Exploration and Analysis of Design of Museum Interactive Experience Based on Virtual Reality Technology

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Abstract. In order to improve the visiting effect of the museum, based on virtual reality technology, this paper combines sensors and gesture recognition algorithms to improve the feature recognition algorithm and builds a museum interactive experience system based on virtual reality technology on this basis. Moreover, starting from the current trend of intelligent development of navigation systems in museums, this paper combines experience design research results with virtual reality systems' design process. At the same time, through detailed research and analysis of the audience's sensory, behavioral, cognitive, and emotional experience levels, this paper proposes a corresponding museum interactive experience system design strategy. In addition, with the help of VR technology principles, powerful development engines, and intelligent wearable VR devices, users can get close contact with virtual cultural museums. Finally, this paper designs experiments to verify and analyze the system. The research results show that the system constructed in this paper is effective.

1 INTRODUCTION

The focus of the museum's display design has changed from exhibit-centered to audience-centered, and the audience's dominant position in the museum has been continuously strengthened. The audience has changed from being a recipient to a server and then into an active builder of museum culture. By actively paying attention to and exploring the new relationship between the museum and the audience, it can also promote the adjustment and change of the museum's own exhibition form, provide a new direction for the innovative development of the museum, and enable the museum to provide better services to the audience [23].

At present, with the rapid development of science and technology, information technology, computer networks, and multimedia technologies such as sound, light, and electricity have become increasingly mature. This provides a better technical platform for interactive experiential design.

Moreover, this display mode of interactive experiential design that emphasizes participation and appreciation is bound to become a new development trend in the design of modern museum exhibition halls. However, compared with foreign countries, the proposal of interactive experiential design is relatively late in China. At first it was mainly used in some science and technology museums. Its main function is to better popularize relevant scientific knowledge for visitors through the actual participation and personal experience of the visitors, so that the visitors will change from a passive information receiver to an active explorer during the whole visit process [16].

In the design of exhibition halls, the overall display of most museum exhibition halls is basically arranged in the form of traditional exhibition cabinets and exhibition boards. However, the core of its design pays more attention to the presentation of objects, thus ignoring human feelings. The object-oriented display mode is still in the first place in the design of modern museum exhibition halls. Its dull, single, boring and boring characteristics are increasingly being rejected by people.

With the rapid change of communication concepts in display design, more and more exhibition hall designs are paying more attention to the communication and communication between people, things and things, and people and things. At the same time, the focus of the museum's exhibition hall design has changed from the object-oriented approach in the past to the human-oriented approach. This change in design philosophy also strongly promotes the rise and development of interactive experience design. In addition, considering the exhibits themselves, it can be seen that a good display mode not only attracts people's attention and love, but also can fully express the inner meaning of the exhibits, so that the public has a more comprehensive and in-depth understanding of the exhibits [10].

2 RELATED WORK

With the advancement of science and technology, the exhibition methods of museums have been continuously developed. In addition to traditional text descriptions and personnel explanations, there are more and more interactive multimedia applications, and various interactive devices such as touch screens, somatosensory devices, projection technology, and interactive theaters have emerged. Nowadays, the interactive multimedia exhibition as understood by most people refers to an exhibition organized mainly with interactive installations made with interactive technology and combined with other multimedia installations or productions such as animated films [13].Interactive multimedia refers to the digital processing of text, graphics, animation, video or sound and other media through computers. As a means of display, multimedia technology can greatly enhance the participation and interactivity of the exhibition [2]. The interactive multimedia of the museum has two characteristics. The one is a multimedia type, which can effectively stimulate the multiple senses of sight, hearing and touch of visitors. The second is an interactive type, which enables visitors to obtain timely feedback and thinking inspiration through operations [17]. Multimedia can combine multiple media to provide audiences with a wide range of information resources and create an active learning environment. According to some relevant research conclusions on the effectiveness of interactive multimedia applications, an effective guide commentary can make it easier for visitors to remember the contents of the exhibition. In the information reception of various sense organs, 10% of the information is learned by auditory sense, and 18% of information is learned by visual sense. However, people can only remember 20% of the information they hear, but can remember more than 50% of the information they see and hear [11].It can be seen from this that if visual effects and interactive operations are added during the visit of the museum, it can effectively improve the understanding and absorption of exhibits information by visitors [15].

