ingegneria sismica
International Journal of Earthquake Engineering
Anno XLIII - Num. 3 - 2026

Research on the Path of Immersive Virtual Reality Technology on the Construction of Cultural Identity in the Context of Digital Art and Design

Enze Li[1] *and Xiaowan Xie*[2,*]

[1] Animation Department ,Huanghuai University, Zhumadian 463000, Henan, China
[2] Art and Design Department ,Huanghuai University, Zhumadian 463000, Henan, China

SUMMARY: *The integration of digital art design and science and technology has become the core industry of the knowledge economy in the 21st century. Immersive virtual reality technology is widely used in cultural preservation and inheritance, providing a new way for cultural digital display. This study explores the path of immersive virtual reality technology on the construction of cultural identity in the context of digital art design. By constructing a virtual scene of digital art and culture based on the virtual engine of the cloud platform and the HTC Vive device, we propose the difference loopback detection algorithm based on the historical model and the binocular parallax virtual stereoscopic display method, and study how the virtual reality technology enhances the user's sense of cultural identity. The experiment conducted a 4×4 mixed design test on 80 college students and found that under the influence of aesthetic rate and contact form, the subjects' attention level, emotional potency and self-esteem level reached significant differences ($P<0.05$). The user satisfaction survey showed that the overall satisfaction with the digital art and culture virtual scene amounted to 4.45 points (out of 5), with the highest score (4.46 points) for the cultural learning dimension. The results of the study show that immersive virtual reality technology can effectively enhance the user's immersive experience of culture and art and improve the sense of cultural identity; the loopback detection algorithm based on the history model and the performance test of SLAM on the cloud platform gained a performance improvement of 49.57%-74.33% compared to the local scheme, which provides technical support for the construction of the digital art and culture virtual scene with strong consistency. This study provides technical and theoretical references for the design of digital art and culture virtual scenes, and promotes the digital protection and inheritance of cultural heritage.*

KEYWORDS: *Immersive virtual reality; digital art design; cultural identity; loopback detection algorithm; binocular parallax; virtual scene*

1 Introduction

With the application and development of computer technology, Internet technology and various designs, creativity and technology have been closely integrated together, and derived from the “digital art and design”, thus breaking the traditional painting and design based on hand-drawing, and has gradually become the core industry of the 21st century knowledge economy [1-4]. At the same time, the application of immersive virtual reality technology in the protection and inheritance of culture has been widely concerned, and its path to the construction of cultural

*20192068@huanghuai.edu.cn
https://doi.org/10.65102/is20261153
Published: 10 June, 2026

identity is of great significance for cultural protection and inheritance [5-7].

Culture is the precipitation and summary of human experience, recording the development of human civilization, and with the development of cultural diversity in today's society, and the development of fusion between various disciplines, digital cultural display methods are gradually being valued by people [8-10]. The universal application of virtual reality technology has also made the science fiction plot, which used to appear only in novels and movies, gradually become a reality [11, 12]. As a technical platform for the future digital display of culture, the effective integration of virtual reality technology and culture has become the main way of digital art design nowadays [13, 14]. In the field of culture, the use of virtual reality can effectively digitalize some of the precious cultural heritage and materials that are easily affected by human factors and environmental factors, which are difficult to be preserved, stored, protected and displayed in an immersive way, which not only effectively improves people's knowledge of culture, but is also an important form of improving cultural identity [15-18].

With the rapid development of computer technology and Internet technology, the deep fusion of creativity and science and technology has given rise to “digital art design”, which breaks the pattern of traditional design and gradually becomes the core industry of knowledge economy in the 21st century. At the same time, the application of immersive virtual reality technology in cultural preservation and inheritance has attracted widespread attention, and the research on the path of cultural identity construction has far-reaching significance for cultural preservation and inheritance. As a record carrier of human civilization development, the way of displaying culture is becoming more and more digital with the diversified development of the society. The popularization and application of virtual reality technology has gradually turned the plots that used to exist only in science fiction works into reality, and has become an important technical platform for the digital display of culture. The use of virtual reality technology can effectively preserve and display the precious cultural heritage that is susceptible to human factors and environmental factors, which not only improves people's knowledge of culture, but also enhances the important form of cultural identity. However, compared with the rapid changes in virtual reality technology, the development of digital art and cultural innovation design theory is lagging behind, resulting in insufficient cultural digitalization and translation, which makes it difficult to meet the increasing demand for cultural experience of contemporary users. Therefore, exploring the effective path of immersive virtual reality technology on the construction of cultural identity has important theoretical and practical value.

This study starts from the relationship between virtual reality technology and the construction of cultural identity, systematically analyzes the characteristics of VR technology and its application in the field of digital art and culture, constructs a virtual scene of digital art and culture based on the virtual engine of the cloud platform and the HTC Vive device, and proposes a difference loop detection algorithm based on the historical model and a binocular parallax virtual stereoscopic display method to form an immersive virtual scene of digital art and culture. Scene. Through experimental tests and user satisfaction surveys on 80 college students, the effectiveness of the proposed technical solutions and design methods is verified, and the effects of aesthetic rate and contact form on users' psychological indicators are explored to assess the effect of the immersive virtual scene on the construction of cultural identity. The research not only provides technical and theoretical support for the design of digital art and cultural virtual scenes, but also provides new ideas for the digital protection and inheritance of cultural heritage, which is of great significance in promoting the integration and development of digital art design and virtual reality technology, enhancing the user's sense of cultural identity, and promoting the innovative inheritance of culture.

2 Virtual Reality Technology and Cultural Identity Construction

Compared to the rapid development of immersive virtual reality technology, the theory of digital art and cultural innovation and design is particularly lagging behind, which leads to insufficient digitalized translation of culture and cannot keep up with the increasing demand for cultural experience of contemporary users. At the same time, the continuous iteration of virtual reality technology makes the display of artworks in public cultural spaces extremely diverse. In short, virtual reality technology leads to new creative content, art forms, material choices, and design thinking, and allows artworks to present a different and unique appearance, which not only enhances the user's participation and sense of cultural narrative, but also makes it easier to stimulate the user's emotional resonance.

