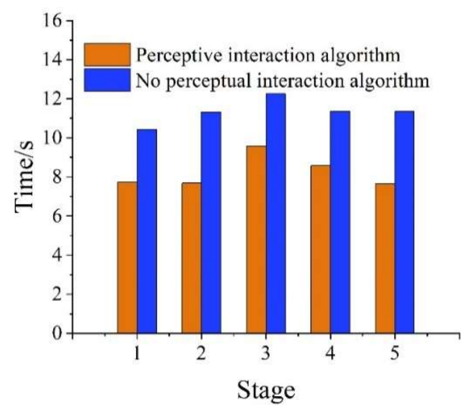
(a) Select object



(b) Translation object



(c) Unscrew



(d) Total time

Figure 3: Two algorithms time comparison diagrams

III. Analysis of the effect of interactive perception of sports events on the enhancement of audience immersion

III. A. Experimental design

III. A. 1) Purpose of the experiment

The purpose of this experiment is as follows:

Obtain the objective perceived information acceptance effect of users of live sports events in different media. In the preparation stage of the experiment, the information points in the experimental video were preset, and in the experiment, the information acceptance effect was quantified objectively with the help of the experimenter's recollection of the information points. This data is designed to address the problem of “relatively little research has been done on the effects of user information acceptance in different media” as stated in the introduction.

III. A. 2) Subjects

Before the experiment, the staff recruited 41 experimenters through a combination of online and offline publicity. After informing the experimenters about the content of the experiment and the way of data recording (including filling out questionnaires and audio recordings on their own, etc.), all 41 experimenters voluntarily participated in the experiment involved in this study.

III. A. 3) Experimental Procedures

This study is expected to quantitatively analyze the effect of information acceptance of the experimenters under different communication media through experiments, the specific process is as follows:

(1) Before the experiment involved in this study is formally conducted, all volunteers are required to complete a pre-test questionnaire, which is mainly used to find out whether the experimenters have any knowledge about the video involved in the experiment.

(2) After completing the pre-test questionnaire, the volunteers were divided into two groups, X and Y, according to gender and age, and ensured that the gender composition, average age and standard deviation of the experimenters in the two groups were not very different. The two groups of experimenters watched the four live sports event videos A, B, C, and D sequentially through different media device sequences, and the order of device use for the experimenters in group X to watch the four videos was VR, iPad, VR, iPad, and the order of device use for the experimenters in group Y to watch the four live sports event videos was iPad, VR, iPad, VR, thus completing the setup of the intergroup control to make a comparison between the two groups of experimenters; the experimental setup makes the experimenters in the same group cross use different devices, not making a group of experimenters use the same experimental device, to complete the setup of within-group control.

(3) After watching a live video of a sports event, the experimenters in each group were required to complete the corresponding video content questions and answers (4 in total), and after watching all the videos, they were required to complete a post-test questionnaire for all the videos. The questionnaire was mainly used to quantify the experimenter's feelings of presence, realism, and participation when watching the live broadcast, which was subjective.

III. A. 4) Experimental equipment

In the experiment, Pico G2 4KS is used as the VR media device, iPad air 3 is used as the traditional media device, and “Aqiyi VR” APP is chosen as the experimental video player, which has a smooth direction tracking function, enabling users to have a more natural sense of looking around when turning the viewpoint. In order to eliminate the non-essential differences of the four panoramic videos in different media, we ensure the consistency of the display clarity, screen brightness, audio volume and stereo level of the four videos in VR and iPad environments.

III. B. Questionnaire design

The scale for this study was designed based on the nature and characteristics of multiple variables, and the questionnaire measured a total of eight variables, including two dependent variables, five independent variables, and one control variable, including immersion experience, algorithmic resistance, perceived algorithmic response, perceived algorithmic slowness, perceived intrusiveness, privacy concerns, algorithmic awareness, and user experience level. Except for the questions related to demographic characteristics, the measurements were uniformly conducted using a five-point Likert scale, with data assigned according to 1 to 5. Scores from lowest to highest represent "strongly disagree", "disagree", "general", "agree", and "strongly agree". Users will rate the questionnaire based on their actual experience and first feeling, and the higher the score, the more the respondent agrees with the statement.

III. C. Results and analysis

III. C. 1) Correlation analysis

In this chapter, Pearson's correlation analysis [18] will be used to test the correlation between the dependent and independent variables in the research model, as well as to prepare for subsequent regression analysis. Correlation refers to the extent to which two variables present a positive or negative relationship with each other.

The correlation test is shown in Table 2, in the Pearson correlation validation between immersion experience and perceived algorithmic response, perceived algorithmic indifference, and perceived intrusiveness, the variables all present a strong correlation. Among them, immersion experience presents a significant positive correlation with perceptual algorithm response ($r=0.433^{**}$, $P=0.000<0.01$); immersion experience presents a significant negative correlation with perceptual algorithm indifference ($r=-0.409^{**}$, $P=0.000<0.01$); immersion experience presents a significant negative correlation with perceptual intrusiveness ($r=-0.359^{**}$, $P= 0.000<0.01$).