The literature [6] mentioned the design method and specific measures of immersive virtual museum. The literature [21] not only introduced the specific design process of the virtual museum system, but also explained the realization process of interactive functions such as roaming in the

virtual museum. The literature [18] explained the design and realization methods of virtual environment, virtual characters and other three-dimensional environments, and analyzed the feasibility of virtual museum construction. The literature [5] explained the key role of virtual reality technology in the construction of digital museums. The literature [4] introduced in detail the key technologies such as virtual reality and 3D modeling used in the construction of virtual museums. The research of these technologies plays a vital role in the construction of virtual museums. The literature [19] introduced the virtual museum about history and culture in detail, so that we can understand the cultural heritage of the Tang Dynasty in real time through the virtual museum.

3   MULTI-SENSOR ATTITUDE FUSION

1. Find the attitude angle according to acceleration:

When the normalized acceleration sampling value is $\left[a_x a_y a_z\right]^T$, and the acceleration value including the influence of gravity is $\left[a_{gx} a_{gy} a_{gz}\right]^T$, the gravitational acceleration vector a_g at two adjacent moments can be calculated, so as to calculate and obtain the pitch angle β and roll angle α in the attitude angle[3]:

$$a_g = \begin{bmatrix} a_x \\ a_y \\ a_z \end{bmatrix} - \begin{bmatrix} a_{gx} \\ a_{gy} \\ a_{gz} \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} a_x \\ a_y \\ a_z \end{bmatrix} = \frac{a_g}{\|a_g\|} \tag{2}$$

$$\beta = -sin^{-1}\frac{g_x}{\sqrt{g_x^2+g_y^2+g_z^2}} \tag{3}$$

$$\alpha = tan^{-1}\frac{g_y}{g_z} \tag{4}$$

2. The expression of the attitude angle calculated by the gyroscope is [7]:

$$\theta_g(t) = \theta_g(t-T) + \int_0^T \omega dt \tag{5}$$

Through a single gyroscope or acceleration sensor, the attitude angle of the movement can be calculated. Although the accelerometer's response is good and can accurately provide the angle of the statement, its dynamic response is poor, so it is not suitable for tracking dynamic angular motion. The gyroscope will cause system drift and random drift due to factors such as friction and temperature changes during mechanical rotation, which will cause cumulative drift problems after long working hours.

Kalman filtering uses multiple observations and estimates to achieve its purpose. It gradually achieves an accurate measurement by adjusting the observed and estimated values step by step. After that, the measured value and estimated value are compared. If the estimated value is smaller than the measured value, then the estimated value plus the deviation between them is used as the new estimated value. The specific solution process is as follows:

First, the state equation and measurement equation of the system are established. Using the derivative relationship between angle and angular velocity, the real attitude angle φ of the system can be used as a state vector. Moreover, the accelerometer data is used to estimate the constant deviation b of the gyroscope. When this deviation is used as the state vector, the state equation and observation equation of the system can be obtained [14]:

$$\begin{cases} X(k) = AX(K-1) + B\omega_{gyro}(K-1) + B\omega_g(K) \\ V_i(k) = HX(k) + \omega_a(K) \end{cases} \tag{6}$$

Among them,

$$X(k) = \begin{bmatrix} \varphi_k \\ b_k \end{bmatrix} \tag{7}$$

ω_{gyro} is the output angular velocity of the gyroscope, φ is the angle value obtained by calculating the acceleration value through the attitude, ω_a is the measurement noise of the accelerometer, ω_g is the measurement noise of the gyroscope, and b is the drift error of the gyroscope. Moreover, ω_g and ω_a are independent of each other, and Ts is the system sampling period.