2.1 Virtual reality technology and application characteristics

2.1.1 Virtual reality technology

Virtual Reality (VR) technology is an important direction of simulation technology, is a collection of simulation technology and computer graphics human-computer interface technology multimedia technology sensing technology network technology and many other technologies, is a challenging cross-cutting technology frontier disciplines and research areas. It combines a variety of technologies, i.e., computer technology, multimedia technology, image processing technology, simulation technology, etc., thus forming a new technology involving the fields of simulation and computers.VR technology mainly consists of simulated environments, perception, natural skills, and sensing devices, etc., and the simulated environments are the computer-generated, real-time dynamic three-dimensional stereo lifelike images [19].

Perception means that the ideal VR should have all the perceptions that people have, in addition to the visual perception generated by computer graphics technology, there are also perceptions such as hearing, touch, force, motion, and even smell and taste, which is also known as multisensory. Natural skills refer to human head rotation, eye, gesture, or other human behavioral actions, which are processed by a computer that processes data appropriate to the participant's actions and responds in real time to the user's inputs and feeds back to each of the user's five senses. Sensing equipment refers to three-dimensional interaction equipment, virtual reality technology is mainly composed of three aspects: virtual object actualization, physical object defuzzification, and computer processing high-performance technology. Among them, physical object virtualization refers to mapping out a multidimensional informational space through the real world.

2.1.2 Characteristics of VR technology applications

VR technology has been applied in many fields, although the ultimate form of virtual reality has not yet been realized, and both hardware and software technologies are in the process of continuous development. The current application of technology is also maximizing the immersive, interactive, multi-sensory, and conceptual technical characteristics of virtual reality technology, which is integrated with the current social development, market status, and user needs [20]. Thus, the current application of virtual reality technology has the following characteristics:

(1) Scenarioization. Constructing real-time trackable three-dimensional virtual scene is one of the important links in virtual reality design and production. Corresponding to the technical

application, extracting the key content of the corresponding field, and carrying out the figurative scene design of it becomes an important link. According to the conditions of the application place and hardware equipment, it can be a full virtual scene or a hybrid scene combining the physical scene and the virtual scene, so as to provide the necessary spatial preparation for realizing the immersive experience of virtual reality technology.

(2) Experientialization. Virtual reality technology has a strong advantage in sensory simulation, and the interaction mode used in specific applications is closer to the natural behavior in the real environment. With the scenario setting of different presentation methods mentioned above, users can obtain richer perceptual experience through sensory feedback.

(3) Conceptualization. Virtual reality technology has been in the stage of high-speed and stable development, and there is still a certain difference between this and the idealized state of virtual reality application. The digital simulation of the five senses is mainly focused on the visual and auditory senses, and the virtual reality products are superimposed and integrated with the media products that have already been maturely used, and are presented in the form of conceptual products. This enables the technology to be verified and adjusted in the direction of development in one active exploration, and also conveys the latest technology and its concepts to the users and gets their feedback to think about the next technology application strategy.

2.2 VR technology empowers digital art cultural identity

2.2.1 Digital Art Cultural Identity

With the arrival of the digital era, cultural space extends the demand for more dimensions under the limited space-time of the physical environment, and cultural monumental spaces and cultural landmarks present a variety of digital creation. Therefore, extending and expanding the spirit of place of cultural space through immersive virtual reality technology has become a common research concern among scholars. Designers have also practiced and explored the virtual reality placemaking examples of cultural spaces through continuous attempts. With the physical space superimposed on the digital representation of the method of intervention in the virtual reality of cultural space placemaking process.

The digital cultural virtual reality space is represented by eye-catching, culturally rich elements and symbols, such as the artifacts of the National Palace Museum and the ancient beasts, which are shaped into the symbolic elements of the exclusive cultural space through concise lines and forms. Abstracting and extracting the connotation of culture and condensing it into a deep cultural visual perception, the graphic language of symbols can convey the spiritual perception of ideology faster and more effectively. The extraction of the image of the ancient beasts on the ridge of the Forbidden City building, showing the ancient worship of the beasts and the spirit of reverence for nature, the symbols of the form of expression for the digital cultural space places to create the finishing touch, so that the public in the virtual reality scenario to better witness the cultural changes, and to promote the construction of the public's sense of cultural identity.

2.2.2 VR technology empowers cultural identity

VR technology is a computer-generated three-dimensional environment that allows users to interact in an immersive way through special equipment (e.g., helmet displays, gloves, etc.). Digital art, on the other hand, is a form of expressing art through creativity and design using digital technology as a medium. The presence, interactivity, creativity, and multi-perception of virtual reality technology provides a new creative platform for digital art, enabling artists to break the limitations of traditional art and create more innovative and expressive works [21]. With the development and innovation of virtual reality technology, digital art will also present

a richer and more diversified appearance. The application of virtual reality technology not only enriches the expression of digital art, but also brings a more diversified sensory experience for human society, which reflects significant innovation and improvement in many aspects.

(1) Creative tools. Virtual reality technology provides digital art with brand-new creation tools, such as virtual sculpture tools, virtual painting tools, etc., which enable artists to create freely in three-dimensional space, breaking the limitations of traditional art forms in space and time.

(2) Interactivity. Virtual reality technology brings stronger interactivity to digital art. The audience can interact with the art works in real time through special equipment, and this interaction not only enhances the audience's sense of participation, but also makes the art works have richer expressiveness and infectious force, and better enhances the public's sense of cultural identity.

(3) Interdisciplinary integration. The combination of virtual reality technology and digital art promotes the integration and communication between different disciplines, and helps to promote the integration and application of advanced technology in various disciplines.

3 Immersive virtual scenes of digital art and culture

With the rapid development of virtual reality technology, applying VR to digital culture and art creation has become a highly potential research direction. Compared with traditional artistic expression, VR technology can provide an immersive immersion experience for the audience, breaking the boundaries between the audience and the work. However, how to make full use of the advantages of VR technology to design an immersive digital art virtual scene that can attract the audience and provide a good experience still faces many challenges.

3.1 VR devices and immersive design of cultural scenes

3.1.1 Immersive virtual set hardware and software

In order to better establish an immersive virtual scene for digital art and culture, this paper utilizes a variety of hardware and software devices for immersive virtual scene construction. The hardware system includes PC, HTC Vive virtual (VR) helmet equipment, and the software system includes UE4, 3ds Max, Photoshop and so on.