Table 2: Correlation test

		Perceptual algorithm response	Perceptual algorithm apathy	Perceptual intrusion
Immersive experience	Pearson correlation	0.433**	-0.409**	-0.359**
	Sig.	0.001	0.001	0.001

**. At the 0.01 level (two-tailed), *. Significant correlation at the 0.05 level (two-tailed).

The correlation analysis of algorithmic resistance with perceived algorithmic response, perceived algorithmic indifference, perceived intrusiveness, algorithmic awareness, privacy concerns, and skill mastery is shown in Table 3, in which algorithmic resistance presents a significant correlation with perceived algorithmic response, perceived algorithmic indifference, perceived intrusiveness, algorithmic awareness, and skill mastery, whereas algorithmic resistance does not present a significant correlation with privacy concerns. Among them, algorithmic resistance showed significant positive correlation with perceived algorithmic response (r=0.433**,P=0.000<0.01); algorithmic resistance showed significant negative correlation with perceived algorithmic indifference (r=-0.267**,P=0.000<0.01); algorithmic resistance showed significant negative correlation with perceived algorithmic intrusion (r=-0.285**,P=0.000<0.01); and algorithmic resistance showed significant negative correlation with privacy concerns. 0.01); algorithmic resistance showed a significant positive correlation with algorithmic awareness (r=0.393**,P=0.000<0.01); algorithmic resistance showed a significant positive correlation with skill mastery (r=0.357**,P=0.000<0.01); and algorithmic resistance did not show a significant correlation with privacy concerns (r=0.31,P=0.637>0.01).

Table 3: Correlation analysis

		Perceptual algorithm response	Perceptual algorithm apathy	Perceptual intrusion	Algorithm consciousness	Privacy concerns	Skill control
Algorithm resistance	Pearson correlation	0.433**	-0.267**	-0.285**	0.393**	0.31	0.357**
	Sig.	0.001	0.001	0.001	0.001	0.637	0.001

III. C. 2) Regression analysis

The results of the regression analysis are shown in Table 4, the correlation coefficient in the model is 0.567, the R-square is 0.327, and the adjusted R-square is 0.311, which indicates that through the introduction of the variables, the explanatory rate of the immersion experience of the audience in the model reaches 31.7%. Among them, algorithm awareness significantly positively affects the audience's immersion experience (β =0.319, p<0.001); perceived algorithmic indifference significantly negatively affects the audience's immersion experience (β =-0.137, p=0.043); and perceived algorithmic response significantly positively affects the audience's immersion experience (β = 0.125, p = 0.036); and Perceived Intrusion significantly and negatively affected the immersion experience (β = -0.151, p = 0.013). In addition, the VIF values of all four variables in the model were less than 3, so none of the four variables were covariant. Therefore, among the effects of the independent variables on the dependent variable, algorithm awareness and perceived algorithmic response have a significant positive effect on immersion experience, and perceived algorithmic indifference and perceived intrusion have a significant negative effect on immersion experience.

Table 4: Regression analysis

Module	β	VIF
Gender	0.051	1.083
Specialty and below	0.079	1.736
undergraduate	-0.112	1.574
Algorithm consciousness	0.319**	1.684
Perceptual algorithm apathy	-0.137**	1.742
Perceptual algorithm response	0.125*	1.852
Perceptual intrusion	-0.151*	1.539
R2	0.327	
Adjusted R2	0.311	
F value	21.074**	

Freedom	234
F change	7.972
R2 change	0.093

IV. Conclusion

This study experimentally verified the effectiveness of the virtual reality live sports event broadcasting system based on the environment interaction perception algorithm in enhancing the audience immersion experience. The experimental results show that the average time of operation for viewers using the algorithm when interacting with the live broadcast of a sports event saves 30% compared with the traditional method, while the smoothness of operation and the sense of experience are significantly improved. In addition, regression analysis results show that there is a significant positive correlation between algorithm awareness, perceptual algorithm response and immersion experience, while perceptual algorithm indifference and perceptual intrusion negatively affect the immersion experience. Therefore, the optimization of perceptual algorithms is of great significance in enhancing the immersion of live sports events.

Based on these findings, it can be seen that the combination of virtual reality and environmental interactive perception algorithms provides a new direction for the future development of live sports events. By continuously optimizing the algorithm and improving the accuracy of interaction perception, future virtual reality live sports events will be able to provide viewers with a richer and more personalized viewing experience. This not only promotes the application of virtual reality technology in live sports broadcasting, but also provides valuable experience and data support for the application of virtual reality in other fields.

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