In the current state:

$$X(k|k-1) = AX(k-1|k-1) + BU(K) \tag{8}$$

Among them, the state transition matrix is [1]:

$$A = \begin{bmatrix} 1 & -Ts \\ 0 & 1 \end{bmatrix} \tag{9}$$

The control matrix is:

$$B = \begin{bmatrix} Ts \\ 0 \end{bmatrix} \tag{10}$$

$X(k|k-1)$ is the result predicted by K, and $X(k-1|k-1)$ is the optimal result at time $k-1$. The covariance corresponding to $X(k|k-1)$ is [22]:

$$P(k|k-1) = AP(k-1|k-1)A^T + Q \tag{11}$$

Then $P(k-1|k-1)$ is the covariance of $X(k-1|k-1)$, Q is the covariance of the system process, and formula (8) and formula (11) are updates to the system state. Then, the optimal estimation value of the state K is $X(k|k)$.

$$X(k|k) = X(k|k-1) + K(k)\big(Z(k) - HK(k|k-1)\big) \tag{12}$$

Among them, $H = [1 \quad 0]$, and K is Kalman Gain, and the value of k depends entirely on the previous estimates and observations, that is, their variances [9]:

$$K(k) = \frac{P(k-1|k-1)}{HPX(k-1|k-1)H^T + R} \tag{13}$$

The optimal estimated value in the K state is $X(k|k)$, and its covariance is:

$$P(k|k) = (I - Kg(k)H)P(k|k-1) \tag{14}$$

Among them, I is the unit matrix. When the system enters the $k+1$ state, $P(k|k)$ is $P(k-1|k-1)$ in equation (11). Formulas (12), (13), (14) are Kalman filter state update equations. After calculating the current time update equation and the measurement update equation, the posterior estimate obtained from the previous calculation is repeated again and used as the prior estimate for the next calculation, so that the iterative operation is repeated until the optimal result is found.

The low-frequency response of the accelerometer is better, low-pass filtering is used to filter out short-term fast-changing signals and retain long-term slow-changing signals. The common method is to multiply the fast-changing signal with a smaller weight coefficient to weaken the influence of

the abrupt signal on the overall result. The general complementary filtering process is shown in Figure 1 [8]:
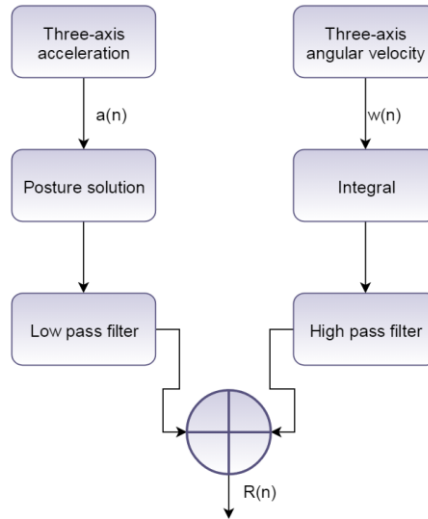

Figure 1: General model of complementary filtering.

$\hat{R}$ is the attitude angle calculated by complementary filtering, R_0 is the observed attitude angle, and μ_H is the error caused by acceleration calculation, which is mainly high-frequency noise. R_c is the attitude angle calculated by the gyroscope, and μ_L is the error calculated by the gyroscope, which is mainly low-frequency noise. Then,

$$\begin{cases} R_0 = R + \mu_H \\ R_c = R + \mu_L \end{cases} \tag{15}$$

To get more accurate results, the above-mentioned high-frequency and low-frequency characteristic errors must be eliminated. Therefore, we set [20]:

$$\begin{cases} G_L(s) = \frac{k}{s+k} \\ G_H(s) = \frac{s}{s+k} \end{cases} \tag{16}$$

$G_L(s)$ is a low-pass filter, $G_H(s)$ is a high-pass filter, and k is a constant. By complementing the two, we can obtain [12]:

$$\begin{aligned} \hat{R}(s) &= G_L(s)R_0(s) + G_H(s)R_c(s) \\ &= R(s) + G_L(s)\mu_H(s) + G_H(s)\mu_L(s) \\ &\approx R(s) \end{aligned} \tag{17}$$

The Kalman filter algorithm has high accuracy, but its entire algorithm is recursive, so it requires multiple iterations and complex and time-consuming matrix inverse operations. Taking a Kalman filter as an example, we use three-axis acceleration data to correct the attitude angle, and the established observation matrix is an 3×4 matrix. At the same time, we use Kalman measurement equations and update equations, namely equations (8), (11), (12), (13), and (14). Therefore, a total of 326 multiplications and 238 addition calculations are required, and the amount of calculation is large, which will limit the performance of the system.