(1) Software part

The software used in this paper is the cloud-based platform Unreal Engine 4 (UE4), which is the latest version of the world's top game EPIC virtual engine. The reason why this engine can create a more realistic picture can not be separated from its lighting and physical rendering system are at the leading level, in addition to the engine also supports DirectX11, physics engine PhysX, NVIDIA 3D technology. At present, the use of UE4 has been widely popularized, thanks to UE4 has been free open source code. In addition, UE4 has a powerful material editor, making it fast rendering, seamless with a variety of 3D graphics production software, realistic physical properties, and other advantages, suitable for the development of immersive virtual scenes for digital art and culture described in this paper. In particular, its new blueprint feature provides operators with a more intuitive editing interface. As a special type of resource, it can use nodes to put some codes in a way that makes the creation of each function time more comfortable. This kind of visualization engine has some advantages in design effect and production efficiency, and has a high degree of popularization in the field of digital art and culture.

(2) Hardware part

Of all the virtual reality products currently on the market, Oculus Rift, HTC Vive, PlayStation VR are the main ones. The current high-end VR equipment can basically achieve a

display resolution of 1200*1080, field of view of 110°, refresh frequency of 90HZ, the virtual experience can achieve better results.

The hardware used in this article HTC Vive is a virtual reality helmet product jointly developed by HTC (cell phone manufacturer) and Valve (software developer) for enterprise users of the Vive virtual reality helmet kit - Vive BE (Business Edition), which includes specialized customer support services.

3.1.2 Digital cultural scene design process

Using cutting-edge information technology equipment (sensors, drones, etc.), we are able to efficiently collect data in the field of culture and art, and then carry out in-depth analyses and careful organization. This process is not only limited to the collection of data, but also to the transformation of large amounts of data into intuitive charts and other forms of visualization that facilitate understanding and insight. Viewers or users are able to personally participate in the interactive display of this data through advanced devices such as touch controllers, enjoying an immersive data exploration experience.

Figure 1 shows the virtual reality scene design process for digital art and culture. By synthesizing data from cultural and artistic works, nature and real-time, the interactive experience of digital art products is constructed, and users are able to feel the value of culture and art in all kinds of scenarios or activities in VR or on the screen, and the audience's sense of cultural identity is fully constructed. Its design process is more complex, how to design a real and accurate and rich in culture and art atmosphere and interactive interesting display effect, the designer can according to the data resources and the characteristics of the target audience, targeted custom design digital art content.

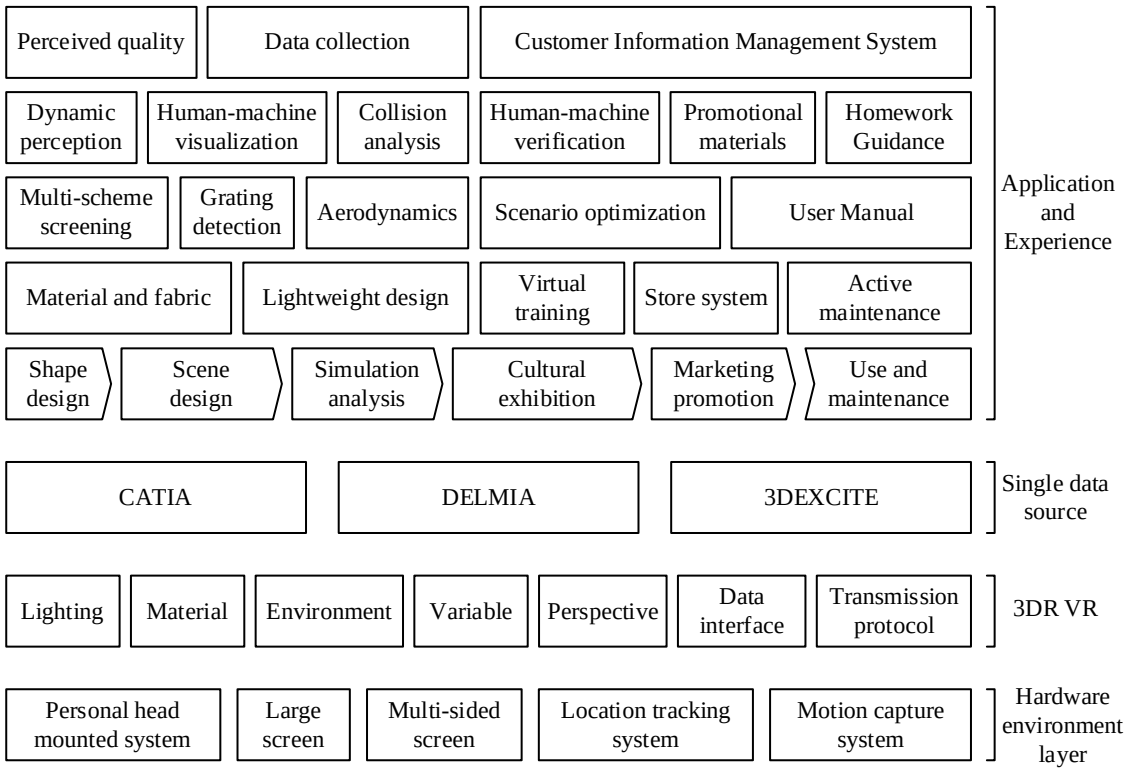

Figure 1: The design process of virtual reality scenes

Virtual Reality design is a subtle blend of colorful graphic elements, intuitive and easy-to-use interface design, and vivid and flexible dynamic effects. Especially in the creation of

interactive experiences in the field of culture and art, its visual design is not only committed to the pursuit of pleasant aesthetic enjoyment and highly realistic reproduction of real-life scenarios, but also puts the rigor and scientificity of the design in a crucial position. We carefully conceptualize and design interactive displays and interactive elements that fit our goals. From the germination of the idea to the sketching stage, based on these sketches, we further developed the interactive visual design. To enhance the sense of motion and interactivity, the user interface design incorporates digital animation techniques, such as button clicking effects and interface switching animations, to show the interaction details in a dynamic form.

3.2 Virtual Reality Stereoscopic Display of Digital Cultural Scenes

3.2.1 Loopback Detection and Relocalization Algorithm

In the virtual reality scenario of digital culture and art scenes, in this paper, when the system starts to build a local scene, it first adopts a more lenient keyframe selection strategy, and then removes redundant keyframes after a strict screening strategy. This allows the system to build local maps robustly even in the presence of fast camera movements, rotations, and difficult external conditions, without being very computationally intensive in the back-end optimization.

In simultaneous localization and map building (SLAM) if large rotations or translations occur, tracking may be lost. And even if tracking is done special processing of these images is required, otherwise the robustness and accuracy of the system will be reduced [22]. In order to enable the algorithm to accurately track image frames with large rotations, in this paper, we use the Lie algebra Euclidean distance between two neighboring frames to represent the drastic degree of rotation. Namely:

$$r_{12} = \sqrt[2]{(\xi_1 - \xi_2)^2} \tag{1}$$

In this paper, we stipulate that the meaning of calculating the rotation degree between any two image frame rotation vectors is the sum of the rotation degrees of the neighboring image frames from i to j, i.e:

$$r_{ij} = \sum_{k=i}^{j-1} r_{k(k+1)} \tag{2}$$

This can effectively avoid the situation where any two frames have similar rotation matrices but contain a large number of rotations in between. This degree of rotation indicates the intensity of rotation during camera motion, and based on this degree of rotation, an improved keyframe selection strategy is proposed in this paper.

Based on the rotation degree, which describes the intensity of rotation, a keyframe dataset containing better results is obtained by the improved keyframe selection strategy. This dataset contains not only keyframes with appropriately large inter-frame distances, but also keyframes with small distances but which produce large rotations and thus bring additional key information. This ensures a good history dataset during loopback detection.

In order to avoid wasting time slowing down the system operation speed in loopback detection, especially when no or few loopbacks occur during the actual motion, this paper proposes a differential loopback detection algorithm based on the history model. The core idea is to utilize the key frames of the whole culture and art scene where the loopback occurs, combine the results of historical loopback detection to predict the location of the key frames to be detected, and then carry out the loopback detection by the differential detection strategy. The

serial number of the key frame where the k th loopback occurs is noted as i_k, and the end is j_k. Then the low probability interval between the occurrence of the 1st loopback and the occurrence of the 2nd loopback again is memorized as:

$$\left(j_1, j_1 + \frac{i_1}{2} \right) \tag{3}$$

Denote the low probability interval that a loopback occurs again after the 2nd loopback occurs and before the 3rd loopback occurs:

$$\left(j_2, j_2 + \frac{\mu_1 + \frac{i_2 - j_1}{2}}{2} \right) \tag{4}$$

By analogy, the low probability interval for a loop to occur again after the k th loop occurs is obtained as:

$$\left(j_k, j_k + \frac{1}{k} \left(\sum_{m=1}^{k-1} \left(\mu_m + \frac{i_k - j_{k-1}}{2} \right) \right) \right) \tag{5}$$

When detecting loopback, first determine whether the current key frame is in the low probability interval, if yes, then adopt the jump detection loopback strategy, if not, then use frame-by-frame detection. The algorithm flow is shown in Fig. 2.

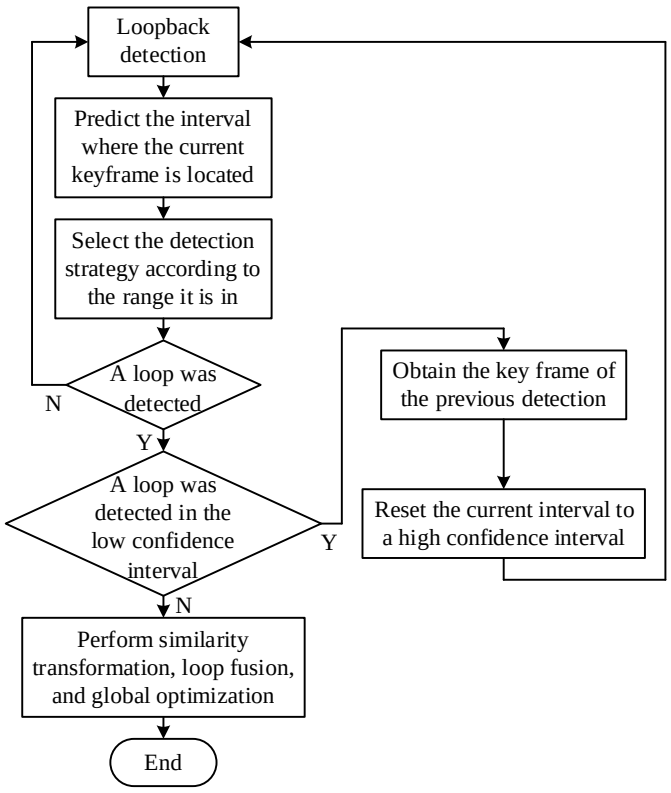

Figure 2: The differential loopback detection process based on historical models

3.2.2 Binocular parallax virtual stereoscopic display

In order to realize the environment three-dimensional model in the virtual reality all-in-one machine to display the reconstruction of the completed digital culture and art scene, first of all, we must establish the imaging model based on the human eye.

The human eye observes the object and produces the three-dimensional sense from the brain is due to the parallax, and the core technology of the plane stereo display is to utilize the parallax, so that the observer can see the three-dimensional object in the plane, similar to produce the "illusion". If different images can be displayed on a two-dimensional display plane, and this set of images is generated according to the structure of the human eye, based on the principle of parallax, then when the human eye observes the two-dimensional display can feel the three-dimensional three-dimensional depth of feeling, so that the observer produces a strong sense of scene and a sense of immersion [23].

The depth and parallax problems of stereoscopic vision are calculated and analyzed using the basic model of small-hole imaging, and the structure of its imaging principle is shown in Figure 3.