The time domain calculation formula of the complementary filter is:

$$\theta(n) = a_{gy} \cdot (\theta(n-1) + w(n) \cdot T) + a_{ac} \cdot \theta_{ac}(n) \tag{18}$$

Among them, T is the sampling period of the gyroscope, $\theta(n-1)$ is the attitude angle calculated at the previous sampling moment, and $w(n)$ is the output signal of the gyroscope.Moreover, $\theta_{ac}(n)$ is the angle obtained by the attitude calculation based on acceleration, a_{gy} is the weight coefficient of the gyroscope, a_{ac} is the weight coefficient of the accelerometer, and$a_{ac} + a_{gy} = 1$.

The focus of research in adaptive complementary filtering is the weight coefficients that can be automatically updated with time t. As mentioned earlier, the high frequency response of the gyroscope is good, and the low frequency response of the accelerometer is good. That is to say, when the angular velocity is large, the weight coefficient of the gyroscope should be set large. However, when the angular velocity is small, the weight coefficient of acceleration should be set larger. Then, we can adjust the weight coefficient a_{gy} according to the magnitude of the angular velocity:

$$a_{gy} = \begin{cases} 0.96, |\omega| > \omega_1 \\ 0.96 - m, \omega_2 \leq |\omega| \leq \omega_1 \\ 0.96, |\omega| < \omega_2 \end{cases} \tag{19}$$

Among them, a and b are the minimum values of the angular velocity of the gyroscope, m is the adaptive adjustment parameter.

$$m = \frac{0.9(\omega_1 - \omega)}{\omega_2 - \omega_1}$$

$$\tag{20}$$

Based on the above analysis, the attitude solution flow chart of the improved adaptive coefficient compensation in this paper is as follows [24]:
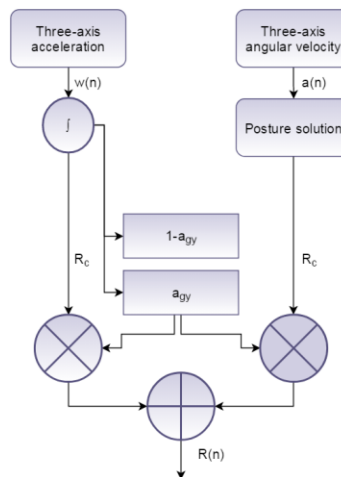

Figure 2: The flow chart of this attitude calculation algorithm.

The quaternion differential equation and iterative update equation are as follows. The difference from the coefficient method is that the acceleration is used to correct the angle error. The flowchart is shown in Figure 3. Among them, β is the error coefficient, which is related to the maximum angular velocity of the gyroscope, and the empirical value is selected as 1.

$$\begin{cases} \dot{q} = \frac{1}{2} q \otimes \omega \\ q(t) = q(t - T) + \dot{q}(t - T) \cdot T \end{cases} \tag{21}$$
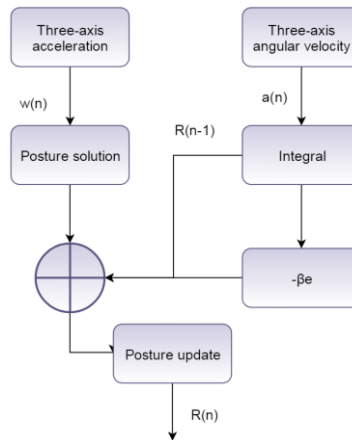

Figure 3: Flow chart of complementary filtering algorithm based on mahony.

In order to compare the performance of these two methods, experiments are performed. We placed the mobile phone on a horizontal desktop and on a vertical wall to do a fixed inclination angle test around the yaw and pitch angles, including the static test, and calculate the attitude angle. The results are shown in Figure 4 and Table 1.
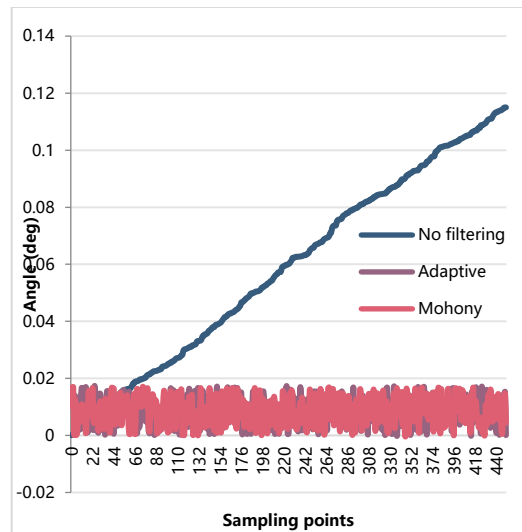