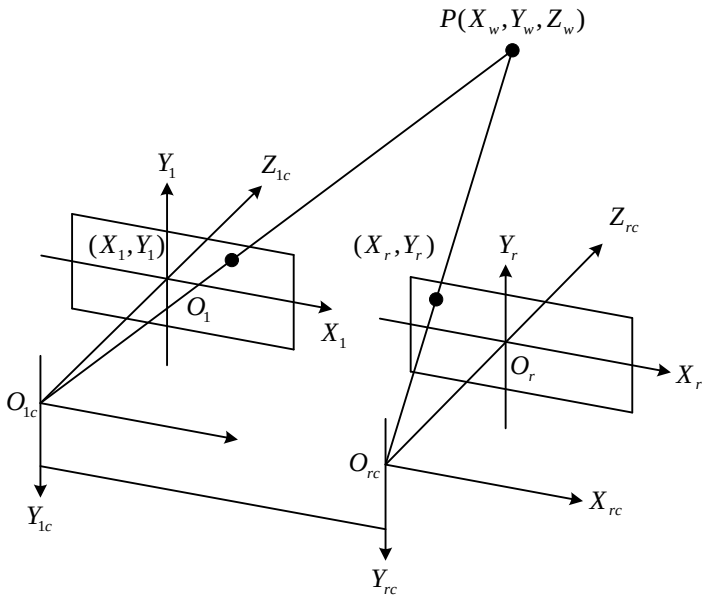

Figure 3: Imaging principal structure

First assume that O_{1c} and O_{rc} are the reception points of the human eye, and that B is the distance between the eyes of a person, i.e., the pupillary distance. VR all-in-one screen that is, two horizontal surfaces in front of the human eye, in the stereoscopic visual spatial scene, assuming that the coordinates of an object point P is (X_w, Y_w, Z_w), the projection of the point on the two imaging planes are (x_1, y_1) and (x_r, y_r). If the human eye observes point P, it is equivalent to looking at two projection points (x_1, y_1) and (x_r, y_r) on the screen, the parallel placement of the human eye model makes the image have no vertical parallax but only horizontal parallax, which means $y_1 = y_r$. This is obtained from the triangular geometry relation:

$$x_l = f \frac{X_w}{Z_w} \tag{6}$$

$$x_r = f\frac{X_w - B}{Z_w} \tag{7}$$

$$y = y_l = y_r = f\frac{Y_w}{Z_w} \tag{8}$$

Parallax is:

$$D = x_l - x_r \tag{9}$$

From this it can be calculated that the 3D coordinates of the point P on the object in the camera coordinate system can be expressed as:

$$X_w = B\frac{x_l}{D} \tag{10}$$

$$Y_w = B\frac{y}{D} \tag{11}$$

$$Z_w = B\frac{f}{D} \tag{12}$$

This system simulates the stereoscopic imaging system of both human eyes. According to this model, the depth information of the reconstructed three-dimensional model of the present digital culture and art virtual reality environment can be restored to the two-dimensional plane, and the three-dimensional model of the environment of the digital culture and art virtual reality scene can be realized as a three-dimensional presentation of the environment by means of the sensory perception of the human eye system on the inspection image.

4 Digital art and culture immersive virtual scene experience

VR technology creates an immersive sense of immersion through the construction of realistic virtual scenes and multi-sensory interaction, opening up a whole new dimension of human-computer interaction. With the popularization of VR equipment and the improvement of the content ecology, VR is penetrating into the field of digital art in an all-round way, triggering a change in the whole industry chain related to the production, dissemination and consumption of content.VR has reshaped the expressiveness and narrative logic of the digital media, blurring the boundaries between the real and the virtual, and the online and the offline, and has given rise to a series of new concepts and forms, such as the immersive experience, the integration of the real and the imaginary and the interactive narrative.The in-depth integration of VR technology with digital art and culture has provided an opportunity for a new dimension of human-computer interaction. The deep integration of VR technology with digital art and culture provides support for the establishment of immersive digital art and culture virtual reality scenes, and better constructs the audience's sense of cultural identity.

4.1 Virtual Reality Stereoscopic Reality Stereoscopic Display Validation

4.1.1 Virtual Scene Loopback Detection Verification

In the process of reconstructing the virtual reality scene of digital art and culture, this paper proposes a loopback detection algorithm based on the history model to assist in realizing the loopback detection and relocation of the virtual reality scene. The loopback detection algorithm based on historical model proposed in this paper includes two parts, firstly, the key frame selection algorithm based on the rotation degree is used to limit the number of frames of the virtual reality scene of digital art and culture, and when the rotation degree is greater than a certain value, regardless of whether it is past 30 frames or not, it is judged as a key frame, which can be adapted to the rapid rotation. Then use the dataset of key frames, combined with the results of historical loopback detection to predict where the key frames to be detected are located, and then carry out loopback detection through the differential detection strategy.

The P-R curve is chosen as the evaluation index, and multiple types of cultural and artistic images are collected from the Internet to establish the relevant dataset, and the performance comparison results of the loopback detection algorithm are obtained as shown in Fig. 4. In the figure, HF-FBoW represents the method of selecting loopback candidate frames by similarity scoring, and ORB-BoW represents the lexicon training and testing of ORB features based on bag-of-words model BoW. All the datasets in this paper use robots mounted with left and right cameras for data acquisition, and in this subsection, all the above three methods are tested in the data acquired by the left and right cameras, and are denoted by Left and Right, respectively.

Accuracy represents the probability of predicting the correct loopback and recall represents the probability that the predicted loopback is correct. In an ideal environment the accuracy and recall can reach 1 at the same time, but in practice, it is difficult for both to reach 1. As can be seen from the figure, the test results of the history model-based loopback detection scheme proposed in this paper still satisfy a high recall when the accuracy is close to 1. The experimental results show that the loopback detection algorithm proposed in this paper is not only able to predict all loopbacks, but also the vast majority of the predicted loopbacks are correct, which is of great significance for the establishment of consistent digital art and culture virtual reality scenarios.