Figure 4: Comparison of static test results.

angle	Adaptive compensation coefficient calculation		Mahony filter solution	
	yaw	pitch	yaw	pitch

0	0.57%	0.64%	0.84%	0.80%
30	2.38%	2.03%	2.69%	2.31%
45	3.01%	2.76%	1.27%	2.42%
60	3.98%	3.55%	3.76%	3.50%
90	3.36%	3.51%	3.28%	3.08%
120	4.22%	4.12%	4.10%	3.95%

Table 1: The average absolute error of the test results of the fixed inclination angle.

The possible reason is that the coefficient threshold that is automatically adjusted according to the angular velocity in the adaptive coefficient method is related to the range of angular velocity. In this research, the frequency of the accelerometer and gyroscope of the mobile phone is not good for testing, so the cut-off frequency is determined according to the empirical value of previous studies, and it cannot dynamically respond to changes in angular velocity. However, Mahony makes three-axis corrections and updates based on the error calculated by the previous attitude and the current acceleration at each moment, which reflects real-time changes more accurately and comprehensively.

In view of the differences between the smart phone sensor-based system in this research and the MEMS sensor system, the value of β should be explored.

When considering the measurement error existing in the dynamic test, only the static test is performed, that is, the mobile phone is placed on a horizontal plane and leaned against a vertical wall. At the same time, different β thresholds are set, and the pitch and yaw angle values calculated by the system are recorded. The standard deviation of the results after statistics is as follows:
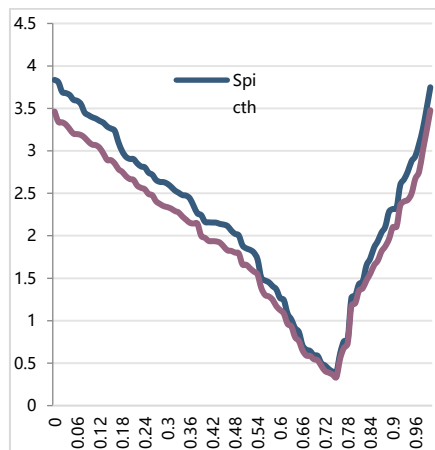

Figure 5: Error coefficient threshold test.

It can be seen from Figure 5 that when the error coefficient is not set, that is, when $\beta = 0$, the standard deviation is very large, which means that the system is extremely unstable. When $\beta = 0.75$,

the standard deviation is the smallest, and the system is very stable at this time, so $\beta = 0.75$ is selected in this study.

4 MUSEUM INTERACTIVE EXPERIENCE SYSTEM DESIGN BASED ON VR VIRTUAL REALITY TECHNOLOGY

This article combines the virtual reality technology to draw the interactive design types of the museum's intelligent navigation into a table, as shown in Figure 6.
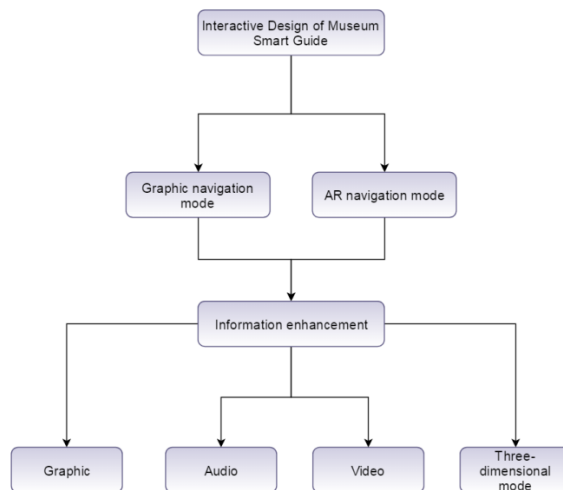

Figure 6: Design elements of museum interactive experience based on virtual reality technology.

As an important node in the process of museum construction, virtual museums have their distinctive features in different aspects (see Figure 7).
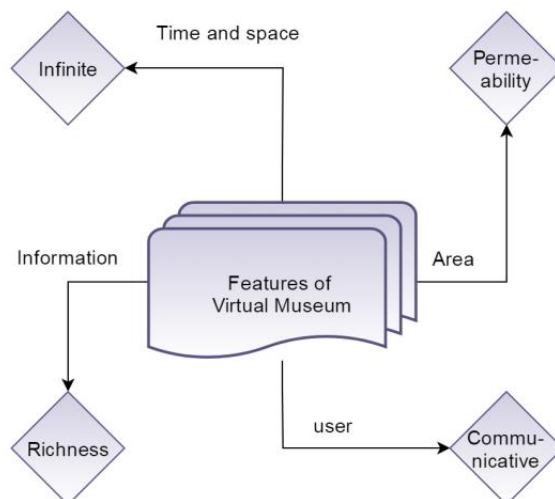

Figure 7: The characteristic structure of a vr-based museum interactive system.

The process of museum system realization can be summarized into three modules. The first is to create the virtual environment of the virtual museum. First of all, it is necessary to import the built models of related intangible cultural heritage such as buildings and clothing into the Unity3d development engine to regulate the location, size and placement of each model. The second module is mainly for stereoscopic display and real-time rendering of cultural virtual museums. The two-dimensional wall, ceiling, booth, floor texture information and cultural relics of the exhibits are converted into a three-dimensional space through the image rendering processing function of the Unity3d engine. At the same time, relevant text introduction, audio, video and other UI information are added to the cultural virtual museum. Interaction design between users and immersive cultural virtual museum. The interactive functions mainly include: the user controls the smart handle to move freely to achieve the purpose of roaming the cultural virtual museum; the user's space switching; the interaction of the disassembly, rotation, and movement of the exhibits. The system function structure is shown in Figure 8.
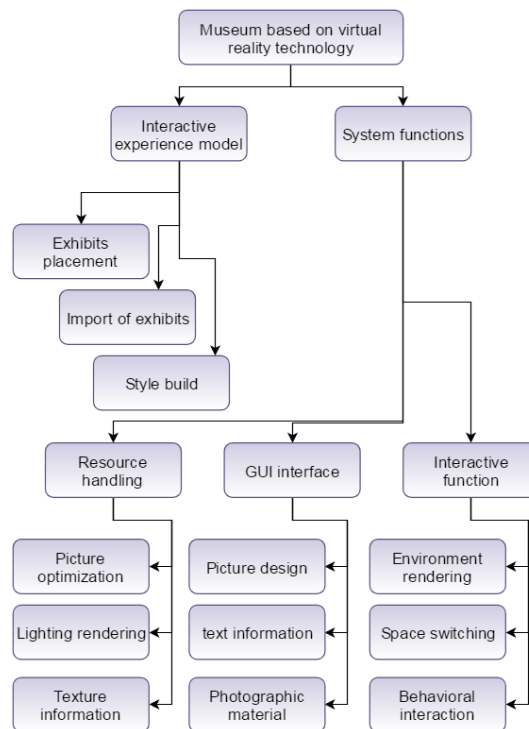

Figure 8: VR-based museum interactive system structure.

The virtual museum displays the intangible cultural heritage, allowing more people to experience the unique national characteristics and cultural connotation. The specific implementation steps are as follows. 1. Content planning: we display a series of related intangible cultural heritage such as buildings, costumes and customs with important meanings. 2. Obtaining reference materials: we go to the ancient town to collect materials to understand the local customs, customs and cultural heritage. 3. Two-dimensional image production and three-dimensional modeling: we use image production software and modeling tools to produce relevant videos and models4. Material import: we import the material model we have made into the Unity3d development engine. 5. Scene construction: we present the material model in three-dimensional.6. Scene display and rendering: we adjust the size, placement angle and display method of each model of cultural relics, bake the