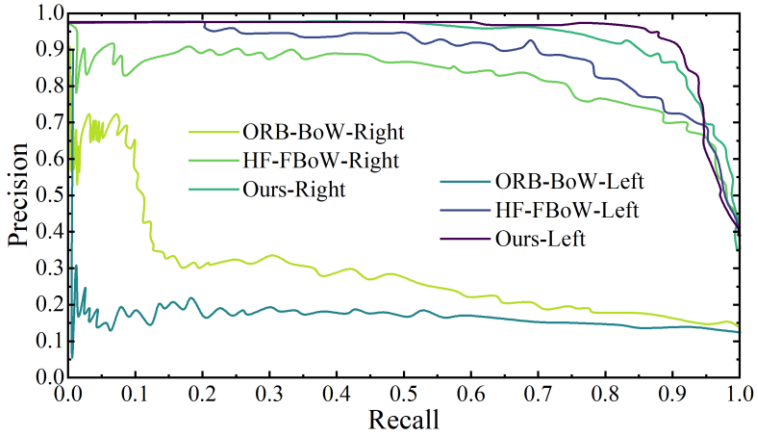

Figure 4: Test results of the loop detection algorithm

4.1.2 SLAM Benchmark Suite Performance Testing

In this paper, when performing the construction of virtual scenes of digital art and culture, the virtual engine is deployed on a cloud platform, which is then combined with binocular parallax

to realize the stereoscopic display of virtual scenes of digital art and culture. In this section, we use the SLAM framework, an open-source visual SLAM benchmarking tool, which we use to further investigate the performance testing of the virtual engine on the cloud platform on the SLAM software package. For SLAM performance testing, the processing flow is divided into three main computationally intensive phases, which are data acquisition, computation phase, and scene rendering. Since two of these phases (data acquisition and scene rendering) are tightly coupled with the robot hardware, only the computation phase is migrated to the cloud for computational performance improvement among the three phases of the SLAM test experiment. Therefore, we choose the local execution of SLAM as a comparison, as well as the virtual engine deployed in the cloud platform as the hardware environment for executing this evaluation suite, the results of which are shown in Table 1.

From the comparison of the computational phases, we can see that the virtual engine under our cloud platform has a significant performance gain compared to the native setup of the two on-board PCs, even though a large amount of RGB-D data and scene rendering has to be transferred over the network in the cloud platform configuration.The gain for the Raspberry is 74.33%, while the gain for the Ultrabook is 49.57% to enable the these two pieces of hardware have relatively close performance in our cloud approach. In addition, it is worth mentioning that the data acquisition and scene rendering phases still demonstrate that our cloud approach has less processing time, especially in the low-end Raspberry's scenario. After analyzing this phenomenon, we found that when the computational burden is migrated to the cloud platform, limited on-board resources can be saved to enhance the execution efficiency of other tasks within the robot, so this phenomenon can be brought by the task cloud to generate additional benefits from another side to better realize the three-dimensional rendering of the virtual scene of the digital art and culture.

Table 1: The execution time of each stage of SLAM (s)

Environmental configuration	Data acquisition	Calculation stage	Scene rendering
Local Raspberry	0.035	2.096	1.361
Local Ultrabook	0.038	1.053	0.726
Cloud Raspberry	0.032	0.538	0.945
Cloud Ultrabook	0.034	0.531	0.643

4.2 Survey and analysis of immersive virtual scene experience feeling

4.2.1 Effect of immersive virtual scene experience

Based on the virtual scene of digital art and culture established in the previous section, the thermal, acoustic and odor environments in the virtual scene were controlled, and the two indicators of aesthetic rate and contact form were selected as independent variables to measure the continuity change of the visual level of the subjects in the virtual scene of digital art and culture. This experiment is a 4*4 mixed design, based on GPower software for sample size estimation, using F-test to select repeated measures ANOVA and main effects interaction effects, the effect size in the relevant parameter settings is 0.3, alpha error is 0.05, the efficacy value selection default setting is 0.95, the number of groups is set to 4, the number of measurements is set to 5, and the final output of the recommended total sample size is 50 people. In the course of this experiment, 80 subjects were finally recruited, all of whom were undergraduate/graduate students enrolled in University Z. This sample combing meets the test conditions.

With the subjects in the immersive virtual scene of digital art and culture, this paper mainly chooses psychological indicators as the evaluation content. The psychological indicators measured in this experiment are attention level, emotional potency, self-esteem level, and

subjective fatigue perception. Attention is the cognitive ability to avoid being diverted by a secondary, and it has a significant impact on short-term memory. Emotion is an important component of mental health, self-esteem is an individual's assessment of self-worth, and there is a correlation between self-esteem and health. Subjective fatigue perception is the degree of fatigue of the audience's physical state in the virtual scene. It was measured using the Schulte square test, the Positive and Negative Emotions Scale, the Rosenberg Self-Esteem Scale, and the Berg Subjective Fatigue Perception Assessment Scale, respectively.

The pre-test psychological indicators of all groups passed the normality and variance chi-square tests, and one-way ANOVA was further used to assess that there were no significant differences between the pre-test psychological indicators of all data before the experiment. All groups of experimental post-test psychological indicators passed normality test with ANOVA chi-square test and were analyzed for main effects and interaction effects, and their specific results are shown in Table 2. In the table, SOS, DF and MS denote sum of squares, degrees of freedom and mean square, respectively, * denotes $P<0.05$ and reaches the level of significance, AR and CF denote the main effect of aesthetics rate and form of exposure, respectively, and AR*CF is the interaction effect.

For the indicators with significant main effects, Bonfroni post hoc multiple comparisons were conducted to analyze the differences in this indicator between different levels of aesthetic rate/contact form, and for the indicators with significant cross effects, simple effects were conducted to analyze the differences in this indicator between aesthetic rate/contact form at a certain level and the other independent variable at a different level. Overall, attention level, emotional potency, self-esteem level and subjective fatigue reached the significance level ($P<0.05$) under both aesthetic rate and contact form, but the cross effects of each indicator were not significant ($P>0.05$). Therefore, under the virtual scenario of digital culture and art, there is a large difference in the psychological indicators of the subjects, which can significantly enhance the aesthetic expression of culture and art, and also lay the foundation for constructing the cultural identity of the subjects.