lights in the venue, and add relevant text introduction, audio, video and other UI information. 7. write interactive function code: we use C++ language to achieve each interactive function.8. Program debugging: we test the system and fix bugs. 9. User feedback: we summarize the shortcomings of the system and optimize all aspects. 10. Release program: we release the .exe program of the cultural virtual museum system based on windows platform. The specific flow chart is shown in Figure 9:
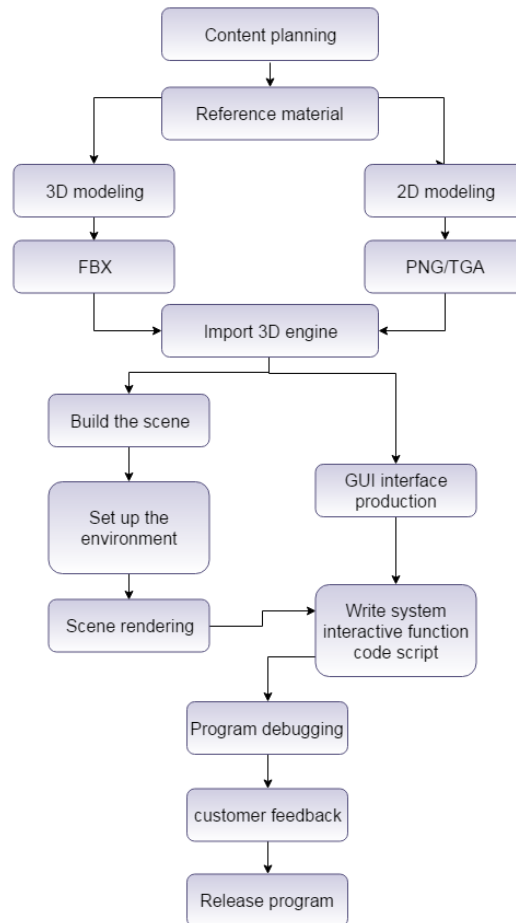
Figure 9: Flowchart of VR-based museum interactive experience system.

5   SYSTEM TEST

After constructing a museum interactive experience system based on VR technology, performance testing of the system is required. In the performance test, this paper mainly analyzes the model design reduction degree of museum items and user experience. First, this paper analyzes the reduction degree of the museum virtual reality model, and obtains the analysis results through professional evaluation, as shown in Table 2 and Figure 10.

NO.	Reduction degree	NO.	Reduction degree	NO.	Reduction degree	NO.	Reduction degree
1	0.999	26	0.988	51	0.976	76	0.975
2	0.981	27	0.979	52	0.976	77	0.971
3	0.990	28	0.979	53	0.999	78	0.994
4	0.991	29	0.978	54	0.995	79	0.986
5	0.975	30	1.000	55	0.984	80	0.977
6	0.970	31	0.996	56	0.978	81	0.973
7	0.972	32	0.991	57	0.983	82	0.989
8	0.987	33	0.976	58	0.989	83	0.981
9	0.996	34	0.998	59	0.989	84	0.997
10	0.995	35	0.988	60	0.984	85	0.999
11	0.985	36	0.999	61	0.994	86	0.978
12	0.977	37	0.980	62	0.977	87	0.979
13	0.980	38	0.991	63	0.972	88	0.998
14	0.974	39	0.981	64	0.978	89	0.995
15	0.979	40	0.997	65	1.000	90	0.994
16	0.998	41	0.994	66	0.997	91	0.991
17	0.979	42	0.999	67	0.999	92	0.977
18	0.996	43	0.978	68	0.979	93	0.975
19	0.994	44	0.981	69	0.979	94	0.983
20	0.997	45	0.992	70	0.979	95	0.994
21	0.980	46	0.988	71	0.977	96	0.990
22	0.971	47	0.988	72	0.971	97	0.991
23	0.987	48	0.988	73	0.988	98	0.997
24	0.989	49	0.975	74	0.994	99	0.980
25	0.994	50	0.999	75	0.994	100	0.997

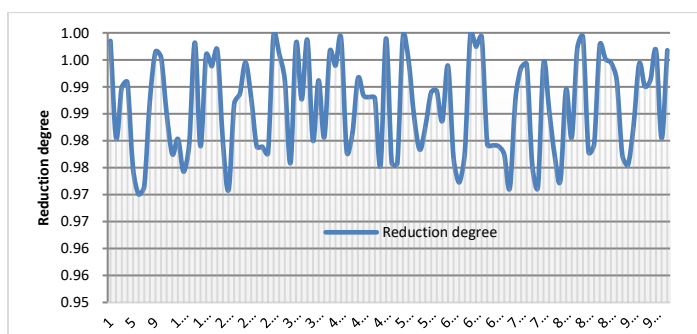**Table 2:** Statistical Table of the Reduction Degree of the Museum.

Figure 10: Statistical diagram of reduction degree of museum.

From the above analysis, it can be seen that the virtual reality system constructed in this paper can highly restore museum exhibits. Next, this paper uses a museum interactive experience system based on VR technology to score user experience. The results are shown in Table 3 and Figure 11.

NO.	Scores	NO.	Scores	NO.	Scores	NO.	Scores
1	86.16	26	90.01	51	92.95	76	91.02
2	89.41	27	86.11	52	98.77	77	98.53
3	97.35	28	92.28	53	93.98	78	93.45
4	89.80	29	95.18	54	90.55	79	95.46
5	93.13	30	86.61	55	86.05	80	92.71
6	96.28	31	87.21	56	95.06	81	91.97
7	94.61	32	92.99	57	99.14	82	99.71
8	98.89	33	86.42	58	92.36	83	87.79
9	85.75	34	93.23	59	92.81	84	91.98
10	87.30	35	87.50	60	90.03	85	89.28
11	86.71	36	89.61	61	94.69	86	85.95
12	95.57	37	96.23	62	99.24	87	86.16
13	97.18	38	91.65	63	99.02	88	91.07
14	99.49	39	88.80	64	93.50	89	91.07
15	89.71	40	89.72	65	93.38	90	89.50
16	92.15	41	98.53	66	94.81	91	94.31
17	96.70	42	97.14	67	98.65	92	90.92
18	96.66	43	86.35	68	99.73	93	92.78
19	87.17	44	94.04	69	96.89	94	94.67
20	91.35	45	93.67	70	86.52	95	89.54
21	87.14	46	90.41	71	96.57	96	89.75
22	97.75	47	98.98	72	97.16	97	85.57
23	96.52	48	90.96	73	94.37	98	90.30
24	95.78	49	94.26	74	93.96	99	85.63
25	96.49	50	87.55	75	96.70	100	98.26

Table 3: Statistical table of user experience scores of museum interactive experience system based on VR technology.
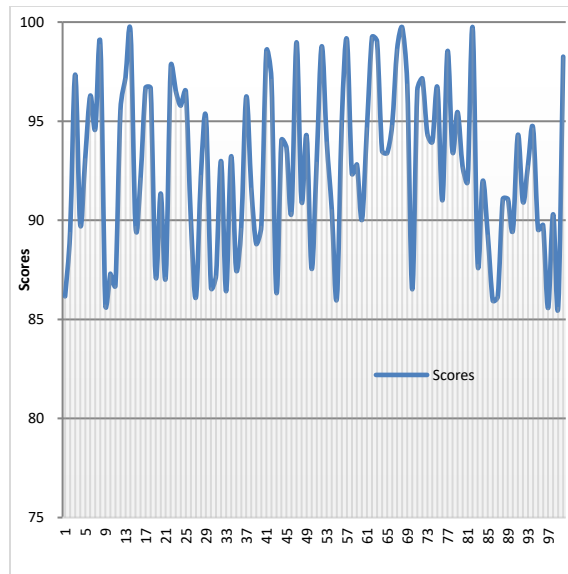
Figure 11: Statistical diagram of user experience scores of museum interactive experience system based on VR technology.

From the above analysis results, the user experience score of the museum interactive experience system based on VR technology constructed in this paper is relatively high, which can meet the actual needs of users in the museum.

6 CONCLUSION

The virtual museum is to combine virtual reality technology with the museum to create an immersive museum environment, and realize the related virtual interactive design that suits the user experience, so as to break free from the shackles of physical factors and change the one-way explanation display method. Moreover, the virtual museum has gradually expanded from the initial two-dimensional and three-dimensional display form to four-dimensional, and even multi-dimensional display forms, three-dimensional display methods and all-round information dissemination methods.

Taking the virtual museum as an example, this paper mainly combines virtual reality technology and wearable smart devices to carry out the research on the interactive mode of immersive virtual museum. This article briefly describes the basic principles of virtual reality, combined with the three characteristics of virtual reality technology, and analyzes the advantages and disadvantages of virtual reality technology as a medium. In addition, from the perspective of users, this paper introduces the principles and purposes of interaction design, and points out the importance of interaction design to the construction of virtual museums. Finally, this paper designs experiments to analyze the performance of the system constructed in this paper. The experimental research results show that the system model constructed in this paper meets the expected demand of constructing the system.

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