Table 2: The main effect and interaction effect of psychological indicators

Index	Effect	SOS	DF	MS	*F*	*P*
Attention level	AR	525.993	3	175.331	15.151	0.005*
	CF	335.376	3	111.792	32.804	0.001*
	AR*CF	6.728	6	1.1213	0.358	0.763
Emotional valence	AR	2185.631	3	728.544	12.539	0.002*
	CF	1320.514	3	440.171	35.143	0.000*
	AR*CF	55.242	6	9.207	0.783	0.547
Self-esteem level	AR	361.018	3	120.339	14.636	0.001*
	CF	84.177	3	28.059	13.421	0.002*
	AR*CF	5.306	6	1.051	0.435	0.284
Subjective fatigue	AR	29.834	3	9.945	1.467	0.218
	CF	262.363	3	87.454	38.962	0.002*
	AR*CF	31.268	6	5.211	2.435	0.063

4.2.2 Virtual Scene Interaction User Evaluation

This questionnaire is conducted after the completion of the design of the immersive virtual scene of digital art and culture, through this questionnaire research, for the user to experience the real feedback of this application to find out the problems and shortcomings of this application, and guide the direction of the subsequent application of the revision. The

questionnaire will take the form of a Likert scale for information collection, in order to obtain the user's satisfaction assessment of the application, the satisfaction level of the questionnaire from low to high were very dissatisfied, dissatisfied, general, satisfied, very satisfied, the value of 1 to 5 points. Through this form, it is possible to understand the user's understanding of this application, and better obtain feedback on application satisfaction.

The content of the questionnaire is shown in Table 3, and this questionnaire is mainly researched from three aspects: application experience, cultural learning, and promotion willingness. The research object of the questionnaire for the previous selection of 80 subjects in the random selection of 15 people, the research mode for the end of the user experience, on-site questionnaire answering, the number of valid questionnaires recovered by the statistics totaled 15, the recovery rate is 100%.

Table 3: The content of the questionnaire

Dimension	Evaluate the problem	Code
Application experience	Whether it can meet the visual experience	T1
	Whether it can satisfy the auditory experience	T2
	Has the dizziness experience been reduced	T3
	The degree of interaction within the application scenario	T4
	Whether it meets the interactive feedback	T5
Chemical acquisition	Whether the acquisition of cultural knowledge	T6
	Whether the learning of cultural classification	T7
	Whether the display of cultural works is clear	T8
	Whether the cultural content is easy to understand	T9
	Whether the form of cultural presentation is appropriate	T10
Willingness to promote	Whether the application experience leaves a deep impression	T11
	The willingness to share and recommend this application	T12

By integrating the results of the questionnaire, the results of the detailed satisfaction quiz data are shown in Table 4.

According to the scores of the various indicators of the user research, it can be seen that most of the users are in a relatively satisfied state with the experience of the virtual scene of digital culture and art, with ratings averaging at the level of 4.4 or more. Among them, the cultural learning part scores the highest (4.46), followed by users are more satisfied with the interactive experience of the application and are willing to recommend this application to others. Some users rated at 3, with a lower satisfaction level, and the authors learned through Q&A with these users that the options with lower ratings were mainly focused on the following points:

(1) Auditory experience. Some users reflected that when conducting the application experience, the background sound effects sound is small and not obvious enough, the variety of sound effects is small, more sound effects are needed to create a sense of atmosphere in the cultural virtual scene, this point needs to be changed in the subsequent update.

(2) Cultural content expression. Some users rated the categorization of cultural works and the display of models highly, and thought that the display method was very innovative, leaving a deep impression on the contents they had already experienced. However, some users still said that when learning the content related to cultural works, they think that it is still difficult to learn the content part of the text, and they think that there is a lack of necessary annotations to assist reading and learning, which needs to be added to improve the content.

Comprehensive analysis of the above, the user rating of the digital art and culture virtual scene is basically in the state of satisfaction, the virtual scene can be a short time to experience the process of letting the user to learn and understand the relevant cultural knowledge, cultivate

their interest in culture, and construct the user's sense of cultural identity, but there is still room for improvement in this application. In response to the problems pointed out by the users, this application will firstly focus on the above two points as the goal of improvement, set up more sound effects for the application environment in line with the traditional cultural atmosphere, and strive to create an audio-visual effect that is dynamic, smooth and not noisy, and secondly, it is necessary to further improve the introduction of culturally relevant text, try to make the text popularized, and increase the amount of annotations, so as to assist the users in their reading and learning. It is believed that through further improvement and optimization, it can effectively enhance the user's interactive experience of the virtual scene of digital art and culture, and also effectively promote the generation of the user's sense of cultural identity.

Table 4: Evaluation result feedback

User	Application experience					Chemical acquisition					Willingness to promote		Mean
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	
1	4	5	5	4	5	4	4	4	5	5	5	4	4.5
2	5	4	5	5	4	5	5	5	5	4	5	5	4.8
3	5	4	4	5	4	5	5	5	4	5	4	4	4.5
4	5	5	5	5	4	5	5	5	4	3	3	5	4.5
5	4	5	4	5	5	4	4	4	5	5	4	4	4.4
6	4	3	4	5	4	4	4	5	4	4	4	4	4.1
7	5	4	4	4	3	4	5	4	5	5	5	4	4.3
8	4	5	5	4	4	5	5	4	4	4	5	5	4.5
9	4	5	4	4	4	5	5	5	4	4	4	3	4.3
10	5	3	5	5	5	5	4	5	3	5	4	5	4.5
11	5	5	4	5	4	4	5	3	5	3	5	5	4.4
12	4	5	5	5	4	5	4	5	4	5	4	5	4.6
13	5	4	5	4	5	4	5	4	5	5	5	5	4.7
14	4	5	4	5	5	5	4	5	4	5	4	4	4.5
15	5	5	4	5	5	4	3	4	4	5	4	5	4.4
Mean	4.5	4.5	4.5	4.7	4.3	4.5	4.5	4.5	4.3	4.5	4.3	4.5	-
	4.50					4.46					4.40		4.47
	4.453												-

5 Conclusion

In this study, by constructing an immersive virtual scene of digital art and culture based on the virtual engine of the cloud platform and the HTC Vive device, we proposed a differential loopback detection algorithm based on the history model and a binocular parallax virtual stereoscopic display method, and explored the paths of immersive virtual reality technology for the construction of cultural identity.

The research results show that the proposed loopback detection algorithm maintains a high recall rate when the accuracy is close to 1 in the loopback detection performance test, ensuring the consistent construction of digital art and culture virtual scenes. The virtual engine deployed on the cloud platform for SLAM performance test obtains 74.33% and 49.57% performance enhancement in the computation phase compared to the local Raspberry and Ultrabook devices, respectively, which provides a technical guarantee for the smooth presentation of the virtual scene. The experiment was tested on 80 college students through a 4×4 mixed design, and the

results showed that under the two independent variables of aesthetic rate and contact form, the subjects' attention level, emotional potency, and self-esteem level reached significant differences ($P<0.05$), but the interaction effect was not significant. The results of the user satisfaction survey showed that the 15 users rated the application experience of the digital art and culture virtual scene at 4.50 points, cultural learning at 4.46 points, and willingness to promote at 4.40 points, and the overall satisfaction reached 4.47 points (out of 5). These data show that the digital art and culture virtual scene constructed based on immersive virtual reality technology can effectively improve the quality of users' cultural experience, enhance their sense of cultural identity, and provide a proven technical way and method for the digital protection and inheritance of cultural heritage. Future research will further optimize the auditory experience and cultural content expression to enhance the overall immersion and sense of identity of users to the cultural virtual scene.

Acknowledgements

(1) Zhumadian City Youth Special Project on Scientific and Technological Innovation (No. QNZX202322).

(2) The China Postdoctoral Science Foundation Program (2022M712484).

(3) Project Plan of Henan Science and Technology Research (No. 242102321143).

(4) Henan Cultural Revitalization Project - Special Program for Cultural Research (2024XWH025).

(5)Young Backbone Teacher Support Program of Huanghuai University (No.502300080013)

References

[1] Dai, Y. (2021, April). Digital art into the design of cultural and creative products. In Journal of Physics: Conference Series (Vol. 1852, No. 3, p. 032042). IOP Publishing.

[2] Kolesnyk, N., Piddubna, O., Polishchuk, O., Shostachuk, T., & Breslavska, H. (2022). Digital art in designing an artistic image. Ad alta, 31(12), 128-133.

[3] Zabora, V., Kasianenko, K., Pashukova, S., Alforova, Z., & Shmehelska, Y. (2023). Digital art in designing an artistic image. Amazonia Investiga, 12(64), 300-305.

[4] Halverson, E. R. (2013). Digital art making as a representational process. Journal of the Learning Sciences, 22(1), 121-162.

[5] Donghui, C., Guanfa, L., Wensheng, Z., Qiyuan, L., Shuping, B., & Xiaokang, L. (2019). Virtual reality technology applied in digitalization of cultural heritage. Cluster Computing, 22, 10063-10074.

[6] Gao, L., Wan, B., Liu, G., Xie, G., Huang, J., & Meng, G. (2021). Investigating the effectiveness of virtual reality for culture learning. International Journal of Human–Computer Interaction, 37(18), 1771-1781.

[7] Li, W. (2018, September). Application of virtual reality technology in the inheritance of cultural heritage. In Journal of Physics: Conference Series (Vol. 1087, No. 6, p. 062057). IOP Publishing.

[8] Dean, L. G., Vale, G. L., Laland, K. N., Flynn, E., & Kendal, R. L. (2014). Human cumulative culture: a comparative perspective. Biological reviews, 89(2), 284-301.

[9] Aiden, E., & Michel, J. B. (2014). Uncharted: Big data as a lens on human culture. Penguin.

[10] Gonizzi Barsanti, S., Caruso, G., Micoli, L. L., Covarrubias Rodriguez, M., & Guidi, G. (2015). 3D visualization of cultural heritage artefacts with virtual reality devices. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 40, 165-172.

[11] Samadbeik, M., Yaaghobi, D., Bastani, P., Abhari, S., Rezaee, R., & Garavand, A. (2018). The applications of virtual reality technology in medical groups teaching. Journal of advances in medical education & professionalism, 6(3), 123.

[12] Xie, B., Liu, H., Alghofaili, R., Zhang, Y., Jiang, Y., Lobo, F. D., ... & Yu, L. F. (2021). A review on virtual reality skill training applications. Frontiers in Virtual Reality, 2, 645153.

[13] Liu, Y., Luo, D., & Zhang, H. (2022). Application of virtual reality technology and traditional cultural elements in landscape regeneration design. Journal of Computational Methods in Science and Engineering, 22(3), 765-775.

[14] Bekele, M. K., Pierdicca, R., Frontoni, E., Malinverni, E. S., & Gain, J. (2018). A survey of augmented, virtual, and mixed reality for cultural heritage. Journal on Computing and Cultural Heritage (JOCCH), 11(2), 1-36.

[15] Berti, M. (2021). The unexplored potential of virtual reality for cultural learning. The EuroCALL Review, 29(1), 60-67.

[16] Loumos, G. E. O. R. G. E., Kargas, A. N. T. O. N. I. O. S., & Varoutas, D. I. M. I. T. R. I. O. S. (2018). Augmented and virtual reality technologies in cultural sector: Exploring their usefulness and the perceived ease of use. J. Media Crit, 4, 307-322.

[17] Trunfio, M., Lucia, M. D., Campana, S., & Magnelli, A. (2022). Innovating the cultural heritage museum service model through virtual reality and augmented reality: The effects on the overall visitor experience and satisfaction. Journal of Heritage Tourism, 17(1), 1-19.

[18] Chen, V. H. H. (2014). Cultural identity. Key Concepts in Intercultural Dialogue, 22(1), 1-2.

[19] Silvia Marciani, Leonardo Franz, Gino Marioni, Cosimo de Filippis, Piero Nicolai & Elisabetta Zanoletti. (2025). Virtual reality simulation for temporal bone surgery training: A systematic review. Current Problems in Surgery, 66, 101738-101738.

[20] Jieun Lee, Aya Ataya & SeungJun Kim. (2025). Effects of attention-demanding task-based technique on reorientation in virtual reality. International Journal of Human - Computer Studies, 199, 103501-103501.

[21] Huihui Wang & Jianhua Li. (2024). Integration path of digital media art and environmental design based on virtual reality technology. Open Computer Science,14(1).

[22] Zhixing Song, Xuebo Zhang, Shiyong Zhang, Songyang Wu & Youwei Wang. (2025). VS-SLAM: Robust SLAM Based on LiDAR Loop Closure Detection with Virtual Descriptors and Selective Memory Storage in Challenging Environments. Actuators, 14(3), 132-132.

[23] Schramm Stefan, Dietzel Alexander, Blum MarenChristina, Link Dietmar & Klee Sascha. (2021). Technical light-field setup for 3D imaging of the human nerve head validated with an eye model. Current Directions in Biomedical Engineering,7(2),433-436.